TRIFIBRE: Development of Sustainable Natural Insulation Using Kapok, Coconut, and Corn Fibers

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ABSTRACT

The sudden rise of global temperature has become a passing concern, intensifying the need of immediate action in mitigating the significant challenges on living conditions and environmental sustainability. Commercial insulators, while effective, contribute to environmental degradation due to high carbon emissions, non-biodegradability, and hazardous organic compounds. This study explores the potential of developing a sustainable thermal insulator using a combination of natural fibers: kapok, corn husk, and coconut husk. These fibers are locally available agricultural waste products known for their thermal resistance and eco-friendliness. The Kruskal-Wallis test was employed to determine whether the significant difference existed between the different variety of trifibre and the commercial insulator given the non-parametric nature of the data. Results showed that Trifibre A holds a thermal conductivity that ranges from 0.06640 to 0.06640W/mmK, Trifibre B holds 0.17582 to 0.18593W/mmK, Trifibre C with 0.15101 to 0.15893W/mmK, and the commercial insulator holds 0.31425 to 0.32182W/mmK. These results show minimal difference compared to commercial insulators, which makes it a probable alternative or substitute to commercial insulators. The study emphasizes the potential for optimizing the fiber blends through structural modifications or hybridization to further improve their insulation performance.

Keywords: trifibre, natural insulator, commercial insulator, sustainable insulator, natural fibers. kapok, corn husk, coconut husk, thermal conductivity, eco-friendly, Kruskal Wallis test.

INTRODUCTION

Rising heat levels due to continuous climate change have been one of the most common issues nowadays. It has significantly increased the impact on indoor comfort, leading to increased energy consumption for cooling indoor spaces. That is where insulation materials come to play the role of mitigating heat from piercing through houses and causing discomfort to residents. These materials are beneficial in improving the thermal quality inside buildings and reduce overall energy consumption. However, conventional insulators are associated with high carbon emissions during production and disposal, and limited biodegradability, contributing to increased landfill waste and long-term environmental damage. Organic compounds present in industrial heat insulation materials pose a significant hazard to human health. This study further discusses and emphasizes the importance of insulation materials in energy efficiency but points out the environmental and health issues associated with conventional insulators, indicating the need for more sustainable insulation solutions to address these challenges.

Urban overheating is documented in more than 400 major cities in the world. Numerous experimental data show that the magnitude of the average temperature increase may exceed 4°C TO 5°C. Among those areas included, the northern region of Nigeria is one of the most affected by the high radiation from the sun. Their people face different side effects causing a toll on their health (Okokpujie et al., 2022). Additionally, more than 10% of the global energy consumption is covered by buildings' heating and cooling space, producing close to 30% of global carbon dioxide (CO_2) emissions. Reducing energy usage in infrastructures using enhanced thermal insulation capacity is one of the efficient ways to minimize negative environmental consequences (Lisowski & Glinicki, 2023). A study in Nigeria demonstrated that particles of coconut husk combined with epoxy resin form a strong thermal insulator (Omar et al., 2022). An insulating earthen material composed of laminaria digitata seaweed, a large brown seaweed also known as oarweed commonly found in the cold waters of the North Atlantic, mixed with cob mix was developed in France by Bouasria et al. (2021). The study showed that adding laminaria digitata, up to 20% with cob mix improves the performance of the material with 34% at 10°C decreased the thermal conductivity in comparison with standard cob. Through its quality, it ensures effective insulation without depending on non-renewable resources, and it can help to reduce environmental impact and temperatures inside residences (Villa et al., 2019).

Climate change continues to fuel record-breaking temperatures worldwide, putting vulnerable populations at risk. In April 2024, Thailand recorded one of its most extreme summer heatwaves, with its effects extending across East Asia and the Pacific, putting millions of children at risk. Exposed to hotter and longer heat waves are 243 million children putting them at risk of multitude of heat-related illnesses, and even death (UNICEF, 2024). The World Meteorological Organization (2024) reported numerous new station temperature records. For example, in Mueang Phetchabun, a town in Thailand, temperatures reached 44.1°C in the fourth month of 2024. Additionally, the average contribution of urban warming across the country has exhibited a significant increase of 0.15°C per decade (Kachenchart et al., 2020). Due to the sudden increase in temperature, the use of insulation materials gathered significant attention throughout Southeast Asian countries such as Malaysia and Thailand. To combat the extreme heat, Thailand and Malaysia developed thermal insulators from materials such as kapok, bagasse, rice hulls, coconut coir, and durian skin. In Malaysia, an innovation utilizing durian waste is a low-cost innovation compared to commercial insulation boards. The optimal resin for creating a durian skin fiber composite was 6% PMDI resin. Based on this result, adding 6% PMDI is regarded as the optimal thermal stability and with a thermal conductivity of 0.07892 W/m.k which achieved the standard with other materials (Alias et al., 2023; Panyakaew & Fotios, 2008). These results highlight the effectiveness of natural fibers as a solution towards the problem in regards to the increasing heat across Southeast Asian countries.

