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Turning Husks into Heat Shields: Corn Fiber-Polyurethane Insulation Panels

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I. Introduction

1.1 Background of the Study

Corn husk fiber is a promising eco-friendly material for insulation panels offering competitive thermal performance with added cost and sustainability benefits. It is well-suited for multiple insulation applications when combined with appropriate treatments and binders.

The effects of global warming and noise pollution on the environment and human health have drawn a lot of attention in the past decades. One of the most significant areas for possible improvement is the industrial sector. In order to do this, thermal insulation and sound-absorbing building materials are being used efficiently. The use of different natural fibers as materials for thermal insulation and/or sound absorption has garnered a lot of attention recently. This study examines the thermal insulation properties of corn husk fiber (CHF) in accordance with these investigations (Fattahi et al., 2023).

In the Philippines, corn is one of the most cultivated crops, local researchers have long explored the utilization of corn husks and other agricultural residues to reduce waste and add value through material innovation (Hapinat, 2023).

Corn husk, a fibrous byproduct of maize cultivation, is abundant in agricultural regions and typically discarded or underutilized. Rich in cellulose and lignin, corn husk fibers possess natural insulating properties, making them a promising candidate for thermal insulation applications. Their lightweight structure and biodegradability further enhance their appeal as an eco-friendly material.

To bind the corn husk fibers into a cohesive and durable panel, polyurethane is selected as the binder. Polyurethane is known for its excellent adhesion, flexibility, and resistance to moisture and ch emicals. Its compatibility with natural fibers allows for the creation of composite materials that maintain structural integrity and thermal performance. While polyurethane is a synthetic polymer, its use in controlled quantities can enhance the lifespan and functionality of bio-based insulation panels without compromising environmental goals.

This study specifically investigates the feasibility of combining corn husk fibers with polyurethane binder to fabricate insulation panels suitable for residential and commercial buildings. Moreover, it evaluates the thermal conductivity, with the objective of identifying a possible substitute for traditional insulation materials. By integrating agricultural waste with modern polymer technology, the research contributes to the development of innovative, sustainable, and cost-effective building solutions.

1.2 Statement of the Problem

In recent years, some synthetic fibers have been utilized as reinforcements in composites. The main drawbacks of synthetic fiber are its long environmental decomposition time, high processing costs, irritability to humans, and toxicity when burned in the atmosphere (Ramya et al., 2025). The majority of thermal insulation materials still use synthetic, non-renewable materials that are harmful to the environment and human health, despite growing interest in sustainable building practices. Corn husk fibers and other agricultural residues are still mostly underutilized, and little is known about their potential as thermal insulators. By assessing the performance of corn husk fiber-polyurethane composites in thermal insulation applications, this study seeks to close the gap. In particular, it evaluates how these composites compare to traditional insulation materials in terms of mechanical strength, and thermal conductivity. This study therefore asks: What thermal conductivity, compressive strength, and water absorption do CHF–PU panels achieve at fiber-to-binder ratios of 60:40, 70:30, and 80:20.

1.3 Objectives of the Study

This study aims to explore the potential of corn husk fiber as a thermal insulation material using the three ratios (60:40, 70:30 and 80:20) by weight.

Specifically, it aims to answer the following:

1. To determine the thermal insulation capacity of corn husk fiber panels of the three ratios by measuring thermal conductivity with parameters:
   - Thermal conductivity in W/m·K
   - Comparative benchmark: $\leq$ 0.04 W/m·K (reference value for conventional insulation materials)
2. To evaluate the effectiveness of polyurethane as a binder of the three ratios by assessing moisture resistance and basic physical stability using:
   - Compressive strength: (ASTM C165 – Standardized Test Method for Measuring the Compressive Properties of Thermal Insulation Materials)
   - Water absorption: (ASTM C209 – Standard Test Methods for Cellulosic Fiber Insulating Board)
3. To compare the performance of corn husk insulation panels with conventional materials based on:

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- Reference materials: Expanded Polystyrene
- Testing standard: (ASTM C578 – Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation)

4. To identify the optimal fiber-to-binder ratio based on a multi-criteria scoring analysis of thermal, mechanical, and moisture performance.

1.4 Significance of the Study

The potential of corn husk fibers as a sustainable insulation component makes this study significant. The research encourages environmentally friendly innovation and advances the creation of renewable substitutes for traditional synthetic insulators by incorporating these natural fibers into polyurethane composites. Using corn husks not only helps save the environment by cutting down on waste, but it also provides an affordable insulation option, especially in areas with high agricultural output. Additionally, the study might find materials with competitive thermal efficiency that can improve building energy conservation. By fostering small-scale production of environmentally friendly building materials and developing new value chains for agricultural byproducts, it also has the potential to boost regional economies.

It also indicates that corn husk biodegradable fibers have a promising future as sources of significant economic benefits and contain enormous quantities of naturally occurring cellulose fibers. The properties of corn husk waste, a readily available, cost-effective, sustainable, and environmentally friendly natural fiber source, need to be further studied. In addition to providing information for a variety of industrial sectors, thorough characterization of plant fibers opens new uses for these natural fibers using inexpensive extraction techniques without sacrificing the fiber's unique qualities for the creation of bio-composite materials (Ramya et al., 2025).

1.5 Scope and Delimitation

This study focuses on the fabrication and laboratory-scale evaluation of corn husk fiber–polyurethane composite panels using three fiber-to-binder ratios (60:40, 70:30, and 80:20) by weight for potential building insulation applications. The scope includes testing for thermal conductivity, water absorption, and compressive behavior to assess thermal performance and basic structural stability. To represent practical and low-cost production methods, the study is limited to treated and minimally processed corn husk fibers. For each panel ratio, a total of ten (10) sampling trials were conducted per test to ensure consistency and reliability of the measured properties.

Mechanical testing is constrained by the unavailability of a Universal Testing Machine (UTM); thus, compressive behavior was assessed using a do-it-yourself (DIY) setup with a constant 50 kg sand load. As a result, all recorded compressive strength values were identical across trials and panel ratios, yielding zero variability. Consequently, statistical analysis and comparative evaluation of compressive strength among the different ratios were not feasible, as the data do not reflect true material response under progressive loading conditions.

Additionally, the custom guarded hot plate used for thermal conductivity measurements exhibited a calibration error of 12.77%, which introduces uncertainty in the reported thermal conductivity values.

Furthermore, none of the fabricated panels met the ≤5% water absorption criterion, which limits their applicability in moisture-exposed environments.

The study excludes long-term durability, fire resistance, field performance, large-scale manufacturing, alternative fibers or binders, and non-building applications such as packaging or automotive use. Comparison with commercial insulation panels was conducted using reference values from expanded polystyrene (EPS), focusing on key performance parameters such as thermal conductivity and water absorption as reported in established standards and literature.

II. Review of Related Literature

2.1 Natural Fiber-Based Insulation Materials

The growing demand for sustainable building materials has greatly aided in the development of environmentally friendly thermal insulation solutions. These solutions have significant environmental benefits and can reduce energy loss by up to 50% when compared to traditional insulation materials. They are frequently made from natural fibers, recycled materials, and agricultural byproducts (Messiry et al., 2025).

Agricultural residues are increasingly investigated as sustainable feedstocks for building insulation because they combine low embodied energy, inherent porosity (trapped air), and abundant availability with opportunities to divert waste from disposal streams. Reviews by Massoudinejad et al. (2019) on waste-derived insulation materials identify corn husk among several promising lignocellulosic candidates, noting that plant fibers generally offer low density and useful thermal and acoustic properties when processed into panels or composite foams. This line of research is driven by ambitions to lower the carbon footprint of building materials while meeting comparable thermal performance to conventional insulators in certain applications (Ye et al., 2025).

According to Yasmin et al. (2024), corn husk fiber (CHF) is a lignocellulosic material composed mainly of cellulose, hemicellulose, and lignin and features a cellular, porous microstructure that contributes to low solid-phase conductivity and the ability to trap air both favorable traits for thermal insulation. According to experimental studies that assessed the thermal performance of corn husk-based panels, their thermal conductivity values are competitive with those of a large number of bio-based insulators. For instance, steady-state and transient tests conducted on processed corn husk panels and composites have yielded effective thermal conductivity values commonly reported as approximately 0.028–0.042 $W \cdot m^{-1} \cdot K^{-1}$; these values vary according to density, treatment, and manufacturing route. These measured values place CHF-derived materials in the same performance neighborhood as several alternative natural insulators when moisture and density are controlled (Ratna et al., 2022).

The pursuit of sustainable construction materials has increased interest in the utilization of natural fibers as thermal and acoustic insulators. Agricultural residues such as rice husk, coconut coir, jute, and corn husk have been explored as low-cost, renewable, and biodegradable alternatives to conventional synthetic insulation (Balador et al., 2019). Studies consistently report that natural fiber insulation materials exhibit thermal conductivity values ranging from 0.03 to 0.06 W/m·K, comparable to commercial insulators such as mineral wool and expanded polystyrene (Pásztory et al., 2023).

Generally, insulation boards are categorized into two types: rigid or pressure-resistant (with densities above 100 kg m^{-3}) and flexible-resistant (with densities below 100 kg m^{-3}). The production of rigid wood fiber insulation boards typically involves a continuous steam process, with diphenylmethandiisocyanate (pMDI) as the standard binder. Flexible types usually incorporate bicomponent fibers (BF) and are manufactured using a hot air process. Recently, researchers have developed a hot air–hot steam process to achieve the higher temperatures required for utilizing natural binders (Cárdenas-Oscanoa et al., 2025).

Natural fiber insulation represents a sustainable and environmentally responsible category of thermal and acoustic insulation materials. It is primarily composed of plant-derived fibers such as cotton, hemp, flax, and straw, which are typically treated with fire-retardant agents and subsequently processed into batts or loose-fill formats for installation.

A key environmental advantage of natural fiber insulation lies in its low carbon footprint. The energy requirements for its production are significantly lower than those associated with synthetic insulation materials, thereby resulting in reduced greenhouse gas emissions. Furthermore, natural fiber insulation is biodegradable, allowing for environmentally safe disposal through composting or landfill degradation at the end of its service life.

In addition to its ecological benefits, natural fiber insulation exhibits favorable performance characteristics. It offers effective thermal regulation by mitigating heat transfer across building envelopes, thereby contributing to improved indoor comfort during both heating and cooling seasons. Its inherent acoustic absorption capabilities also make it particularly suitable for applications requiring sound attenuation, such as in residential media rooms or recording studios.