Situated in the tropics, the Philippines has a predominantly hot and humid climate. In a recent report from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), numerous regions are experiencing temperatures of 40°C and above, and went as high as 55°C in Eastern Samar was recorded, it was known to be the highest temperature ever recorded in the Philippine Heat Index, and is not considered normal (Daanoy, 2024). PAGASA also declared that Digos City was categorized as orange index value, which means that the heat index of the sun is already ranging from 42°C to 51°C, which is already among the many in the danger zone. Being exposed to heat for just several days or just experiencing severe heat inside homes can cause a lot of risky health-related problems such as dehydration, heat stroke, or even death (Laouadi et al., 2020). In addressing this issue, Filipinos frequently rely on air conditioning to preserve their comfort in the face of excessing heat, which consequently leads to an escalation in their electricity expenses. Corn husk fibers are waste products that are abundant in the Philippines and often used as home furnishing, carpet, rugs, and packaging of food grains and crops. This versatility led to the development of ceiling panel thermal insulation incorporating corn husk fibers. Experimental results indicate a thermal conductivity of 0.119 W/m·K. (Manalindo et al., 2023). Similarly, the study of Punongbayan et al. (2021) evaluated the potential of banana peel and cardboard waste products as a substitute for the production of polyurethane thermal insulation. This shows that plenty of research has been conducted about using waste products and biodegradable materials as a substitute for commercial insulators across the country.

The study is urgently needed due to worsening climate conditions. Despite the significant progress in thermal insulation technologies, an essential gap remains in understanding the performance of thermal insulators especially in combining more than one material or fiber in the production of these insulators. Individual research for different natural fibers such as kapok,corn, and coconut, already have shown potential for insulating heat and multiple studies have tackled combining two different types of fibers with different ratios in one insulator, but existing studies have yet to explore multi-fiber combinations incorporating kapok, corn, and coconut for thermal insulation. Using the Theory of Porosity, which explains how the void spaces within a material influence its ability to trap air and reduce heat transfer, this study aims to investigate the effectiveness of multi-fiber combinations incorporating kapok, corn, and coconut fibers for thermal insulation.

Statement of the Problem

The main objective of this research is to evaluate the thermal conductivity and thermal resistance of an insulator

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board made up of combined kapok, corn husk, and coconut husk fibers in comparison to commercially available thermal insulators. Specifically, the study will seek to answer the following questions:

1. What is the level of thermal conductivity of trifibres and commercial insulators?

   1.1. 90.00g of coconut fibre(45%), 40.00g of corn fibre (20%), and 70.00g of kapok fibre (35%);

   1.2. 70.78g of coconut fibre (20%), 100.40g of corn fibre (35%), and 127.40g of kapok fibre (45%);

   1.3. 126.55g of coconut fibre (35%), 165.55g of corn fibre (45%), and 71.80g of kapok fibre (20%); and

   1.4. Commercial insulator?

2. What is the level of thermal resistance of trifibres and commercial insulators?

   2.1. Trifibre A with 90.00g of coconut fibre(45%), 40.00g of corn fibre (20%), and 70.00g of kapok fibre (35%);

   2.2. Trifibre B with 70.78g of coconut fibre (20%), 100.40g of corn fibre (35%), and 127.40g of kapok fibre (45%);

   2.3. Trifibre C with 126.55g of coconut fibre (35%), 165.55g of corn fibre (45%), and 71.80g of kapok fibre (20%); and

   2.4. commercial insulator?

      1. Is there a significant difference on the thermal conductivity based on the different combinations of kapok, corn husk, coconut husk fibers and the commercial insulator?

      2. Is there a significant difference on the thermal resistance based on the different combinations of kapok, corn husk, coconut husk fibers and the commercial product?

Hypothesis

To answer the problems listed in the preceding section objectively, the given null hypothesis was formulated:

Ho_1: There are no significant differences between the different ratios of kapok, corn, and coconut, and commercial insulators in terms of thermal conductivity.

Ho_2: There are no significant difference between the different ratios of kapok, corn, and coconut, and commercial insulators in terms of thermal resistance.

Significance of the Study

This study aims to investigate using kapok seed fibers blended with coconut and corn husk as an excellent thermal insulator for the rising heat problem in Digos City, Davao del Sur.

Department of Science and Technology. The result of the study will help the Department of Science and Technology (DOST) in facilitating the development of advanced materials in using raw materials for heat insulators to contribute to a cooling, and convenient environment.

Housebuilders. The result of the study will help housebuilders influence the selection and application of effective heat insulators and contribute to improvements in indoor comfort, reduce energy costs, and sustainable insulation solutions for better building standards and energy-efficient homes.

Future Researchers. The result of the study could provide foundational insights to future researchers that can guide the development of innovative heat insulators using raw materials, by contributing to energy efficiency and sustainability of thermal insulation.

Scope and Limitations

This study focuses on evaluating the thermal properties of sustainable insulation materials by combining kapok fibers, coconut husks, and corn husks in different ratios. Conducted at a state university laboratory, the research measured thermal conductivity to assess the effectiveness of these natural fibers as alternative insulators. The scope includes analyzing the relationship between material thickness and the thermal conductivity of the fibers to determine the thermal resistance, as well as comparing the performance of these natural fibers with conventional insulating materials. The findings aim to contribute to the development of eco-friendly insulation solutions suitable for tropical climates.

The study is limited to the thermal conductivity and thermal resistance of the materials, excluding other relevant properties such as moisture absorption, durability, and fire resistance. The experiments were conducted under controlled laboratory conditions, which may not fully represent real world environmental factors such as humidity and temperature fluctuations. Additionally, the results are specific to the samples and dimensions tested, and variations in fiber composition or processing methods may yield different outcomes. Further research is needed to evaluate the long-term performance and practicality of these materials in actual building applications.

Definition of Terms

The following terms were defined to have a better understanding of this study:

Trifibre. It refers to an eco-friendly composite material made by combining natural fibers from kapok, corn, and coconut to create a lightweight, durable, and biodegradable insulator board. There were 3 setups, identified as A, B, and C where A is a percentage-based ratio of 45:20:35 coconut fibre, corn fibre, and kapok fibre; B has a ratio of 20:35:45; and C has a ratio of 35:45:20.