From a health and safety perspective, natural fiber insulation is non-toxic and hypoallergenic. Unlike conventional synthetic alternatives, it does not release hazardous substances or volatile organic compounds (VOCs) that may compromise indoor air quality. This renders it a suitable choice for occupants with respiratory sensitivities, including those with asthma or allergies.

While the initial cost of natural fiber insulation may exceed that of conventional materials, its long-term benefits such as energy savings and enhanced property value can offset the upfront investment. Moreover, it is a durable material with a prolonged functional lifespan, maintaining its insulating properties over several decades.

In summary, natural fiber insulation offers a compelling combination of environmental sustainability, occupant health protection, and functional performance. Its adoption in building applications aligns with broader goals of reducing ecological impact and promoting healthier indoor environments (CDAA Inc., 2025).

2.2 Corn Husk Fibers as Insulation

Beyond thermal performance by (Mohammed, 2022), studies consistently highlight three engineering challenges when using plant fibers for building insulation: moisture management (natural fibers are hygroscopic, which affects thermal conductivity and dimensional stability), mechanical integrity (adequate compressive and flexural properties for panel handling and installation), and fire safety (plant fibers are combustible and often require flame-retardant strategies to meet building code requirements). Researchers therefore evaluate pre-drying, chemical surface modification (e.g., alkaline or silane treatments), coupling agents, and non-halogenated fire-retardant additives or mineral fillers to mitigate these issues. Fire performance in particular is a recurrent concern and a major barrier to broader adoption unless effective, economical retardant systems are identified that do not unduly increase thermal conductivity (Ye et al., 2025).

On sustainability and life-cycle grounds a research study by Cascione et al., (2025), demonstrates through cradle-to-gate and comparative assessments of bio-based insulation show potential reductions in embodied carbon and the beneficial diversion of agricultural waste, but results are sensitive to processing energy, binder chemistry, and transport logistics. Several recent review articles recommend that material innovations be coupled with realistic supply-chain and LCA studies to confirm net environmental benefits at scale the economics likewise depend on regional availability of corn husk and the cost of pretreatment and binder materials. In short, environmental advantages are promising but context dependent and require integrated techno-economic and environmental assessment to validate claims of sustainability (Shanbhag et al., 2024).

A research study by Bhaskaran et al. (2023) indicates that, although the body of work demonstrates clear promise, notable research gaps remain, motivating the present study. First, focused investigations of corn husk specifically (as opposed to more general "agricultural residues") are still fewer in number, especially studies that systematically compare surface treatments, particle size distributions, and their direct effects on PU foaming behavior and long-term durability. Second, scalable, halogen-free flame-retardant strategies tailored to CHF–PU composites that preserve thermal and acoustic benefits require more experimental validation. Third, long-term aging studies (moisture cycling, ultraviolet exposure, biological resistance) and full cradle-to-grave LCAs that include realistic supply chains are underrepresented in the literature (Berardi et al., 2025). Addressing these gaps by optimizing CHF pretreatment and PU formulation, quantifying thermal/acoustic/mechanical tradeoffs, and assessing fire and durability performance will materially advance the case for corn-husk-based insulation panels as sustainable, multifunctional "heat shields" for buildings.

The concept that corn husk fiber can be transformed into effective insulation products when paired with polyurethane or used in panel form: CHF's cellular structure and low density yield promising thermal and acoustic behavior, and PU-based routes offer practical manufacturing paths. However, performance is highly dependent on processing, fiber–matrix interactions, moisture control, and fire mitigation (Fattahi et al., 2024).

Corn husk fiber (CHF) is a natural, lignocellulosic material characterized by its renewability and biodegradability. It is derived from the outer foliar sheath of the corn fruit, commonly referred to as the corn husk. Corn, scientifically known as *Zea mays*, is a member of the grass family and typically grows to heights ranging from 1 to 4 meters, featuring a central stalk and elongated leaf blades. The biomass composition of the corn plant consists approximately of 50% stalks, 23% leaves, 15% fruit, and 14% husk. Despite its structural significance in protecting the corn kernels, the husk is frequently discarded as agricultural waste.

Structurally, the corn husk is thin and planar, resembling foliar leaves. Corn husk fibers are extracted from these outer layers and are composed predominantly of cellulose and hemicellulose (80–87%), with a minor lignin content (6–7%). In terms of composition and performance, CHF is comparable to other lignocellulosic fibers such as jute and cellulosic fibers like cotton. It exhibits favorable mechanical and physical properties, including pliability, moderate tensile strength, durability, and high moisture retention capacity. Its relatively low crystallinity enhances its elongation behavior and facilitates chemical reactivity, making it suitable for various material applications.

As a textile or composite material, CHF has gained recognition for its functional performance, aesthetic qualities, and environmental compatibility. Its utility in sustainable material development underscores its potential as an alternative to conventional fibers in both industrial and consumer applications (Yasmin et al., 2024).

Several studies highlight their potential as insulation due to their porous and lightweight structure. Chokphoemphun et al., 2019, reported that treated corn husk fibers used as insulation in a flat-plate solar collector achieved thermal conductivity values of 0.0287–0.0316 W/m·K. Similarly, Fattahi et al., 2023 developed insulation panels from waste corn husk fibers and observed thermal conductivity values of approximately 0.038–0.042 W/m·K, while also demonstrating acoustic absorption properties. These findings suggest that corn husk fibers not only provide thermal resistance but may also serve as dual-purpose insulation for soundproofing applications.

Corn stover (husks, stalks, and leaves), sugar palm, pineapple leaves, and oil palm are examples of agricultural harvest wastes that are generated in enormous numbers each year, are abundant, inexpensive, and can be used as a sustainable supply of bio-materials. Only a small portion of these enormous quantities of remaining material are utilized as animal fertilizer or household fuel; the majority are typically burned, which has a detrimental effect on the environment because it contaminates the air (Ibrahim et al., 2019).

The climate in the Philippines is primarily hot and humid. According to a recent report by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), temperatures in many areas are 40°C and higher, with Eastern Samar recording a temperature of 55°C, which is the highest temperature ever recorded in the Philippine Heat Index and is not considered as normal (Daanoy, 2024). To combat this problem, Filipinos usually turn to air conditioning to stay comfortable during periods of extreme heat, which subsequently raises their electricity costs. In the Philippines, corn husk fibers are a plentiful waste product that is frequently utilized for carpeting, rugs, home furnishings, and packing crops and food grains. Because of its adaptability, maize husk fibers were used to create thermal insulation for ceiling panels. According to experimental findings of the thermal conductivity is 0.119 W/m·K (Manalindo et al., 2023).

2.3 Polyurethane Binder in Natural Fiber Composites

Polyurethane is a highly effective binder known for its strong adhesion and flexibility. It cures through a moisture-driven reaction, forming a durable and resilient film that bonds well to various substrates. This binder offers excellent resistance to wear, chemicals, and environmental factors such as UV exposure and temperature fluctuations. Its mechanical strength and elasticity make it ideal for applications requiring both toughness and adaptability. Additionally, polyurethane can be formulated to reduce VOC emissions, making it a more sustainable choice in modern composite materials.

Polyurethane (PU) especially rigid PU foam is widely used for thermal insulation because of its low intrinsic thermal conductivity and structural properties; consequently, combining PU with natural fillers has become a popular route to hybridize performance and sustainability (Horvat et al., 2024). The literature shows two main composite strategies: (1) dispersing fibers/particles into PU before foaming to create bio-filled rigid foam, and (2) binding fibers into panel form using PU as an adhesive or binder. Studies of natural-fiber reinforced PU foams report that filler type, size, and loading (plus drying and surface treatment of the fiber) strongly influence foaming chemistry, cell morphology (closed-cell fraction and cell size), density, and hence thermal and mechanical properties. To obtain stable low-density, well-insulating foams, researchers commonly optimize filler loading and use treatments (alkali, silanes, or compatibilizers) to reduce hydrophilicity and improve interface adhesion (Kirpluks et al., 2024).

Several recent experimental works combine research by Mirițoiu et al. (2021) corn-derived residues (cob, stalk, or husk) with polymeric matrices and report both feasibility and promising thermal/acoustic outcomes. Specific investigations into corn husk panels and corn-husk-filled composites demonstrate acceptable thermal conductivity alongside notable acoustic absorption: research on corn husk fiber panels reports noise reduction coefficients and thermal conductivities that suggest multifunctional capability (thermal + acoustic) for CHF-based products. Related work that uses corn stalk or cob particles in polyurethane show thermal conductivity values in the low-hundredths of $W \cdot m^{-1} \cdot K^{-1}$ (e.g., ~0.042 $W \cdot m^{-1} \cdot K^{-1}$ in some composites), supporting the idea that corn residues can be integrated into PU systems without sacrificing basic insulation performance when formulation and processing are controlled (Karapınar, 2020).

By enhancing binders' flexibility, adhesion, and bonding qualities, polyurethane (PU) offers superior sealing capabilities and excellent adhesive performance. Great bonding strength between materials, durability, and resistance to environmental factors make polyurethane-based adhesives a great choice for a wide range of industrial applications (Kimpur, 2021). Modern materials such composite wood depend greatly on polyurethanes. Long-strand lumber, medium-density fiberboard, oriented strand board, laminated veneer lumber, strawboard, and particleboard are all firmly bonded with organic ingredients using polyurethane-based binders in composite wood products (American Chemistry Council, 2025).

Polyurethane (PU) foams are widely used in insulation due to their low thermal conductivity, closed-cell structure, and lightweight nature. Rigid polyurethane foams typically demonstrate thermal conductivities ranging between 0.025 and 0.046 W/m·K (Zhang et al., 2020). Similarly, the addition of nanocellulose into PU foams has been shown to refine cell morphology, reduce average cell size, and lower thermal conductivity at low fiber loadings (Kurańska et al., 2021). These findings support the hypothesis that corn husk fibers, when combined with polyurethane binders, can improve the overall thermal insulation performance of fabricated panels.

Polyurethane (PU) is a synthetic polymer widely used in insulation due to its excellent thermal performance and long service life. Rigid PU foam can last over 50 years under proper conditions, thanks to its closed-cell structure that resists water absorption and thermal decay (Excellence in Insulation, 2025). However, conventional PU is petroleum-based and non-biodegradable, raising concerns about its environmental impact. Recent developments in bio-based PU formulated with renewable polyols have introduced partially biodegradable alternatives that offer a more sustainable profile (Kaur et al., 2022; Kognou, 2022).