Thermal Resistance. It refers to the ability of natural and commercial insulators to resist the flow of heat, and it is measured in watts per meter per Kelvin (W/m·K) in laboratory settings to evaluate their effectiveness in insulating against heat transfer.

Thermal Conductivity. It refers to the ability of natural and commercial insulator to conduct heat, and it is measured in watts per meter per Kelvin (W/m·K) in laboratory settings to evaluate trifibre effectiveness.

METHODS

This chapter outlines the methods used to conduct the study. It addresses the aspects of the methodologies used in the study such as research design, sampling methodologies, selection of respondents, procedures for data collection, measurement techniques, methods of analysis and interpretation, as well as ethical consideration.

Research Design

This study employed a quantitative research design to examine the thermal insulation properties of combined kapok, coconut, and corn as natural insulation materials. According to Creswell (2020), quantitative research is a research approach that involves collecting and analyzing numerical data using statistical methods to identify patterns, test hypotheses, and explore causal relationships between variables. This approach will be selected to allow for an accurate assessment of the materials' insulation performance through measurable and statistically analyzed data.

In addition, this study utilized the concept of experimental research design. According to Campbell and Stanley (1963), Experimental research design is defined as a systematic approach to research that emphasizes proper control, randomization, and manipulation of variables to establish cause-and-effect relationships. This approach is chosen for the study because it consists of an experimental group of natural insulators using kapok, coconut, and corn and a controlled group of commercial insulators made out of polyethylene foam. This allows us to test

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the effect of each material on insulation performance while controlling other factors.

Pre-Experimental Protocol

The researchers engaged in discussions with professional engineers to deepen their understanding of the binding process for the insulating materials and the methodologies involved in testing these materials. This consultation was vital, as it allowed the researchers to gather expert insights on best practices and the technical requirements needed for effectively combining the natural fibers for an insulator. The engineers provided guidance on various binding techniques and the significance of ensuring a strong and durable connection between the materials. Additionally, they offered recommendations on the appropriate testing methods that would yield reliable results. By collaborating with these professionals, the researchers aimed to enhance the quality of their work and ensure that their experimental procedures were grounded in sound engineering principles. This collaborative effort was instrumental in preparing the researchers for the subsequent phases of their project.

Afterward, the researchers identified all the necessary materials required for the successful execution of their project. To ensure a comprehensive approach, they sourced these materials through various methods. Some of the materials were obtained naturally, including coconut husks, corn husks, and kapok, which are recognized for their effective insulating properties. These natural materials were carefully selected for their availability, cost-effectiveness and sustainability. In addition to the naturally sourced items, the researchers also bought a wood glue from a local hardware store in Digos City. This combination of sourcing strategies enabled the researchers to gather a diverse range of materials, ensuring that they had everything needed to carry out their experiments effectively and contribute valuable insights to the field of insulating materials.

In the final phase of the study, researchers sought a suitable laboratory to test the thermal conductivity and thermal resistance of various insulating materials. This search was crucial to ensure accurate and reliable data on how these insulators perform under controlled conditions. The selected laboratory needed to possess the appropriate tools and expertise in thermal testing to guarantee trustworthy results. Securing an appropriate facility for these tests aimed to strengthen the study’s findings and contribute valuable insights to the field of materials science and engineering.

Materials

1. **Coconut husk.** It is used as an ingredient in the production of natural fiber heat insulators.
2. **Corn husk.** It is used as an ingredient in the production of natural fiber heat insulators.
3. **Kapok husk.** It is used as an ingredient in the production of natural fiber heat insulators.
4. **Wood Glue.** Serves as a strong adhesive for the interior of the insulator, ensuring good quality and good thermal insulation.

METHODS

Hardware design

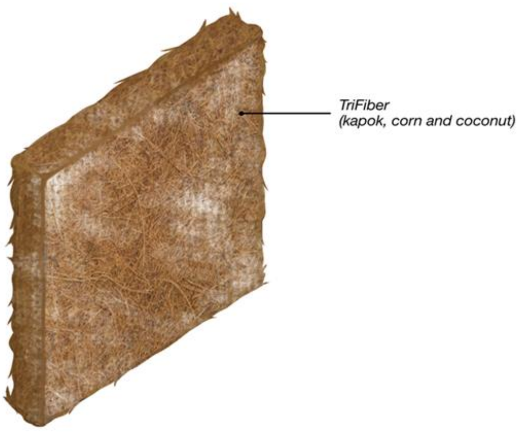

Figure 1. Orthographic View of the Thermal Insulator

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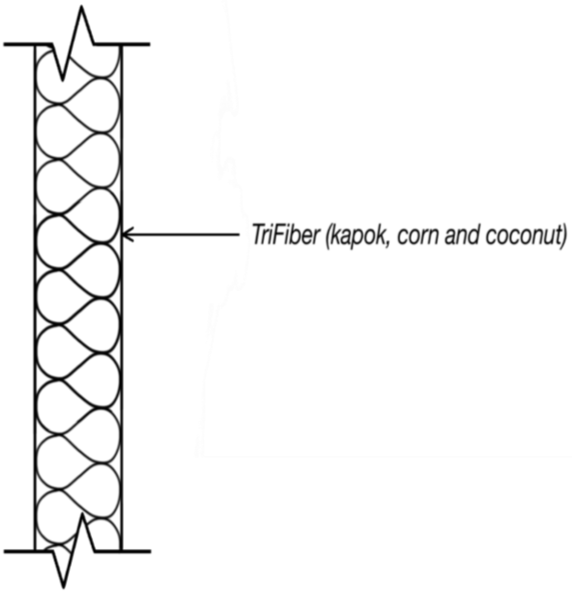

Figure 2. Isometric Left Side View of the Thermal Insulator

Table 1 shows the actual composition and thickness of the insulating material, labeled A, B, and C, each with different ratios of coconut, kapok, and corn fibre. Setup A has a percentage-based ratio of 45:20:35, setup B with 20:35:45, and setup C with 35:45:20. These different fibre compositions allow for the evaluation of various material properties based on theirr blend proportions.

Table 1. Composition and thickness of Trifibre Mixture Samples and Commercial Insulator

Ratio and thickness (in grams and wt%; in millimeter)					
Mixtures	**Coconut Fiber**	**Corn Fiber**	**Kapok Fiber**	**Polyethylene Foam**	**Thickness (mm)**
Trifibre A	90.00g (45%)	40.00g (20%)	70.00g (35%)	—	18.72
Trifibre B	70.78g (20%)	100.40g (35%)	127.40g (45%)	—	20.39
Trifibre C	126.55g (35%)	165.55g (45%)	71.80g (20%)	—	18.51
Commercial	—	—	—	100%	15.33

Hardware Implementation

The hardware implementation of this project includes attachment and configuration of physical components, such as corn husk, kapok and coconut husk fibers to create a sustainable insulation material.

Collection and Shredding of the Plant Fiber Materials

1. Researchers will collect and prepare the exact materials in a different manner.
2. The coconut husk will be soaked in water for at least 24 hours to soften the husks. After that, the researchers will wait for the fibers to dry.
3. Kapok will be prepared by separating the seeds from the fibers and is stored in a container for later use. Meanwhile, coconut husk and corn husk are shredded manually into equal and uniform fibers.
4. All fibers are then weighted to a desired ratio.

Mixing with Wood Glue

1. Three containers will be utilized in mixing the different varieties of trifibre. One variety will have a higher ratio of kapok, another variety will have a higher ratio of corn husk, and the last one will have a higher ratio of coconut husk.

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2. Each container will have the same amount of wood glue to maintain uniformity. After that, manually mix the materials until it is fully mixed together.

Molding, Compressing, and Drying the Insulator

1. Place the fiber-glue mixture in a flat setup with plastic cover to prevent the wood glue from sticking anywhere else.

2. The researchers will then utilize three materials weighing 5kg each to compress the insulators. Leave it for 24 hours to assure a fully compressed material, by that time the material should also be fully dried.

3. The researchers will then proceed to cutting the material into an 8x8 size with a thickness of 2 inches.

Assessing the Thermal Conductivity/Resistance of theTrifibre Insulator

1. The researchers will place the samples in a Heat Flow Meter (HFM) machine where it will measure the thermal conductivity and thermal resistance of the rambutan peel.

2. The Heat Flow Meter (HFM) machine will then show the gathered data of the trifibre insulator samples.

3. The gathered data will be collected by the researchers and be computed by a statistician.

Measures

This study utilized primary sources of data, which is the data shall be obtained through experiments to assess the thermal resistance and thermal capacity of natural materials, specifically kapok, corn, and coconut, as potential sustainable for insulation. In order to obtain firsthand information for research purposes, Kothari (2019) states that a variety of methods, including surveys, interviews, observations, and experiments, can be used to collect primary data. According to Creswell (2018) surveys, experiments, and interviews are some of the most Important methods for gathering primary data, with the method chosen based on the goals and design of the study. On the other hand, secondary data encompasses information already assembled or generated by other researchers, including sources like census data, government publications, and service records, among others.

Other sources of data were from the literature that were reviewed by the researcher which will give light to understanding better the problem of the study. To measure the variables, an experiment was used by the researchers. The experiment consisted of three parts. The first part is preparing the fiber, such as kapok corn and coconut. The second part assessed their thermal resistance, while the third part was to assess the thermal capacity. The experimental on Thermal Resistance contained 1 item with 5 results and 5 indicators: Practical Application for Energy Efficiency, Environmental Sustainability, Impact of Material Composition on Thermal Insulation, Thermal Resistance Effectiveness, Understanding of Thermal Resistance of the Material Mixture.

Furthermore, the experiments were done in the laboratory that meets the research criteria. Because the intention was to gather initial data on the thermal resistance properties of natural insulation materials for pilot testing, the convenience sampling technique was applied.

Table 2. Interpretation of the Thermal Conductivity of the Commercial Insulator

Mean Range [W/m·K]	Descriptive reading	Interpretation
≤ 0.020	Exceptional	Ultra-high-performance insulation, used in specialized applications requiring maximum thermal resistance. Often expensive and used in extreme conditions.
0.021 - 0.035	High	Common in high-efficiency insulation for buildings, refrigeration, and industrial applications. Balances cost and performance well.

0.036 - 0.045	Good	Suitable for most residential and commercial insulation applications. Offers moderate cost-to-performance efficiency.
0.046 - 0.060	Average	Provides insulation but may require additional thickness for better efficiency. Often used in eco-friendly or alternative insulation methods.
0.061 - 0.100	Low	Basic insulation properties. Usually requires extra layers to achieve good thermal performance. Common in budget-friendly solutions.
> 0.100	Poor	Allows significant heat transfer, providing minimal thermal resistance. Often structural materials that require external insulation layers.

Table 2 shows the interpretation of the thermal conductivity and resistance for commercial insulators. Meanwhile, Table 3 shows the thermal conductivity of the trifibre as well as their thermal resistance.