When CHF is combined with PU to form hybrid insulation panels, the result is a material that balances sustainability with durability. The natural fiber component reduces reliance on fossil-based fillers, while the PU binder extends the panel's functional lifespan to 20–30 years, depending on fabrication methods and environmental exposure (Dela Cruz et al., 2025). Although the composite is not fully biodegradable due to the synthetic binder, it still offers a reduced environmental footprint and aligns with circular economy principles by repurposing agricultural waste into high-performance building materials.

2.4 Foreign Studies

International investigations a research study by (Berardi et al., 2025) of agricultural residues as building insulators have steadily grown over the last decade, driven by circular-economy and low-carbon building goals; several foreign studies show that corn husk and other lignocellulosic wastes can be processed into low-density insulating boards or incorporated as fillers in polymer foams with measurable thermal and acoustic benefits. For example, comparative block-type insulation work that included corn husk among other agricultural fibers used statistical design to tune processing conditions and reported that properly processed corn husk fibers produce panels whose thermal resistance and acoustic properties are competitive with other bio-based insulators, especially when density and fiber orientation are optimized (Rodríguez-Neira et al., 2023).

Detailed material-level studies by Sari and Suteja (2020) from abroad characterize corn husk fiber as a porous lignocellulosic material whose cellular morphology and high porosity help trap air and lower solid-phase thermal conductivity properties favorable for insulation applications. Experimental thermal testing on processed corn husk (used in flat plate solar collector insulation and related panel forms) has produced thermal conductivity values in ranges that demonstrate feasibility for thermal-control uses, with results depending substantially on panel density, compaction method, and pre-treatment (drying or alkali treatment) of the husks (Hazrol et al., 2023). These foreign experimental reports demonstrate that, under controlled manufacturing and moisture conditions, corn husk panels can approach the thermal performance necessary for building insulation components.

A substantial body of international literature a research study by Li et al. (2020) also examines how natural fibers interact with polyurethane matrices. Reviews and experimental studies from multiple countries document two practical manufacturing routes: dispersing pretreated fibers into rigid PU formulations before foaming or producing particleboard-style panels using PU as the binder. These foreign studies consistently report that fiber size, loading fraction, and surface chemistry strongly affect PU foaming kinetics, cell morphology (closed-cell fraction), density and therefore thermal performance; consequently, researchers abroad recommend optimizing fiber pretreatment (e.g., drying, mild alkali, silane coupling) and keeping filler loadings within ranges that preserve desirable foam microstructure (Kuranchie et al., 2021).

Several experimental foreign studies by Sari et al. (2017) report combined thermal and acoustic benefits from corn husk products. Work published in international journals has shown that corn husk fiber panels and composites can deliver useful noise-reduction performance (high NRC/absorption at mid–high frequencies) while still providing low-to-moderate thermal conductivity values when manufactured under controlled conditions; these dual-function results suggest that CHF-PU panels can be positioned as multifunctional "heat-and-sound" shields in building applications (Tang et al., 2018). At the same time, foreign researchers emphasize that results vary across studies thermal conductivity measurements reported in the international literature span a range because of differences in test method, density, and moisture content.

Fire safety, moisture sensitivity, and long-term durability are recurring concerns flagged by foreign work and are treated as key barriers to broad adoption (Yang et al., 2021). International experimental programs and recent developments in bio-based polyurethane research show progress toward biobased or improved PU formulations that aim to combine low thermal conductivity with enhanced fire retardancy, but the literature stresses that effective, economical, halogen-free fire-retardant systems tailored to corn-husk-filled PU composites remain an active area of study (Vahabi et al., 2020). In short, foreign studies demonstrate conceptual and laboratory feasibility for CHF–PU insulation panels while repeatedly identifying moisture management, fiber–matrix interface

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optimization, and fire performance as priorities for translational research.

Taken together, the foreign related studies form a clear foundation for the present research as they validate corn husk as a promising feedstock for thermal and acoustic insulation, outline concrete production routes for integrating CHF with polyurethane, and highlight the processing levers (pretreatment, particle size, filler loading, and PU formulation) that control final properties. They also identify key research gaps that this study aims to address, including the systematic optimization of CHF surface treatment for PU compatibility, the quantification of long-term moisture and biodegradation effects under accelerated aging, and the development and testing of halogen-free fire-retardant strategies for CHF–PU panels, making the proposed project both timely and well-grounded in the international literature (see Pandecha et al., 2015).

2.5 Local Studies

In the Philippines, a country where corn is one of the most cultivated crops, local researchers have long explored the utilization of corn husks and other agricultural residues to reduce waste and add value through material innovation (Hapinat, 2023). Several studies from Philippine universities have reported on the potential of corn husk fibers as raw material for particleboards, handmade paper, and fiber-reinforced composites, noting that their cellulose-rich structure provides tensile strength and porosity advantageous for both structural and insulation applications. For instance, engineering research projects have investigated corn husk boards bonded with locally available resins and found them to have acceptable thermal resistance and sound absorption, suggesting potential for use as eco-friendly construction materials. Similarly, investigations into agricultural waste as insulation materials in the country frequently highlight corn husks, rice hulls, and coconut coir as abundant and low-cost resources that can reduce dependence on imported synthetic insulators (Amper et al., 2018).

With corn widely grown in Luzon, Visayas, and Mindanao, husk residues often end up discarded or burned, contributing to environmental pollution. Philippine research into sustainable housing and green construction materials has thus encouraged turning these wastes into useful insulation and panel products. For example, some student theses and institutional research have fabricated insulation boards from corn husks and reported thermal conductivity values comparable to other natural fiber insulators, reinforcing the feasibility of corn husk-based panels in tropical climates where both heat control and cost-effectiveness are critical (Esconde, 2021).

Furthermore, Philippine studies in material science have explored the use of polyurethane (PU) and other polymeric binders with natural fibers, pointing out the compatibility challenges due to the hydrophilic nature of lignocellulosic fibers (Olanrewaju et al., 2025). Local experimental work has shown that pretreatments such as drying, alkaline washing, or simple mechanical cleaning improve fiber–binder adhesion and panel durability. While most local efforts have focused on small-scale particleboards or fiber mats, they provide a strong baseline for extending this research to CHF–PU insulation panels with enhanced thermal performance (Malaluan, 2019).

A study by Bungag (2018) reflects growing recognition of corn husks as a renewable, underutilized material resource in the Philippines. Studies converge on three key points: (1) corn husk fibers are technically viable for insulation and composite applications; (2) their use directly addresses agricultural waste management and supports sustainable construction; and (3) there is a pressing need for further experimentation with modern binders like polyurethane to optimize thermal conductivity, moisture resistance, and fire safety of husk-based panels. These findings establish a clear local context and justification for the present study on developing corn husk fiber–polyurethane insulation panels as "heat shields" for buildings.

2.6 Thermal Performance Benchmarks

The thermal conductivity of natural fiber-based insulation varies widely depending on fiber type, density, and treatment. Corn husk fiber insulation panels have reported thermal conductivities ranging from 0.029 to 0.042 W/m·K (Fattahi et al., 2023). For comparison, rigid polyurethane foams have thermal conductivity values between 0.025 and 0.046 W/m·K (Zhang et al., 2020). This indicates that corn husk fiber–PU composites have the potential to achieve conductivity values competitive with both natural fiber and commercial insulators. Still, humidity absorption is a serious worry because a higher water content increases thermal conductivity and lowers insulation efficiency (Pásztory et al., 2023). Thus, density control and surface treatments are key considerations in panel design.

Materials for thermal insulation reduce energy loss in both commercial and residential structures. By maximizing the capacity of existing heating and cooling systems, these insulation approaches can be used all year round. Additionally, it lowers the high operating expenses of air conditioners and water heaters as well as the high maintenance costs of these systems. When CO_2 emissions are significantly reduced, electricity consumption can be decreased, improving living conditions and creating a more serene environment for people (Okokpujie et al., 2022).

Empirical evidence has demonstrated that thermal insulation in buildings significantly reduces heat loss through transmission, thereby lowering energy consumption for heating. Regulatory standards governing thermal insulation were established in many developed nations over three decades ago. Initially, research in this domain was grounded in practical experience, which subsequently informed the development of theoretical frameworks, analytical methodologies, and computational procedures aimed at optimizing insulation systems.

The thermal insulation market has historically been dominated by synthetic materials, primarily derived from fossil fuels. Due to their widespread use and increasing demand, concerns have emerged over the environmental implications and the potential depletion of these non-renewable resources. Consequently, enhancing thermal insulation in residential buildings remains a critical objective within the broader sustainability agenda, with implications for environmental stewardship and public health.

In southern Chile, inadequate thermal insulation in residential structures has led to elevated heating energy consumption. This, in turn, contributes to significant levels of air pollution, particularly from particulate matter generated through biomass combustion for domestic heating. According to the World Health Organization and the Chilean Ministry of Environment, such pollution poses serious health risks to the population.

Within this context, the integration of natural fibers into insulation materials presents a viable and environmentally responsible alternative. The adoption of bio-based insulation solutions offers the potential to mitigate adverse environmental impacts while maintaining indoor thermal comfort. However, the development and production of natural fiber insulation must be carefully managed to avoid competition with food crops. Instead, emphasis should be placed on utilizing residual biomass from existing agricultural and industrial processes to ensure both ecological and economic sustainability. (Rojas et al., 2019).

2.7 Fiber Surface Treatment and Interfacial Bonding

Chemical treatments such as acetylation (CH_3CO), acrylation (CH_2CHOOH), alkaline ($NaOH$), benzoylation ($C_6H_5C_{14}O$), dicumyl peroxide ($C_{18}H_{22}O_2$), potassium permanganate ($KMnO_4$), maleated coupling agents (MaPOs), methacrylate ($CH_2C(CH_3)$ COO), silane (SiH_4), sodium chlorite ($NaClO_2$), and stearic acid ($CH_3(CH_2)_{16}COOH$) have been widely used for surface modification of NFs. Alkalization is considered economical, enhancing the surface roughness by disrupting hydrogen linkages within the networking structure. Consequently, the number of (−OH) groups adds to NF surfaces, resulting in enhanced wetting, thermal stability, and adhesion with polymer matrices (Khoaele et al., 2024).

Chemical treatments have a considerable effect on NFRPC's mechanical properties owing to hydroxyl groups from cellulose and lignin. Chemical-treatment strategies commonly rely on reagent functional groups/active groups capable of responding superiorly with natural-fiber structures, just as adequately removing non-cellulosic materials from the fibers. Moreover, hydrogen bonding between hydroxyl groups created by chemical treatments within cellulose atoms might restrict movement into the matrix. Therefore, chemical changes either generate these groups or introduce fresh moieties that may efficiently interlock with the matrix, establishing a strong bond.

The poisonous and reactive synthetic chemicals are sometimes added to the composite to stop an organic attack, which is the basis for the wood-preservation industry. Many surface treatments, for example, alkali, acetylation, silane, and peroxide treatments, have been conducted to improve fiber properties (Khalid et al., 2021).

These treatments are especially important because moisture can significantly increase thermal conductivity and reduce the insulating effectiveness of panels, as well as promote biodegradation. Therefore, well-treated fibers contribute to insulation panels that are both mechanically stable and durable under real-world environmental conditions.

Continued research into surface modification techniques aims to enhance the longevity and performance of natural fiber composites while keeping the processes eco-friendly and cost-effective, supporting the overall goal of producing sustainable, high-performance insulation materials.

2.8 Fabrication of Fiber-Based Insulation Panels

The way fiber-based insulation panels are made greatly affects their thermal and mechanical properties. Typically, hot-pressing is used, where natural fibers are mixed with a binder and compressed under heat. This process helps to form a strong panel with a specific density and porosity, both of which are key factors in determining insulation effectiveness. Optimizing the ratio between fiber and binder is crucial to find the right balance between mechanical durability and thermal resistance. If the panel is too dense, its insulating efficiency goes down, but if it's too light or loosely packed, it might lack the durability needed for practical use (Li et al., 2020).

Recent innovations include combining different agricultural fibers, such as corn husk with coconut or sugar palm fibers, to enhance mechanical strength while maintaining low thermal conductivity (Rojas et al., 2019). Additionally, adjusting pressing temperature and pressure during fabrication can tailor the panel's characteristics for instance, temperatures between 120–150 °C are commonly used to cure polyurethane binders effectively without degrading the natural fibers (Li et al., 2020). These fabrication parameters must be carefully controlled to create panels that can withstand environmental changes like humidity and temperature shifts, ensuring their long-term performance in real-world building applications.

Overall, the fabrication process is a fine balance of materials and techniques designed to produce insulation panels that are strong, durable, and thermally efficient while keeping the process as sustainable and eco-friendly as possible.

2.9 Health and Safety Considerations in Using Natural Fiber Insulation

Natural fiber insulation is increasingly regarded as a safer and healthier alternative to many conventional synthetic insulation materials. One of the fundamental benefits is that natural fibers, including corn husk fiber, do not emit harmful volatile organic compounds (VOCs) or respirable mineral fibers that can irritate or damage respiratory systems (Petrović et al., 2025). This property makes natural fiber insulation well-suited for environments with occupants suffering from asthma, allergies, or chemical sensitivities, as it helps maintain superior indoor air quality without triggering adverse health effects (CDAA Inc., 2025).

In addition to low emissions, natural fibers contribute to moisture regulation by absorbing and releasing water vapor due to their hygroscopic nature. This moisture-buffering capability helps stabilize indoor humidity levels, reducing condensation risks and improving indoor air quality (Przybek, 2025). Maintaining optimal humidity is also known to limit the growth of mold, dust mites, and bacteria that can compromise occupant health. The moisture-buffering capacity of natural fiber insulation is especially beneficial in humid climates or buildings prone to moisture infiltration, helping maintain balanced humidity levels and reducing the risk of dampness-related respiratory problems.

From a fire safety perspective, natural fibers are inherently combustible, but when treated with suitable fire retardants, they exhibit enhanced resistance to ignition and flame spread, meeting stringent building and fire safety codes (Yasmin et al., 2024). These fire-retardant treatments aim to improve the fire performance of natural fiber composites while maintaining their environmental benefits. However, challenges remain in meeting fire safety standards due to the inherent flammability of natural fibers, requiring continued research to optimize formulations without compromising sustainability (Przybek, 2025).

Regulatory and market considerations are increasingly recognizing natural fiber insulation as a viable green building material. Its use supports certifications like LEED and WELL Building Standard, which emphasize indoor environmental quality and occupant health alongside sustainability goals (Petrović et al., 2025). However, current building regulations and certification frameworks such as LEED and BREEAM play a critical role in material acceptance, and further standardization and validation are needed to support the broader adoption of natural fiber insulation (Przybek, 2025).

2.10 Physical and Thermal Characterization

Pretreatment of corn husk with 10% NaOH solution at various reaction times yields different fiber percentages (Pandecha, 2015). This shows reaction time has an effect on fiber quantity as shown in Table 2.1.

Table 2.1. *Percentage of Crude Fiber of Corn Husk Fiber after Pretreatment with 10% NaOH at Various Reaction Times*

Corn husk	Crude Fibers (%)
Non-pretreatment	33.03
Pretreatment with 10% NaOH for 30 minutes	39.49
Pretreatment with 10% NaOH for 45 minutes	39.95
Pretreatment with 10% NaOH for 60 minutes	44.54
Pretreatment with 10% NaOH for 90 minutes	44.72

Source: Table 2.1 Thermal properties of corn husk fiber as insulation for flat plate solar collector, Pandecha, 2015.

As appeared in Table 2.1, during pretreatment of corn husk with 10% NaOH, ranging reaction times from 30 to 90 minutes, it is found that sodium hydroxide solution affects fiber quantity in terms of reaction time when compared with the specimen without pretreatment. This results in destroying bond between various fibers such as cellulose, hemicellulose and others which causes fiber quality to be improved. However, total reaction time for 60 minutes is selected because there is only marginal difference between 60 and 90 minutes results. Chemical composition of corn husk with and without pretreatment can be seen in Table 2.2.

Table 2.2. *Chemical Composition of Corn Husk*

Chemical composition	% (By dry weight)	
	Non-pretreatment	Pretreatment
Cellulose	47.00	61.37
Hemicellulose	43.96	19.93
Lignin	4.13	2.23
Ash	2.93	12.48

Source: Table 2.2 Thermal properties of corn husk fiber as insulation for flat plate solar collector, Pandecha, 2015.

Table 2.2 shows the percentage of the corn husk fiber soaked in 10% NaOH solution for 60 minutes, the percentage of cellulose is increased while percentage of hemicellulose and lignin is decreased because the amount of starch is removed and structure of hemicellulose is destroyed, while cellulose is the major part for producing fiber insulation board (Pandecha et al., 2015).

Thermal Resistance (R-value)

R-values will be computed using the formula:

$$R_t = \frac{L}{k \cdot A} \qquad \text{Equation 2.1}$$

Where:

R_t is the thermal resistance (in K/W)
L is the material's thickness parallel to heat flow (in m)
k is the material's thermal conductivity (in W/(m·K)), and
A is the cross-sectional area perpendicular to the heat flow (in m²)

Testing Standards for Thermal Characterization

Thermal characterization tests are performed following established standards such as (ASTM C177 – Standard Test Method for Determining Thermal Conductivity of Insulation Materials Using a Guarded-Hot-Plate Apparatus). Table 2.3 shows the classification and thermal conductivity ranges of commonly used insulation materials. The values presented serve as reference benchmarks for assessing the thermal performance of the fabricated corn husk fiber–based insulation panels (Le et al., 2021).

Table 2.3. *Classification of the Commonly used Insulation Materials and Uncertainty about their Thermal Conductivity.*

Main group	Subgroup	Insulation Material	Temperature (°C)	Density (kg/m³)	Thermal conductivity (W/ (m.K))
Inorganic	Fibrous	Glass wool	−100–500	13–100	0.03–0.045
		Rock wool	−100–750	30–180	0.033–0.045
	Cellular	Calcium silicate	300	115–300	0.045–0.065
		Cellular glass	−260–430	115–220	0.04–0.06
		Vermiculite	700–1600	70–160	0.046–0.07
		Ceramic	N.A.	120–560	0.03–0.07
Organic	Foamed	EPS	−80–80	15–35	0.035–0.04
		XPS	−60–75	25–45	0.03–0.04
		PUR	−50–120	30–100	0.024–0.03
		PIR	−20–100	30–45	0.018–0.028
		Cork	110–120	110–170	0.037–0.050
	Foamed, expanded	Melamine foam	N.A.	8–11	0.035
		Phenolic foam	150	40–160	0.022–0.04
		Polyethylene foam	−40–105	25–45	0.033

Jocelyn Davalan and Jeshier John Feliciano, "Turning Husks into Heat Shields: Corn Fiber-Polyurethane Insulation Panels," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 9, Issue 2, pp. 466-483, July 2026.

Continuation of Table 2.3

		Fiberglass	−4–350	24–112	0.033–0.04
		Sheep wool	130–150	25–30	0.04–0.045
		Cotton	100	20–60	0.035–0.06
		Cellulose fibers	60	30–80	0.04–0.045
	Fibrous	Jute	N.A.	35–100	0.038–0.055
		Rice straw	24	154–168	0.046–0.056
		Hemp	100–120	20–68	0.04–0.05
		Bagasse	160–200	70–350	0.046–0.055
		Coconut	180–220	70–125	0.04–0.05
		Flax	N.A.	20–80	0.03–0.045
		Gypsum foam	N.A.	N.A.	0.045
Combined	Boards	Wood wool	110–180	350–600	0.09
		Wood fibers	110	30–270	0.04–0.09
Advanced materials		VIPs	N.A.	150–300	0.002–0.008
		Aerogel	N.A.	60–80	0.013–0.014

Source: Table 2.3 An overview of factors influencing thermal conductivity of building insulation materials, Le Duong Hung Anh and Zoltán Pásztory, December 2021.

III. Methodology

This chapter presents the materials, fabrication process, and testing procedures used in the development of corn husk fiber-based insulation panels bonded with polyurethane. The methodology focuses on controlled panel fabrication and standardized thermal and mechanical characterization to evaluate the suitability of agricultural waste fibers as sustainable insulation materials.

3.1 Research Design

This study employed a quantitative experimental research design to fabricate and thermally characterize corn husk fiber-based insulation panels using a polyurethane binder. The approach integrated principles from materials science and environmental engineering, with emphasis on occupational safety, sustainability, and waste valorization. The study investigated the influence of varying fiber-to-binder ratios, curing conditions, and panel dimensions on thermal conductivity, mechanical integrity, and moisture resistance.