Table 3. Interpretation of Thermal Conductivity of Trifibre

Mean Range [W/m·K]	Descriptive reading	Interpretation
≤ 0.035	High	High thermal insulation, comparable to commercial materials. The blend has high air-trapping capability, reducing heat transfer. Has excellent thermal resistance, ideal for energy-efficient building and eco-friendly insulation.
0.036 - 0.045	Good	Effective for general insulation purposes. The blend retains air pockets well but may require additional thickness in extreme climates.
0.046 - 0.060	Average	Provides moderate insulation but may not be as effective as synthetic foams. Performance depends on fiber density and treatment. Suitable for non-critical insulation.
≥ 0.061	Low	Limited thermal performance and has less effective thermal resistance. Best suited for applications where insulation is secondary to structural durability. May need densification or treatment to improve insulation.

Analysis and Interpretation

In analyzing the data, both descriptive and inferential statistics were utilized. Interpretations were based on a 0.05 level of significance. The statistical tools are enumerated below.

Mean scores with standard deviations were used to evaluate the thermal capacity and thermal resistance of trifibre as natural insulators for sustainable use. Analyzing the mean values and standard deviations of every combination of fibers helps to understand their average thermal performance, therefore guiding knowledge of their efficiency as insulating materials.

A Kruskal-Wallis test was employed to determine whether significant differences existed between the trifibre and the commercial insulator, as the results were not normally distributed. A p-value below 0.05 indicates statistical significance, warranting further post-hoc analysis to identify the most effective concentration.

Additionally, Dunn's Test was used for pairwise comparisons to identify the optimal combination of natural fibers. This test allowed for more accurate information of the differences between the groups, ensuring a clear understanding of which concentration offered the best thermal resistance.

Findings from this analysis identify the optimal combination of natural fibers that maximize thermal resistance and minimize heat transfer, offering valuable insights for potential applications in sustainable insulation.

Ethical Consideration

This study places significant importance on ethical considerations to protect and minimize harm to the researchers during the conduct of the study.

Informed Consent is a vital component for this study. Researchers must voluntarily agree and are given permission after fully understanding the experiment's purpose, procedures, risks, and benefits. Parents of the researchers will be thoroughly informed of the whereabouts and well-being of their children while performing experiments. Consent should be provided, and the researchers have the right to withdraw anytime.

Avoidance of Harm and Risk is a must for the successful conduct of this research. To ensure that the experiment does not cause physical harm to the researchers, necessary protective measures shall be provided. Ensure that materials used are handled safely, especially if heat sources are involved. Transportation to one place and another is also overlooked to ensure the safety of the researchers after conducting the study.

Environmental Responsibility should be applied during the process of making the insulators. Materials should be disposed responsibly and ensure that they are composted or disposed of sustainably.

Compliance with Ethical Guidelines and Institutional Approval is necessary to legally conduct the experiments in an institution. As a form of respect and appreciation to the institution for their assistance, approval from an ethics review board before starting the experiments is needed to obtain. Following local and international research standards to avoid any institutional damages is a must.

RESULTS AND DISCUSSION

This chapter deals with the presentation, analysis, and interpretation of data. The results indicate that the thermal capacity of the natural fibers as insulators is directly affected by its mass and specific heat capacity. The different insulators vary in thermal conductivity and thermal resistance affecting the overall performance of the trifibre. These differences influence their sustainability for specific insulation applications.

Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers and the Commercial Insulator in Terms of Thermal Conductivity

The study investigated the insulation capacity of the different natural insulator setups of kapok, corn husk, and coconut husk fibers and the commercial insulator by assessing the thermal conductivity of the following experiment set up presented in table 5 and a commercial insulator. The researchers assessed the thermal conductivity using the replicate R1, R2, R3, R4, and R5 of Trifibre A, Trifibre B and Trifibre C along with the commercial insulator by utilizing a heat flow meter based on the Post-Equilibrated or Properly Equilibrated, where the system has reached its thermal equilibrium, as these values are considered more reliable for final analysis. Hence, the researchers obtained the following results.

Table 4. Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers and the Commercial Insulator in Terms of Thermal Conductivity

	Replicate (in Lambda W/mmK)					Mean	SD
	R1	R2	R3	R4	R5		
trifibre A	0.06640	0.06619	0.06584	0.06574	0.06640	0.06590	0.00040
trifibre B	0.11597	0.10967	0.11163	0.11127	0.11358	0.11240	0.00240
trifibre C	0.12258	0.11736	0.11669	0.11667	0.11647	0.11800	0.00260
Commercial	0.04877	0.04860	0.04764	0.04764	0.04830	0.04820	0.00050

Table 4 presents the thermal conductivity values of the three setups of Kapok, Corn Husk, and Coconut Husk fiber insulators, as well as the commercial insulator. Based on the results, trifibre A has an average thermal conductivity of 0.06590 W/mmK with minimal variation (SD = 0.00040). This indicates that trifibre A exhibits the lowest thermal conductivity among the tested materials, suggesting it offers the best insulation capacity. The second setup, trifibre B, has an average of 0.11240 W/mmK with minimal variation (SD = 0.00240). This indicates that trifibre B has a higher thermal conductivity than trifibre A, implying a reduced insulation capacity. However, it still provides a moderate level of insulation. The third setup, trifibre C, has an average of 0.11800 W/mmK with minimal variation (SD = 0.00260). This suggests that trifibre C exhibits slightly higher thermal conductivity than trifibre B, resulting in a somewhat lower insulation capacity. Despite this, its insulation performance remains moderate, and the minimal variation indicates consistent performance across replicates. Meanwhile, the commercial insulator has an average thermal conductivity of 0.04820 W/mmK with minimal variation in replicate data (SD = 0.00050). This indicates that the commercial insulator has the lowest thermal conductivity overall, making it the most efficient material for insulation among those tested. The minimal variation suggests that it provides highly reliable and consistent performance across replicates.