3.2 Research Locale

The experiment was conducted at Western Mindanao State University, specifically within the College of Engineering laboratory located at the main campus in Baliwasan, Zamboanga City. The facility was equipped with the necessary tools and equipment for fiber processing, while other equipment and testing tools were provided by the researcher.

3.3 Material Collection

The collection of raw materials was an essential initial step in ensuring the quality and consistency of the insulation panels. This study focused on utilizing readily available agricultural waste, specifically corn husk fibers, to promote sustainability and reduce environmental impact. Proper collection and preparation of these materials ensured reliable processing, uniform fabrication, and accurate evaluation of the panels' thermal and mechanical performance.

3.3.1 Corn Husk Fibers

Corn husks were collected from local agricultural waste streams in Zamboanga City to promote sustainable resource utilization. The stem portions were manually removed to eliminate rigid, non-fibrous components, and the husks were thoroughly cleaned to remove dirt and impurities. Subsequently, the cleaned husks were sun-dried for 48 hours to reduce moisture content and minimize the risk of microbial growth. Figure 3.1 shows the collected untreated corn husks.

Figure 3.1. Untreated Corn Husks

3.4 Material Processing

Material processing was a crucial stage that prepared both the corn husk fibers and polyurethane binder for panel fabrication. This step ensured that the raw materials were refined, treated, and conditioned to achieve consistent quality and optimal performance. Proper processing enhanced fiber-binder compatibility, improved the structural integrity of the composite, and supported accurate evaluation during testing.

3.4.1 Fiber Processing

The dried corn husks first underwent chemical pretreatment by soaking in a 10% sodium hydroxide (NaOH) solution for one hour. Figure 3.2 shows the sodium hydroxide used in this study. This treatment aimed to remove lignin and hemicellulose, increase the cellulose content, and improve fiber–matrix adhesion, thereby enhancing the thermal insulation properties of the final product. Figure 3.3 shows the treated corn husk fiber after the chemical treatment, the husks were thoroughly sun-dried to remove residual moisture. Once dried, the corn husks were mechanically shredded to reduce the fiber length; however, the resulting fibers exhibited non-uniform lengths due to the limitations of the shredding process. The reduction in fiber size achieved through shredding also contributed to lower porosity during panel fabrication, leading to improved material compactness and thermal performance.

Figure 3.2. Sodium Hydroxide (NaOH)

Figure 3.3. Treated Corn Husks with Sodium hydroxide (NaOH)

3.4.2 Polyurethane Binder

A commercially available polyurethane resin was used as the binding agent due to its low thermal conductivity, compatibility with lignocellulosic fibers, mechanical flexibility, and environmental stability. Safety throughout processing was guaranteed by handling the binder with proper personal protective equipment and keeping it in sealed containers.

3.5 Panel Fabrication

The panel fabrication section outlined the systematic process of transforming corn husk fibers and polyurethane binder into thermal insulation panels. This involved precise mixing of fibers and binder at varying ratios, molding the mixture into standardized panel dimensions, and controlled curing to ensure optimal bonding and mechanical integrity. Each step was designed to enhance the composite's thermal performance and structural stability, setting the foundation for subsequent testing and evaluation of insulation efficiency.

3.5.1 Mixing Procedure

The corn husk fibers and polyurethane binder were mixed at three different weight ratios: 60:40, 70:30, and 80:20 (fiber to binder) the corn husk weighs 500 grams, only the binder varies per ratio. In the first ratio, 60 parts by weight of corn husk fiber were combined with 40 parts by weight of polyurethane binder. In the second ratio, 70 parts of fiber were mixed with 30 parts of binder, while the third ratio consisted of 80 parts fiber and 20 parts binder. Each batch was mixed in a clean mixing chamber to ensure that the binder was uniformly distributed and the fibers were optimally wetted, which was critical for the composite's structural integrity and performance.

3.5.2 Molding and Curing

The fiber-binder mixture was poured into a custom mold measuring 0.30 m × 0.30 m × 0.020 m, as shown in Figure 3.4, which was lined with a silicone-based release agent. Manual compression was applied for ten minutes to ensure uniform thickness, adequate binder penetration, and reduced air voids. The panels then underwent natural curing at ambient temperature (25–30 °C) for 24 hours.

Figure 3.4. Molder of the Corn Husk Insulation Panels

3.5.3 Demolding and Post-Curing

After curing for 24 hours, the panels were carefully demolded to prevent edge damage. They were then subjected to oven drying at 60 °C for one hour to promote polymer cross-linking, enhance mechanical strength, and reduce residual moisture.

3.5.4 Conditioning

The post-cured panels were conditioned in a controlled-environment chamber at room temperature for 72 hours. This conditioning step ensured equilibrium moisture content and stabilized the panels prior to thermal and mechanical testing.

3.5.5 Fabrication of the Custom-Designed Guarded Hot Plate

The outermost layer of the setup serves as insulation to minimize heat loss. Surrounding the main heater, a guard layer was maintained at the same temperature as the heater to prevent heat dissipation from the primary heat source by providing thermal isolation on five sides. The primary heat source consists of a bulb, with an aluminum foam insulation positioned between the sample and the heat source to ensure uniform heat distribution. A Peltier device was employed as the cold source, accompanied by a fan to facilitate even dispersal of the cooled air.

Following complete assembly, the calibration procedure for the guarded hot-plate apparatus begins with selecting an insulation panel that has a certified and known thermal conductivity value, serving as the reference standard. The reference panel was positioned within the apparatus in the same manner as the test specimens, ensuring consistent contact and alignment. The apparatus was then operated under the same test conditions planned for the actual samples, including maintaining the hot plate at 39°C and the cold plate at 28°C to establish the target temperature differential. This calibration step was essential to verify the apparatus's accuracy and reliability. Upon successful calibration, the apparatus was utilized to evaluate the thermal performance of the fabricated insulation panels.

Figure 3.5. Modified Guarded Hot Plate

Figures 3.5 illustrates the modified guarded hot plate apparatus used to evaluate the thermal conductivity of the fabricated corn husk fiber–based insulation panels. The testing configuration was based on the ASTM C177 standard, which is a widely accepted method for determining steady-state thermal transmission properties of flat insulation materials under controlled conditions.

The apparatus consisted of a heated hot plate section and a cooled cold plate section, with the insulation specimen placed between them. Temperature sensors were strategically positioned on both the hot and cold sides to accurately monitor the temperature gradient across the panel. Insulation layers surrounding the hot plate minimize lateral heat losses, ensuring that heat transfer occurs predominantly in the one-dimensional direction, as required by the ASTM standard. This guarded configuration improves measurement accuracy by maintaining a stable and uniform heat flow through the test specimen.

3.6 Testing

The testing section evaluated the thermal insulation and mechanical properties of the fabricated corn husk fiber panels. Thermal conductivity was measured using a guarded hot-plate apparatus, while mechanical strength and water absorption tests ensure durability and structural performance. These tests provided essential data to assess the panels' suitability for insulation applications.

3.6.1 Thermal Conductivity Testing

Thermal conductivity of the corn husk fiber insulation panels was determined using a custom-designed guarded hot-plate apparatus operating under steady-state conditions. A target thermal conductivity of $\leq 0.04\ W \cdot m^{-1} \cdot K^{-1}$ was adopted as a performance benchmark to quantify and control the material's resistance to heat flow. Thermal conductivity is a fundamental parameter that describes the rate at which heat is conducted through a material; lower values indicate superior insulating capability due to reduced conductive heat transfer.

The testing procedure followed the steady-state technique outlined in ASTM C177 (Standard Test Method for Determining Thermal Conductivity of Insulation Materials Using a Guarded-Hot-Plate Apparatus). During the experiments, both the hot and cold plates operated simultaneously to induce unidirectional heat flow through the sample. The hot plate temperature was maintained at 39 °C, while the cold plate was maintained at 28°C, resulting in an approximate temperature differential of 11 °C across the specimen.

Each panel sample, measuring 0.30m × 0.30m with a thickness of 0.020m, was positioned within the fully insulated metering section of the apparatus to minimize heat losses. Thermocouples were installed on both surfaces of the panel to accurately capture the temperature gradient, and a wattmeter monitored the electrical power supplied to the heater. Data acquisition continued until steady-state conditions were established, defined by temperature fluctuations of less than 0.5 °C at each thermocouple and power variations within 2% over a continuous 30-minute interval.

Steady state was considered achieved when the temperatures on the hot and cold sides (T_h and T_c) and the wattmeter readings remained stable for 30 minutes, with thermocouple temperature changes not exceeding 0.5 °C and power fluctuations limited to 2%. Testing proceeded until these criteria were met whenever steady-state conditions were not initially satisfied. Upon confirmation of steady state, average values of T_h, T_c, electrical power (Q), guard plate readings, and the specimen's mean thickness measured at multiple points were recorded over the 30-minute duration. This procedure was repeated for each specimen, and for every composite formulation, ten independent replicates were conducted to ensure result reliability.

The net heat flow (Q) was determined from the measured power input. Thermal transmittance (U) was then calculated using Equation 3.1:

$$U = \frac{Q}{A\Delta T} \qquad \text{Equation 3.1}$$

Where A is the metering area and ΔT is the temperature difference. Thermal conductivity (k) was subsequently computed using Equation 3.2:

$$k = U \times d \qquad \text{Equation 3.2}$$

Where d represents the panel thickness. Ten trials were performed for each composite ratio (60:40, 70:30, and 80:20), and the results were expressed as mean values with corresponding standard deviations.

3.6.2 Mechanical Testing

Compressive strength test was conducted by a do-it-yourself (DIY) method to verify the minimum compressive strength of the panels, each panel was laid flat on the floor then a 50 kilogram of sand was placed on top of it, the new thickness was recorded after.

The set-up limits achieving the 150 kPa for compression test due to the unavailability of the Universal Testing Machine (UTM). The 50 kg sand load which generates approximately 1.64 kPa pressure was way too lower than the target stress, the test was only intended as a scaled, preliminary assessment of the panel's load bearing behavior because 150 kPa is about 4.6 tons load which is unachievable for a simple testing set up. The DIY does not replicate the full compressive stress specified in the standardized procedures, but it provides insight into the initial compressive stress response of the panels.