Moreover, the results are aligned to the statement of Zach and Peterková (2015) assessed that natural fiber-based insulating materials were shown to have similar qualities to industrially synthetic insulating materials in construction markets. Although, synthetic fiber composites are generally not eco-friendly due to their high production energy demands and reliance on petrochemicals, in comparison to natural fibers which are fully sustainable, and produce fewer pollutants during production, exhibiting desirable physical, thermal, and chemical properties (Bakar et al., 2020).

Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers and the Commercial Insulator in Terms of Thermal Resistance

The study examined the insulation capacity of the different ratios of the experiment of kapok, corn husk, coconut husk fibres, and the commercial insulator by assessing the thermal resistance. The researchers assessed the thermal resistance of the following setup by having three different ratio samples of trifibre insulator presented in table 3. Hence, the researchers obtained the following results.

Table 5. Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers, and the Commercial Insulator in Terms of Thermal Resistance

	Replicate (in $m^2 \cdot K/W$)					**Mean**	**SD**
	R1	**R2**	**R3**	**R4**	**R5**		
TriFibre A	0.28193	0.28281	0.28435	0.28477	0.28624	0.28402	0.00169
TriFibre B	0.17582	0.18593	0.18265	0.18325	0.17952	0.18143	0.00388
TriFibre C	0.15101	0.15772	0.15863	0.15866	0.15893	0.15699	0.00338
Commercial	0.31432	0.31546	0.32180	0.32182	0.31425	0.31753	0.00394

Table 5 presents the thermal resistance of the fibre setup insulators and the commercial insulator. It shows that the trifibre A had the highest average thermal resistance of 0.28402 $m^2 \cdot K/W$ with minimal variation (SD = 0.00169), indicating a high thermal resistance which means it is an effective insulator as it resists heat flow more efficiently. This suggests that trifibre A could be suitable for applications requiring high thermal insulation, such as building materials for energy conservation. Its minimal variation (SD = 0.00169) also implies consistent performance, enhancing its reliability for practical use. Trifibre B followed with an average thermal resistance of 0.18143 $m^2 \cdot K/W$ (SD = 0.00388), suggesting a high thermal resistance which indicates that, although trifibre B has a lower thermal resistance than trifibre A it still exhibits high thermal resistance, indicating its capability to reduce heat transfer effectively. This suggests that trifibre B can serve as an alternative insulator in applications where moderate insulation is sufficient. Its relatively low standard deviation (SD = 0.00388) implies stable and predictable thermal performance, but with a slightly lower capacity than trifibre A. trifibre C had the lowest thermal resistance of the natural fibers at 0.15699 m²·K/W (SD = 0.00338), reflecting a reduced insulation capacity while still maintaining high thermal resistance. In comparison, the commercial insulator exhibited the highest thermal resistance of 0.31753 m²·K/W (SD = 0.00394), making it the most efficient insulator in terms of thermal resistance, with a high thermal resistance which implies that the commercial insulation reduce heat transfer the most compared to the Trifibre A (0.28402 m²·K/W), Trifibre B (0.18143 m²·K/W), and Trifibre C (0.15699 m²·K/W). This means that commercial insulators can maintain temperature differences more effectively, and leads to a better energy conservation compared to those Trifibres.

Moreover, the results are in congruence to the statement of Zach and Peterková (2015) that natural fibre-based insulating materials have shown similar qualities to industrially synthetic insulating materials in construction markets. This supports the composition of the trifibre A, Trifibre B, and trifibre C. Additionally, Coconut fibre insulation performs comparably to synthetic materials for green roofing, offering excellent moisture management, and it is ideal for eco-friendly construction (Fabbri et al., 2020), which explains the thermal resistance performance of the trifibres, mainly the trifibre A. Furthermore, the study of Sun et al. (2024) kapok fibres make a promising eco-friendly alternative to traditional materials because Kapok fibre cores have over 94% porosity and a very low thermal conductivity of 6.12 mW/(m·K) at a specific pressure, meaning they insulate well. This aligned with the thermal resistance performance of the Trifibre, mainly Trifibre B.

Significant Difference in the Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers and the Commercial Insulator in Terms of Thermal Conductivity

Table 6 presents the results of the comparative analysis of the insulation capacity between the experimental groups and the control group in terms of its thermal conductivity. To evaluate the statistical validity of the study, a normality test using the Kolmogorov-Smirnov test was conducted to determine if the data followed a normal distribution. The test indicated a significant deviation from normality (W = 0.279, p = 0.000), suggesting that the data on the thermal conductivity did not meet the assumptions necessary for parametric analysis. As a result, alternative statistical methods were considered. Therefore, the Independent-Samples Kruskal-Wallis Test was employed for analysis, as it is a nonparametric statistical method used to assess whether samples come from identical distributions. The null hypothesis for this test posits that the mean ranks across the groups are equivalent, and one of its advantages is that it does not require the assumption of a normal distribution for the underlying data (Xia, 2020).

It can be noted that the test statistic value for the overall thermal conductivity is 17.871, with 3 degrees of freedom and a p-value of 0.000 which is lesser than 0.05. This means that the study needs to reject the null hypothesis. This indicates that there is a significant difference in the thermal conductivity of the experimental and control setups. Further, this means that different setups have varying degrees of insulation capacity in terms of thermal conductivity.

Table 6. Significant Difference in the Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers and the Commercial Insulator in Terms of Thermal Conductivity

Variables Reviewed	Test Statistic	df	p-value	Decision	Interpretation
Thermal Conductivity	17.871	3	0.000	Reject H_o	Significant Difference

To determine which of the three setups significantly differ from the others, a post hoc analysis was conducted, specifically pairwise comparisons of sample means using the Dunn's test. The Dunn's Test is used to assess pairwise differences between treatment groups for significance, specifically when conducting multiple comparisons. This non-parametric test compares all possible pairs of groups while controlling the probability of making one or more Type I errors (Dinno, 2015).

Table 7 presents the results of post hoc comparisons conducted using Dunn's test. The Dunn's test confirmed a significant difference between Commercial and both trifibre B (p = 0.045) and trifibre C (p = 0.000), indicating that Commercial and trifibre A are significantly better at insulating than trifibre B and trifibre C. Since trifibre B and trifibre C had higher thermal conductivity values, meaning they are less effective at preventing heat transfer

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compared to the other samples, and therefore not as good at insulation. However, no significant difference was found between trifibre B and trifibre C (p = 1.000), suggesting that their insulation properties are comparable. Overall, Commercial proved to be the most effective insulator, followed by trifibre A. In contrast, trifibre B and trifibre C exhibited higher thermal conductivity, indicating they are less efficient at insulating, with similar performance in thermal insulation.

Table 7. Post Hoc Comparisons using the Dunn's Test

	Test Statistic	SE	p	Decision	Interpretation
Between trifibre A and trifibre B	-5.000	3.740	0.181	Fail to Reject H_o	Not Significant
Between trifibre A and trifibre C	-10.000	3.740	0.008	Reject H_o	Significant
Between trifibre A and Commercial	5.000	3.740	0.181	Fail to Reject H_o	Not Significant
Between trifibre B and trifibre C	-5.000	3.740	0.181	Fail to Reject H_o	Not Significant
Between trifibre B and Commercial	10.000	3.740	0.008	Reject H_o	Significant
Between trifibre C and Commercial	15.000	3.740	0.000	Reject H_o	Significant

This means that trifibre A has significantly lower thermal conductivity compared to trifibre B and trifibre C. This suggests that coconut fibers contribute to better insulation capacity, effectively slowing down heat transfer. This could be attributed to the structural properties of coconut fibers, which contain more lignin and a denser cellular arrangement, enhancing their ability to resist heat flow. Conversely, trifibre B and C exhibited higher thermal conductivity, indicating lower insulation effectiveness. The lack of significant difference between trifibre B and trifibre C suggests that kapok and corn fibers have comparable thermal conductivity, likely due to their similar solid structures and less porous composition compared to coconut. The commercial insulator, however, demonstrated the lowest thermal conductivity, highlighting its superior insulation performance.

These findings align with studies on the thermal properties of natural fibers. According to Mahmud et al. (2023), fibers with higher lignin content and denser cellular structures, such as coconut, exhibit lower thermal conductivity due to reduced air permeability. Similarly, Hassan et al. (2020) found that Kapok and Corn fibers, having less dense and more hollow structures, allow slightly more heat flow, thus exhibiting higher thermal conductivity. This explains the comparable performance between trifibre B and C. Furthermore, the superior performance of the commercial insulator aligns with research by Cai et al. (2024), which emphasizes the optimized synthetic composition of commercial insulators, designed specifically to minimize thermal conductivity and maximize energy efficiency.

Significant Difference in the Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers and the Commercial Insulator in Terms of Thermal Resistance

Table 8 presents the results of the comparative analysis of the insulation capacity between the experimental and control groups in terms of its thermal resistance. Using the Kolmogorov-Smirnov test, it shows that the data is not normal hence the Independent-Samples Kruskal-Wallis Test was employed. It can be noted that the test statistic value for the thermal resistance is 17.857, with 3 degrees of freedom and a p-value of 0.000, which is less than 0.05. This means that the study needs to reject the null hypothesis. This indicates that there is a significant difference in the thermal resistance of the experimental and control setups. Further, this means that different setups have varying degrees of insulation capacity in terms of thermal resistance.

Table 8. Significant Difference in the Insulation Capacity of Kapok, Corn Husk, Coconut Husk Fibers and the Commercial Insulator in Terms of Thermal Resistance

Variables Reviewed	Test Statistic	df	p-value	Decision	Interpretation
Thermal Resistance	17.857	3	0.000	Reject H_o	Significant Difference

Table 9 presents the results of post hoc comparisons conducted using Dunn's test. The analysis revealed significant differences in the thermal resistance of trifibre and the commercial insulators. Based on the results, the comparison between trifibre A and trifibre B showed no significant difference, with a p-value of 0.181, indicating comparable insulation capacities. However, trifibre C exhibited a significantly higher thermal resistance than trifibre A, as evidenced by a p-value of 0.008, suggesting that T3 ranks higher in insulation capacity. In the comparison between the commercial insulator and trifibre A, no significant difference was found with a p-value of 0.181, implying that both materials have similar insulation properties. Similarly, the comparison between trifibre B and trifibre C showed no significant difference with a p-value of 0.181. Trifibre B was found to have a significantly higher insulation capacity than the commercial insulator with a p-value of 0.008). However, the commercial insulator significantly outperformed trifibre C in thermal resistance (p-value = 0.000), indicating its superior insulation performance among the materials tested. These findings suggest that while certain natural fibers, such as trifibre B, offer promising insulation capabilities, the commercial insulator remains the most effective material in terms of thermal resistance.