3.6.3 Physical Testing

Water absorption was measured by immersing samples in water for 24 hours and recording the weight gain to ensure that absorption was ≤ 5% by weight, in accordance with ASTM C209.

3.7 Selecting the Best Proportion

The determination of the optimal fiber-to-binder proportion was carried out through a structured evaluation of all experimental data obtained from thermal conductivity testing, mechanical testing, and water absorption assessment. Each composite ratio (60:40, 70:30, and 80:20) was examined based on its ability to comply with the performance standards established in this study, specifically a thermal conductivity of ≤ 0.04 W/m·K, a minimum compressive strength of 150 kPa, and a water absorption value of ≤ 5% by weight.

To ensure an objective and evidence-based selection process, the researcher applied a scoring and rating system to quantify the performance of each ratio across all criteria. The scoring method assigns higher points to results that fully meet or surpass the required thresholds, while lower points are given to those that only approach or fail to achieve the set standards. Specifically, scores of 7–9 points indicate that a result is highly suitable, fully meeting all required standards. Scores of 4–6 points reflect a moderately suitable outcome, meeting most standards but with some limitations. Scores of 3 points or below denotes low suitability, where key benchmarks are not achieved. The total performance score for each formulation is determined by summing the ratings across all test categories, ensuring a comprehensive evaluation of overall performance.

The formulation that achieved the highest overall score was identified as the optimal fiber-to-binder proportion, as it reflected superior performance across thermal, mechanical, and durability parameters. This systematic comparison ensured a rigorous and unbiased selection of the proportion most suitable for developing high-quality corn husk fiber-based insulation panels.

Table 3.1 outlines the evaluation method for selecting the best fiber-to-binder proportion. Each criterion, thermal conductivity, compressive strength, and water absorption, is rated on a scale of 1 to 3, with 3 points for excellent performance, 2 points for acceptable performance, and 1 point for poor performance. The overall performance score is obtained by totaling the scores from all categories, with 7–9 points signifying formulations that are very appropriate, 4–6 points reflecting moderate suitability, and 3 points or below indicating low suitability.

Table 3.1. *Scoring Rubric for Selecting the Best Fiber-to-Binder Proportion*

Criterion	Score: 3 (Excellent)	Score: 2 (Acceptable)	Score: 1 (Poor)
Thermal conductivity (k)			
Compressive strength			
Water absorption			

Interpretation of Total Scores:

7-9 points → Highly suitable; meets all required standards.
4-6 points → Moderately suitable; meets most standards.
3 points and below → Low suitability; fails to meet key benchmarks.

3.8 Data Analysis

The collected data were analyzed to evaluate the thermal and mechanical performance of corn husk fiber-based insulation panels fabricated with varying fiber-to-binder ratios. Thermal conductivity measurements obtained from the guarded hot-plate apparatus were statistically processed to determine the mean values and standard deviations for each composite ratio (60:40, 70:30, and 80:20). This quantitative analysis identified trends and relationships between fiber content and thermal insulation efficiency.

Thermal transmittance (U) and thermal conductivity (k) values calculated using Equations 3.1 and 3.2, respectively, were compared across sample groups to assess the influence of fiber loading on heat-transfer characteristics. Analysis of variance (ANOVA) was conducted to test for statistically significant differences in thermal properties among the different composite ratios, with the level of significance set at $p < 0.05$.

Compressive strength test and water absorption, were similarly analyzed by calculating mean values and standard deviations in accordance with ASTM C165 (Standard Test Method for Measuring Compressive Properties of Thermal Insulations) and ASTM C209 (Standard Test Methods for Cellulosic Fiber Insulating Board). Compressive strength results were compared against the minimum threshold of 150 kPa to determine the suitability of the panels for structural applications. Water absorption percentages were evaluated to assess moisture resistance and material durability.

To analyze and compare the performance of a commercially available expanded polystyrene insulation with the research-developed corn husk fiber-polyurethane insulation panels, a comprehensive multi-criteria evaluation was conducted. The analysis began with sample preparation, wherein expanded polystyrene were sourced based on manufacturer specifications, while corn husk panels were fabricated in accordance with the established research methodology. Consistency was maintained in fiber treatment, binder ratio, and curing conditions to ensure a valid comparison.

For the data analysis of the thermal and mechanical performance of the corn husk insulation panels, statistical tools such as mean and standard deviation calculations were employed to summarize the data for each fiber-to-binder ratio. Analysis of variance (ANOVA) was used to assess whether differences in thermal conductivity and compressive strength among the different ratios were statistically significant ($p < 0.05$). This approach ensured rigorous comparison and reliable interpretation of test results, supporting evidence-based selection of the optimal composite formulation. The Kruskal–Wallis test was employed as a nonparametric statistical tool to analyze the water absorption characteristics of the tested samples. This test was selected due to its suitability for comparing multiple independent groups when the data did not satisfy the assumptions of normality and homogeneity of variance required for parametric tests. In the water absorption test, samples from different treatment groups or material compositions were evaluated based on their percentage of water uptake. The Kruskal–Wallis test was used to determine whether there were statistically significant differences in median water absorption values among the groups at a 95% confidence level.

The data analysis focused on evaluating the thermal, mechanical, and physical performance of corn husk fiber–polyurethane (CHF–PU) insulation panels fabricated at different fiber-to-binder ratios (60:40, 70:30, and 80:20). The analysis aimed to determine the influence of material composition on thermal conductivity, compressive strength, and water absorption, as well as to identify statistically significant differences among the formulations. All experimental tests were conducted in multiple trials to ensure the reliability and reproducibility of the results.

The primary analytical variables included thermal conductivity (W/m·K), compressive strength (kPa), and percentage water absorption (%). Descriptive statistics, including mean values and standard deviations, were computed for each parameter and formulation to summarize the experimental data.

Water absorption was determined using Equation 3.3:

$$\%\text{Water Absorption} = \frac{W_f - W_i}{W_i} \times 100 \qquad \text{Equation 3.3}$$

Where W_i is the initial dry weight of the specimen and W_f is the final weight after 24 hours of immersion.

To evaluate whether significant differences existed among the performance of different fiber-to-binder ratios, independent samples t-tests were employed. The t-tests were used to compare the mean values of thermal conductivity, compressive strength, and water absorption between pairs of formulations at a 95% confidence level ($\alpha = 0.05$). This statistical method determined whether the observed variations in performance were statistically significant or attributable to random experimental error.

All experimental results were evaluated against established performance benchmarks and relevant ASTM standards, including ASTM C177 for thermal conductivity, ASTM C165 for compressive strength, and ASTM C209 for water absorption.

IV. Results and Discussion

Corn husk fiber–polyurethane (CHF–PU) panels were fabricated by first chemically treating corn husk fibers using a 10% sodium hydroxide (NaOH) solution to improve fiber bonding. The treated fibers were then washed, dried, and shredded before being mixed with a polyurethane binder at ratios of 60:40, 70:30, and 80:20 (fiber:binder). The mixtures were subsequently molded, compressed, cured, and conditioned to form insulation panels suitable for performance evaluation.

Results showed that thermal conductivity decreased with increasing fiber content, with mean values of 0.1107 W/m·K (60:40), 0.0983 W/m·K (70:30), and 0.0976 W/m·K (80:20). This trend indicates that higher fiber content enhances insulation performance, likely due to increased air voids within the panel structure. Statistical analysis confirmed normality, homogeneity of variance, and significant differences among the ratios. However, all values remain higher than those of expanded polystyrene (EPS) (0.029–0.038 W/m·K), indicating lower thermal efficiency compared to commercial insulation materials.

Compressive strength testing was conducted using a constant 50 kg sand load due to the absence of a Universal Testing Machine (UTM). All panel ratios produced identical compressive strength values of 5.45 kPa, resulting in zero variability across trials. Consequently, statistical analyses such as tests for normality, homogeneity, and differences yielded unreliable or misleading results, as these methods depend on variation within the data. Although deformation observations were recorded, the compressive strength results do not accurately represent the true mechanical behavior of the panels, and no valid comparison among ratios or with EPS could be established.

Water absorption increased significantly with fiber content, with values of 28.43% (60:40), 53.32% (70:30), and 99.43% (80:20). Statistical analysis indicated normal distribution but unequal variances among the groups, and the Kruskal–Wallis test confirmed significant differences. All panel compositions exhibited substantially higher water absorption than EPS (less than 1%), highlighting a major limitation in moisture resistance.

Based on the overall results, the 80:20 ratio exhibited the lowest thermal conductivity but showed limitations in structural integrity due to insufficient binder content. In contrast, the 60:40 ratio demonstrated more balanced thermal and moisture performance, along with relatively better structural stability. Therefore, the 60:40 ratio is identified as the most suitable composition among the tested ratios for potential use in non-load-bearing, sustainable insulation applications.

4.1 Thermal Conductivity

Thermal conductivity testing was conducted to evaluate the insulating performance of the fabricated corn husk fiber–based insulation panels bonded with a polyurethane binder. Since the primary function of the developed panels is thermal insulation, determining their ability to resist heat flow is essential in assessing their suitability as a sustainable building material. The test focuses on measuring the rate of heat transfer through the panels under controlled conditions, directly reflecting the influence of corn husk fiber content and panel structure on thermal performance.

The group with ratio 1 (60:40) had the highest average thermal conductivity with a value of 0.1107 W/m·K and a standard deviation of 0.0014, indicating low insulation efficiency compared to the other groups. On the other hand, the group with ratio 2 (70:30) had an average thermal conductivity of 0.0983 W/m·K and a standard deviation of 0.0010, while the group with ratio 3 (80:20) had the lowest average thermal conductivity with a value of 0.0976 W/m·K and a standard deviation of 0.0014, which denotes high insulation efficiency.

The observed decrease in thermal conductivity with increasing fiber content is consistent with existing studies on natural fiber–based insulation materials. Previous research has shown that increasing the proportion of natural fibers in polymer composites reduces thermal conductivity due to increased porosity and air entrapment, which limits heat transfer. A study by Sakthivel et al. (2018) reported that thermal conductivity decreases as fiber content increases in natural fiber–reinforced composites. Similarly, Tao et al. (2016) found that the addition of straw fibers in polyurethane composites significantly reduced thermal conductivity, improving insulation performance.

In addition, Manalindo et al. (2023) reported a thermal conductivity value of 0.119 W/m·K for corn husk insulation panels, which is comparable to the results of the present study, supporting the use of corn husk fibers as insulating material. The thermal conductivity data for the insulation panels of different fiber-to-binder ratios is given in Table 4.1 for ten trials.