Table 9. Post Hoc Comparisons using the Dunn's Test

	Test Statistic	SE	p	Decision	Interpretation
Between trifibre A and trifibre B	5.000	3.742	0.181	Fail to Reject H_o	Not Significant
Between trifibre A and trifibre C	10.000	3.742	0.008	Reject H_o	Significant
Between trifibre A and Commercial	-5.000	3.742	0.181	Reject H_o	Significant
Between trifibre B and trifibre C	5.000	3.742	0.181	Fail to Reject H_o	Not Significant
Between trifibre B and Commercial	-10.000	3.742	0.008	Reject H_o	Significant
Between trifibre C and Commercial	-15.000	3.742	0.000	Reject H_o	Significant

This means that trifibre C exhibits significantly higher thermal resistance compared to trifibre A, indicating that corn fibers are more effective at resisting heat flow. This suggests that corn fibers possess structural properties conducive to higher thermal resistance, possibly due to their thicker cell walls and compact fiber arrangement, which enhance their ability to trap air and impede heat transfer. In contrast, trifibre A demonstrated moderate thermal resistance, comparable to that of the commercial insulator, suggesting that coconut fibers still provide effective insulation but at a slightly lower capacity than corn. Interestingly, trifibre B exhibited higher thermal resistance than the commercial insulator, highlighting kapok's competitive insulation capability. This is likely due to the hollow lumen structure of kapok fibers, which efficiently traps air and minimizes heat transfer.

These observations are supported by related literature on the thermal resistance of natural fibers. A study by Mohammed et al. (2022) found that Corn fibers' dense and compact structure enhances their thermal resistance by minimizing air movement within the fiber matrix. This supports the superior performance of trifibre C. Additionally, He et al. (2023) noted that the hollow lumen structure of Kapok fibers effectively traps air, increasing thermal resistance, which explains the high insulation capacity of TriFibre B. Conversely, Rahman et al. (2023) observed that Coconut fibers, while effective insulators, have a slightly lower thermal resistance due to their denser composition, which reduces air entrapment. This aligns with the moderate performance of TriFibre A.

SUMMARY

The study aimed to assess the different ratios of insulators, namely Trifibre A, with more coconut husk, Trifibre B with more kapok, and Trifibre C containing more corn husk fibers. Utilizing laboratory experiments to test the thermal conductivity and resistance of the insulator with different ratios provides accurate data. The research aims to address the sudden increase in global temperature that has become a passing concern, intensifying the need for immediate action in mitigating the significant challenges to living conditions and environmental sustainability. Which became the cause of developing an eco-friendly, locally available, and sustainable alternative trifibre insulator.

The Kruskal-Wallis test was employed to determine whether the significant difference existed between the different varieties of trifibre and the commercial insulator and a post-hoc comparison of Dunn's test was utilized to compare the trifibre and commercial insulators in terms of thermal resistance and thermal conductivity. Results showed that trifibre C exhibited the highest thermal conductivity and thermal resistance among the trifibres. In comparison to the commercial insulator, although Trifibre C produced great results, commercial insulators remained superior in both tests (p value = 0.000). However, synthetic fiber composites are generally not eco-friendly due to their high production energy demands and reliance on petrochemicals, meanwhile natural fibers are fully sustainable, and produce fewer pollutants during production, exhibiting desirable physical, thermal, and chemical properties. Thus, in conclusion, the study suggests that synergistic effects of combining natural fibers enhance insulation properties and emphasizes the potential for optimizing these fiber blends through structural modifications or hybridization to further improve their insulation performance.

CONCLUSION

After a thorough investigation of the thermal conductivity and thermal resistance of the trifibre insulator composed of kapok, coconut, and corn husk fibers, the following conclusions are drawn:

1. The study revealed that Trifibre A (coconut-dominant) exhibited the lowest thermal conductivity among the three trifibre compositions, making it the most effective natural alternative for insulation. Trifibre B (kapok-dominant) and Trifibre C (corn-dominant) exhibited higher thermal conductivity, meaning they were less effective in preventing heat transfer. However, all trifibre samples showed potential for insulation when compared to the commercial insulator.

2. Among the trifibre samples, Trifibre C demonstrated the highest thermal resistance, indicating its effectiveness in resisting heat flow. However, Trifibre A and B also performed well, showcasing competitive insulation properties. The commercial insulator, while still superior in both thermal conductivity and resistance, was only marginally better than the trifibre samples, suggesting that the natural insulators could serve as viable eco-friendly alternatives.

3. The Kruskal-Wallis test confirmed significant differences between the trifibre samples and the commercial insulator in terms of thermal conductivity and resistance. Post-hoc analysis using Dunn's test further established that Trifibre A was the most comparable to the commercial insulator in insulation performance.

RECOMMENDATIONS

Based on the results and conclusion of this study, the following recommendations are given:

1. The Department of Science and Technology should establish testing facilities and certification programs to ensure the performance and safety of new insulating materials. By developing national standards and guidelines, industries will benefit and adopt these innovations with confidence.

2. As for the housebuilders, implementation of sustainable and eco-friendly practices are recommended. Choose insulation materials with low environmental impact, such as materials made up from recycled or renewable resources. Encouraging the use of non-toxic and biodegradable insulators that can contribute to greener constructions. As well as provide training for construction workers and contractors on proper insulation and installation to avoid or mitigate health related risk.

3. To future researchers, we recommend exploring insulators with multi-functionalities such as noise reduction, fire resistance, anti-microbial properties, and electromagnetic shielding for specialized applications. Also to perform side-by-side comparisons of innovative insulators with traditional materials to highlight advantages, limitations, and potential areas of improvement.

APPROVAL SHEET

This study entitled "Trifibre: Development of Sustainable Natural Insulation Using Kapok, Coconut, And Corn Fibers" Prepared and Submitted by Feb Russel M. Dela Cruz, Mheyaka Rosselyn Dela Peña, Chriz Andrei S. Flores, Emmanuel Vardly A. Gimeno, Justine Dwyane N. Goc-Ong, Keizen T. Panga Doyon, Jhelaica Jane Pellerin, Jhon Reil Repollo Piogo, And Ricamae C. Rivera in partial fulfillment of the requirements in the Practical Research, is hereby accepted.

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