Table 4.1. Thermal Conductivity for Ratios 1,2, and 3

No. of Trials	Thermal conductivity (W/m•K)		
	Ratio 1 (60:40)	Ratio 2 (70:30)	Ratio 3 (80:20)
1	0.1115	0.0968	0.0989
2	0.1098	0.0980	0.0968
3	0.1094	0.0972	0.0976
4	0.1132	0.0993	0.0993
5	0.1123	0.1001	0.0984
6	0.1102	0.0972	0.0942
7	0.1102	0.0980	0.0976
8	0.1123	0.0993	0.0968
9	0.1085	0.0993	0.0993
10	0.1098	0.0976	0.0968
Mean	**0.1107**	**0.0983**	**0.0976**
Standard Deviation	**0.0014**	**0.0010**	**0.0014**

The Shapiro–Wilk Test results shown in Table 4.2 indicate that the data for all ratios are normally distributed. Ratio 1 obtained a test statistic of 0.9352 with a p-value of 0.5287, Ratio 2 had a test statistic of 0.9083 with a p-value of 0.2762, and Ratio 3 had a test statistic of 0.8951 with a p-value of 0.1966. Since all p-values are greater than 0.05, there is no significant deviation from normality in any of the groups. Therefore, the assumption of normality is satisfied, allowing the use of parametric statistical tests for further analysis.

Table 4.2. *Shapiro-Wilk Test for Normality*

Ratio	Test Statistics	p-value	Interpretation
Ratio 1	0.9352	0.5287	Normally distributed
Ratio 2	0.9083	0.2762	Normally distributed
Ratio 3	0.8951	0.1966	Normally distributed

Table 4.3 presents the results of Levene's Test for Homogeneity of Variances, yielding an F-statistic of 0.232 and a p-value of 0.7945 for degrees of freedom (2, 27). Since the p-value exceeds the 0.05 significance level, the variances are considered homogeneous across the three panel ratios. This result confirms that the assumption of homogeneity of variance required for parametric statistical tests is satisfied.

Table 4.3. *Levene's Test for Homogeneity of Variances*

DF Between Groups	DF Within Groups	F-Statistics	p-value	Interpretation
2	27	0.232	0.7945	Variances are homogenous

Table 4.4 presents the results of the one-way ANOVA for thermal conductivity. The analysis yielded an F-statistic of 274.43 with degrees of freedom (2, 27) and a p-value of 0.0001. Since the p-value is less than the 0.05 significance level, the result indicates a statistically significant difference in thermal conductivity among the three ratios. This confirms that variation in the fiber-to-binder ratio has a significant effect on the thermal performance of the insulation panels.

Table 4.4. *One – Way ANOVA for Thermal Conductivity*

DF Between Groups	DF Within Groups	F-Statistics	p-value	Interpretation
2	27	274.43	0.0001	Significant difference between variances

4.2 Compressive Strength Test

Compressive strength testing was performed to assess the mechanical strength and load-bearing capability of the developed corn husk fiber–based insulation panels bonded with a polyurethane binder. Since insulation materials are often subjected to compressive loads during installation and service, evaluating their resistance to deformation under applied stress is essential for determining their structural reliability in practical applications. The test specifically examines the compressive behavior of the panels as influenced by the incorporation of corn husk fibers and the binder matrix.

Table 4.5 shows the Compressive Strength values obtained for all three panel ratios were identical, with a recorded value of 5.45 kPa across all trials. This uniformity in the results can be attributed to the testing method employed in the study. Due to the unavailability of a Universal Testing Machine (UTM), a constant load of 50 kg was manually applied to all panel specimens during testing. As a result, each sample was subjected to the same applied force, leading to identical computed compressive strength values. The use of a constant manually applied load prevents the determination of true compressive strength, which requires measuring the maximum stress a material can withstand before failure under gradually increasing load. A Universal Testing Machine (UTM) is typically required to obtain accurate and comparative mechanical strength values.

Table 4.5. Compressive Strength Test for Ratios 1,2, and 3

No. of Trials	Compressive Strength (kPa)		
	Ratio 1 (60:40)	Ratio 2 (70:30)	Ratio 3 (80:20)
1	5.45	5.45	5.45
2	5.45	5.45	5.45
3	5.45	5.45	5.45
4	5.45	5.45	5.45
5	5.45	5.45	5.45
6	5.45	5.45	5.45
7	5.45	5.45	5.45
8	5.45	5.45	5.45
9	5.45	5.45	5.45
10	5.45	5.45	5.45
Mean	5.45	5.45	5.45
Standard Deviation	0	0	0

This indicates that the recorded results reflect the fixed applied load rather than the actual compressive strength or maximum load-bearing capacity of the panels. Consequently, variations in mechanical strength among the different fiber-to-binder ratios could not be accurately determined using this approach. While the test provided a basic indication of the panels' resistance to compression, it does not fully represent their true mechanical performance. For more precise and reliable measurements, the use of a standardized compression testing machine is recommended in future studies.

Table 4.6 presents the results of the Shapiro–Wilk Test for Normality for the compressive strength data of the three panel ratios. The table shows identical test statistics and extremely small p-values for all ratios, which indicates that the data are not normally distributed.

Table 4.6. Shapiro-Wilk Test for Normality

Ratio	Test Statistic	p- value	Interpretation
Ratio 1 (60:40)	0	1.037e-7	Not normally distributed
Ratio 2 (70:30)	0	1.037e-7	Not normally distributed
Ratio 3 (80:20)	0	1.037e-7	Not normally distributed

However, this result primarily reflects the nature of the dataset rather than the true distribution of the material properties. Since all recorded compressive strength values are identical across trials, there is no variability in the data. Statistical tests for normality rely on variation among values to assess whether the data follow a normal distribution. In this case, the absence of variation leads to an invalid or misleading outcome, resulting in the classification of the data as "not normally distributed." Therefore, Table 4.6 indicates that the compressive strength data cannot be properly evaluated for normality due to uniform measurements. This limitation is directly linked to the testing method used, where a constant load was applied in the absence of proper testing equipment. As a result, the normality test does not accurately reflect the actual behavior of the insulation panels.

Table 4.7 presents the results of Levene's Test for Homogeneity of Variances for the compressive strength data across the three panel ratios. The table shows an F-statistic of 0 and a very small p-value (1.037×10^{-7}), leading to the interpretation that the variances are not homogeneous. However, this result primarily reflects a limitation in the dataset rather than an actual difference in variances. The F-statistic value of 0 indicates that there is no variation between and within the groups, which is consistent with the identical compressive strength values recorded for all samples. Since variance depends on the spread of data, identical values result in zero variance, affecting the reliability of the statistical test. As a result, the conclusion that the variances are not homogeneous may be misleading. The absence of variability caused by the use of a constant applied load and the lack of appropriate testing equipment affect the outcome. Therefore, Table 4.7 indicates that the homogeneity of variance assumption cannot be accurately assessed using the current data. More reliable results require measurements obtained through standardized testing methods that generate variable and precise values.

Table 4.7. *Levene's Test for Homogeneity if Variances*

DF Between Group	DF Within Group	F-Statistic	p-value	Interpretation
2	27	0	1.037e-7	Variances are not homogenous

Table 4.8 presents the results of the Kruskal–Wallis Test used to determine whether there are significant differences in compressive strength among the three panel ratios. The table shows a test statistic of 0 and a p-value of 1.037×10^{-7}, which is lower than the 0.05 significance level.

Based on this, the result indicates a statistically significant difference among the groups. However, this finding should be interpreted with caution. The test result is influenced by the nature of the dataset, where all compressive strength values are identical due to the use of a constant applied load (50 kg) in the absence of proper testing equipment. Because there is no variation in the data, the test cannot accurately detect real differences in compressive strength among the panel ratios. Therefore, although Table 4.8 suggests a significant difference, it does not reflect the true mechanical performance of the panels. Instead, it highlights the limitation of the testing method and the need for standardized equipment to obtain reliable and variable data.

Table 4.8. *Kruskal-Wallis Test for Compressive Strength*

Test Statistics	p-value	interpretation
0	1.037e-7	Significant difference $p < 0.05$

4.3 Water Absorption Result

Jocelyn Davalan and Jeshier John Feliciano, "Turning Husks into Heat Shields: Corn Fiber-Polyurethane Insulation Panels," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 9, Issue 2, pp. 466-483, July 2026.

Water absorption testing was conducted to evaluate the moisture uptake capacity of the corn husk fiber–polyurethane insulation panels after 24-hour immersion. The dry and wet weights of the samples were measured to determine the percentage of water absorbed. This property is critical for insulation materials because high water absorption can reduce thermal performance, increase material weight, promote biological degradation, and compromise dimensional stability during service. Therefore, assessing water absorption is essential in determining the suitability of the panels for building applications, particularly in environments exposed to humidity or moisture.

The results are summarized in Table 4.9. Ratio 1 (60:40) exhibited the lowest mean water absorption at 28.43% ± 0.69%, followed by Ratio 2 (70:30) with 53.32% ± 1.60%, while Ratio 3 (80:20) showed the highest absorption at 99.43% ± 1.64%. The relatively low standard deviations indicate consistent results across all trials. An increasing trend in water absorption was observed with increasing fiber content. This behavior is attributed to the hydrophilic nature of natural fibers and the reduced binder content at higher fiber ratios. Natural fibers contain cellulose and hemicellulose, which readily absorb moisture, while the binder acts as a protective matrix that limits water penetration. This trend is consistent with reported studies on natural fiber composites, where higher fiber content results in increased water absorption due to greater exposure of hydrophilic fiber surfaces (Elmoudnia et al., 2025).

Table 4.9. *Water Absorption Test Results*

No. of Trials	Water Absorption (%)		
	Ratio 1 (60:40)	**Ratio 2 (70:30)**	**Ratio 3 (80:20)**
1	27.14	50.77	96.67
2	27.86	52.31	98.33
3	28.29	53.08	99.17
4	28.57	53.85	100.00
5	28.86	54.62	100.83
6	29.29	55.38	101.67
7	28.14	52.62	98.67
8	28.71	53.54	99.67
9	28.43	52.00	98.00
10	29.00	55.08	101.33
Mean	**28.43**	**53.32**	**99.43**
Standard Deviation	**0.69**	**1.60**	**1.64**

Additionally, reduced binder content leads to lower fiber encapsulation, allowing more water to penetrate the material structure. Studies also show that insufficient matrix coverage increases porosity and void content, further contributing to higher moisture uptake (Tao et al., 2016).

Furthermore, the observed increase in water absorption with higher fiber loading also suggests implications for the durability and thermal performance of the developed insulation panels. Elevated moisture uptake can negatively affect dimensional stability, promote swelling, and potentially reduce the insulating efficiency of the material over time. This is because absorbed water can replace trapped air within the porous structure, thereby increasing thermal conductivity. Consequently, while higher fiber content may enhance certain properties such as biodegradability and lightweight characteristics, it also necessitates careful optimization of the fiber-to-binder ratio or the incorporation of water-repellent treatments to balance performance.

Table 4.10 presents the results of the Shapiro–Wilk Test for water absorption values, indicating that all three ratios are normally distributed. Ratio 1 (60:40) obtained a test statistic of 0.963 with a p-value of 0.876. Ratio 2 (70:30) and Ratio 3 (80:20) both recorded a test statistic of 0.975, with corresponding p-values of 0.970 and 0.974, respectively. Since all p-values are greater than the 0.05 significance level, there is no evidence of deviation from normality across the groups. These results confirm that the water absorption data follow a normal distribution, supporting the reliability and consistency of the measurements for all panel ratios.

Table 4.10. *Shapiro-Wilk Test for Normality*

Ratio	Test Statistic	p- value	Interpretation
Ratio 1 (60:40)	0.963	0.876	Data is normally distributed
Ratio 2 (70:30)	0.975	0.970	Data is normally distributed
Ratio 3 (80:20)	0.975	0.974	Data is normally distributed

Table 4.11 presents the results of Levene's Test for Homogeneity of Variances, which yielded an F value of 3.940 with degrees of freedom (2, 27) and a p-value of 0.032. Since the p-value is less than the 0.05 significance level, the assumption of equal variances is not satisfied. This indicates that the variances among the three panel ratios are significantly different, showing that the variability in water absorption is not consistent across the tested formulations.

Table 4.11. *Levene's Test for Homogeneity if Variances*

DF Between Group	DF Within Group	F-Statistic	p-value	Interpretation
2	27	3.940	0.032	Variances are not homogenous

The outcomes of Kruskal-Wallis Test on water absorption are displayed in Table 4.12 above, with the test statistic being equal to 25.81 and the p-value amounting to 0.000025. With the value of the p-value being smaller than the level of significance, which is set at 0.05, the null hypothesis of no difference between groups is rejected. This means that there is a significant difference in water absorption across the three panel ratios.

Table 4.12. *Kruskal-Wallis Test for Water Absorption*

Test Statistics	p-value	interpretation
25.81	0.000025	Significant difference $p < 0.05$

4.4 Selecting the Best Proportion

This section presents the evaluation and selection of the most suitable corn husk fiber–polyurethane (CHF–PU) panel proportion based on its overall performance across key parameters, including thermal conductivity, water absorption, and compressive behavior. The objective is to identify the optimal fiber-to-binder ratio that provides a balanced combination of insulation efficiency, structural integrity, and durability. By comparing the results obtained from the different panel compositions, the study determines the proportion that demonstrates the most practical potential for sustainable, non-load-bearing insulation applications.

Table 4.13 illustrates the ranking of the panels' insulation quality in terms of water absorption, compressive behavior, and thermal conductivity. All three ratios achieved equal raw totals of 5 points. However, when weighted according to practical importance thermal conductivity (50%), water absorption (25%), and compressive strength (25%) the results reveal different performance levels. Ratio 3 (80:20) achieved the highest weighted score (2.00), followed by Ratio 2 (70:30) with 1.75, and Ratio 1 (60:40) with 1.50.

Table 4.13. *Ranks of the Insulation Panels*

Criteria	Ratio 1	Ratio 2	Ratio 3
Water Absorption	3 points	2 points	1 point
Compressive Strength	1 point	1 point	1 point
Thermal Conductivity	1 point	2 points	3 points
Total points	5 points	5 points	5 points

Although Ratio 3 appears superior numerically due to its strong thermal conductivity, its low binder content resulted in poor adhesion and limited structural response. This outcome is consistent with findings that excessive fiber content increases porosity and water absorption while reducing compressive strength, ultimately compromising structural reliability (Tao et al., 2016; Pech-Can et al., 2024). Elmoudnia et al. (2025) emphasize that binder content is critical for effective stress transfer between fibers, and insufficient binder leads to weak adhesion even if thermal performance appears favorable. Similarly, studies on hygrothermal behavior of natural fiber composites highlight that water absorption significantly degrades mechanical properties over time, reinforcing the need for balanced fiber–matrix proportions (Bhuvaneswari, 2022).

Considering both the weighted ranking and literature evidence, Ratio 1 (60:40) emerges as the most practical choice. It offers consistent compressive strength, superior resistance to water absorption, and acceptable thermal conductivity, aligning with published research that stresses the importance of overall integrity rather than excelling in a single property.

4.5 Comparing Panels with Commercial Insulation Materials

This section presents a comparative evaluation of the fabricated corn husk fiber–polyurethane (CHF–PU) panels against commonly used commercial insulation materials, particularly expanded polystyrene (EPS). The comparison focuses on key performance indicators such as thermal conductivity, water absorption, and mechanical behavior to assess the relative efficiency and practicality of the developed panels. The objective is to determine how the CHF–PU panels perform in relation to standard materials and to identify their potential advantages and limitations for sustainable insulation applications.

A comparison of the developed CHF–PU insulating panels and commercial expanded polystyrene (EPS) panels in relation to some key parameters is shown in Table 4.14 below.

Table 4.14. *Comparison of the Panels with Commercial Insulations*

Parameters	Expanded Polystyrene insulation	Corn fiber-polyurethane insulation panel
Water Absorption	less than 1% by volume	28.43%
Compressive Strength	70-250 kPa	
Thermal Conductivity	0.029-0.038 W/mK	0.1107 W/mK

Firstly, EPS insulations have much better moisture resistance, with water absorption usually less than 1%, while for the developed panel, the percentage of water absorbed is about 28.43%. The compression test could not be performed for the developed panel using the universal testing machine (UTM), but in lieu of that, a DIY setup was used to test the compression behavior for the CHF–PU panels using a 50 kg load. Finally, the thermal conductivity of the EPS panels lies within the range of 0.029–0.038 W/m·K, whereas for the developed panel, the value was 0.1107 W/m·K, indicating better insulation efficiency.

As can be seen, EPS panels exhibit superiority to the CHF–PU panels in terms of insulation and moisture resistance. However, this does not mean that they cannot serve the purpose of insulating walls. Thus, the results clearly indicate the ability of the panels to perform insulation functions, albeit poorly compared to EPS.

V. Conclusions And Recommendations

5.1 Conclusion

This study successfully evaluated the potential of corn husk fiber–polyurethane (CHF–PU) composite panels as thermal insulation materials by addressing the stated objectives. The panels were successfully fabricated at fiber-to-binder ratios of 60:40, 70:30, and 80:20, enabling the assessment of their thermal, mechanical, and moisture-related properties. The findings revealed that increasing fiber content generally reduced thermal conductivity, with Ratio 3 (80:20) achieving the lowest value (0.0976 W/m·K), followed by Ratio 2 (70:30) at 0.0983 W/m·K, while Ratio 1 (60:40) recorded the highest value (0.1107 W/m·K). Although none of the panels met the desired benchmark of ≤ 0.04 W/m·K, the results demonstrate the potential of corn husk fibers in enhancing thermal insulation performance.

The evaluation of compressive strength was limited by the absence of a Universal Testing Machine, resulting in the use of a constant 50 kg load for all samples. Consequently, all panel ratios produced identical compressive strength values (5.45 kPa), yielding no variability in the dataset. This prevented meaningful comparison of mechanical performance among the different compositions. While the test provided a general indication of resistance to applied load, it did not accurately represent the true mechanical strength of the panels. Therefore, the objective of fully evaluating compressive behavior across different ratios was only partially achieved.

In terms of moisture performance, water absorption increased significantly with fiber content. Ratio 1 (60:40) exhibited the lowest absorption (28.43%), followed by Ratio 2 (70:30) at 53.32%, and Ratio 3 (80:20) at 99.43%. These findings indicate that higher fiber content leads to increased moisture susceptibility due to the hydrophilic nature of natural fibers. All panels showed substantially higher water absorption compared to expanded polystyrene (EPS), highlighting a key limitation in durability.

Based on the combined results, Ratio 3 provided the best thermal performance but exhibited poor moisture resistance and uncertain mechanical reliability due to insufficient binder and limitations in testing. In contrast, Ratio 1 (60:40) demonstrated more balanced thermal conductivity, lower water absorption, and relatively better structural consistency. Thus, despite not achieving the lowest thermal conductivity, Ratio 1 is identified as the most practical formulation among those tested.

Overall, the study confirms that CHF–PU panels have potential as sustainable insulation materials, particularly for non-load-bearing applications. However, further improvements in binder optimization, moisture resistance, and standardized mechanical testing are necessary to enhance their performance and ensure their competitiveness with conventional insulation materials such as EPS.

5.2 Recommendations

Based on the results of this study, the following recommendations are proposed to further improve the performance and applicability of corn husk fiber–based insulation panels:

1. *Improve Binder Content Optimization*

   Future studies should explore additional fiber-to-binder ratios, particularly increasing the polyurethane content beyond 40%, to enhance fiber encapsulation and improve mechanical stability while maintaining acceptable thermal performance.
2. *Use Standardized Compression Testing*

   It is recommended to conduct compressive strength testing using a Universal Testing Machine (UTM) to obtain accurate stress values (in kPa or MPa) in accordance with ASTM standards. This will enable direct comparison with commercial insulation materials.
3. *Reduce Water Absorption*

   Treatments such as fiber surface modification (e.g., silane treatment, wax coating) or the application of protective coatings on the panels should be investigated to improve moisture resistance and reduce water absorption.
4. *Enhance Thermal Performance*

   Further refinement of panel structure, such as optimizing density and improving internal pore distribution, is recommended to reduce thermal conductivity and approach the performance of commercial materials like EPS.
5. *Conduct Additional Performance Tests*

   Future research should include fire resistance, durability, aging, and weathering tests to evaluate long-term performance and safety for building applications.

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