RESEARCH ARTICLE OPEN ACCESS

PERFORMANCEEVALUATIONANDCOMPARATIVE ANALYSIS OF CELLULOSE- BASED INSULATION MATERIAL WITH NATURAL ADDITIVES : A COMPREHENSIVE STUDY IN COMPARISON WITH COMMERCIALLY AVAILABLE PRODUCTS IN THE MARKET

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Abstract:

In response to the urgent global challenge of climate change and the escalating need for sustainable solutions, this research endeavors to investigate and compare the viability of cellulose composite boards derived from paper combined with agricultural fibers, specifically bamboo, miscanthus, and rice straw, for thermal insulation applications. The study aims to comprehensively assess the thermal resistance, durability, and safety characteristics of these composite materials through standardized testing methodologies. This research seeks to identify the most efficient composite material among the tested variants for thermal insulation applications, considering factors such as performance, cost-effectiveness, and environmental sustainability. Additionally, the study explores the feasibility of developing an ovel thermal in sulation board using agricultural fibers and recycled paper, aiming to provide an affordable and environmentally friendly alternative to conventional insulation materials available in the market. By examining sustainable alternatives for thermal insulation, this study contributes to addressing these pressing challenges while offering practical solutions for reducing carbon footprint and promoting sustainable development. In light of the escalating heat in dices experienced world wide, the development of efficient and eco-friendly thermal insulation materials assumes critical significance, making this research both timely and imperative in the pursuit of a more sustainable future

Keywords—**ThermalInsulation,Cellulose**

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1. INTRODUCTION

Philippines'geographicallocationissituatedclose to the equator, which means it receives direct and intense sunlight throughout the year. This proximity to the equator results in a tropical climate with high temperatures.Itfallswithinthetropicalclimatezone, which is characterized by consistently warm to hot temperatures. This climate is influenced by the equatorial location and the warm ocean current that makes the Philippines a hot and humid place for much of the year.

AccordingtoAccuWeatherPhilippines,The2022 average monthly temperature in the Philippines duringthesummermonthscanoftenexceed35°Cto 36°C. While it'sstillwarm, temperaturesmight bea bit lower during the rainy season. Average temperaturestypicallyrange from32°Cto33°C,the coolest time of the year in the Philippines, with temperaturesrangingfrom30°Cto31°C.Ingeneral, the country has a tropical climate with high temperatures. [1]

According to Utilities One, a Well-insulated structurecanoffer better protectionagainst extreme weather conditions. The use of effective thermal insulation can help mitigate extreme heat weather problems by reducing heat transfer into buildings and structures. High-quality insulation materials create a barrier that prevents outdoor heat from infiltrating indoor spaces. This helps maintain a cooler and more comfortable indoor temperature. Also, by reducing the need for air conditioning and cooling systems, effective insulation can lower energyconsumptionandutilitybills,makingitmore sustainable and cost-effective to maintain indoor comfortinextremeheat.Andbyloweringtheenergy consumptionitalsoreducethecarbonfootprint whichisimportantformitigatingthebroader effects of climate change. In terms of health, Thermal insulationsprovideamorecomfortableandhealthier living environment during hot weather. It can preventissueslikeheatstressandheat-relatedhealth problems. [2]

Itisimportanttochoosetherighttypeandamount of insulation based on the specific climate and building requirements. Cellulose-based thermal insulation is a sustainable and effective choice for improving a building's energy efficiency, comfort, and environmental impact. It has excellent thermal properties, providing effective resistance to heat transfer. Cellulose insulation is often made from recycled paper products, making it an eco-friendly choice. It reduces waste in landfills and minimizes the need for new resources. Different types of cellulose insulation may have varying thermal properties. Using Cellulose based material as thermal insulation also benefits consumers in some factors: Environmentally Friendly, Energy Efficiency, Fire Resistance, Sound Insulation, Low VOC Emissions, Pest Resistance, Easy Installation, and Cost Effective . [3]

Thus, Identifying the best one ensures that the insulation will provide the highest level of energy efficiency,reducingheatingandcoolingcosts.Some celluloseinsulationmayhavealowerenvironmental impactthanothersduetofactorssuchasthesourcing of raw materials and the manufacturing process. Choosing the best option can contribute to sustainabilitygoals. Determining the best cellulose-basedthermalinsulationcomparedtoothercellulose options is essential to achieve the desired level of performance,sustainability,andsafetyinabuilding. It requires a careful evaluation of the specific requirementsoftheproject,includingfactorslike climate,buildingtype,budget,andenvironmental goals.

1.2 REVIEWOFRELATEDLITERATURE

1.2.1 DifferentTypesofInsulatingMaterialsandits Effectivity

The researchers conduct an investigation for cork that was used as a low density aggregate in the production of ultra-lightweight and low thermal conductivity inorganic polymer (geopolymer) composites. This novel and highly sustainable material, synthesized at room temperature (23 °C), maydecreasetheenergylossesinsidebuildings,thus contributing to the United Nations development goals regarding energy and climate change. The ultra-low density (260 kg/m3) and low thermal conductivity(72 mW/m K) shown by the cork-composites are the second lowest ever reported for inorganicpolymer composites, onlybeing surpassed bythat ofpolystyrene-inorganic polymer composites. [12]

The thermal potentialities of insulation panels made of cork have been explored by means of a numerical approach based on experimental data. A comparativeanalysisbetweenthepanelsinunaltered state, and then covered with an innovative shield coating(COIB250®)wascarriedout.Inaddition, a defect simulating an inner detachment of the panel was fabricated to understand its behavior during a dailysolarthermalload.Thesitewasselectedadhoc to avoid any shadow cast effect on the panel itself and any conduction phenomenon from the surrounding area. The external floor on which the panelwasmountedwascompletelyisolatedfromthe soil.Twosimilardayswithclearskyconditionswere selected, real meteorological data recorded by a weather station installed near the inspected site and data deriving from a NASA software were used respectivelyfor theambient temperatureandfor the solarradiation,inordertoprovideasoliddiscussion of the findings. Results show how a cork panel, usually employed in civil engineering as an insulation system, may benefit a lot of a shield coating.Thelatterproducttendsalsotominimizethe impactofasubsurfacedetachmentduringthe thermal conduction via heat transfer; this behavior will be in-depth clarified in this work. [13]

These panels are usually employed as external or internalinsulator,dependingonseveralfactors,such as the mechanical properties, the capability to react to harsh environmental stimuli, the ability to resist biological attacks, etc. However, the use of a shield coating is highly recommended in order to enhance thefeaturesmentionedabove,aswellasthethermal properties.

Figure 1
CorkSource:edenhotlimemortar.co.uk

The building sector is constantly innovating in its useofmaterialswithregardstosustainability.There is a need to use cost effective, environmentally friendlymaterialsandtechnologieswhichlessenthe impact of a construction in terms of its use of non-renewable resources and energy consumption. Cellulose fiber insulation is an eco-friendly thermal insulationmaterialmadefromrecycledpaperfibers. It offers good thermal properties and has a low embodiedenergy.Howeverduetoalackofexpertise initsapplicationandproperties, cellulose insulation is not widelyused incomparisonto moretraditional insulation materials. As has been shown by the availableliterature,CFIisaninnovativeeco-friendly insulation material that presents similar characteristics in terms of thermal comfort and performance to its non-renewable counterparts. Nevertheless the material presents some disadvantages compared to less eco-friendly insulationmaterialsandhasshowntheneedformore optimization and development.[14]

Although the typical value for CFI's thermal conductivity is around 0.040 W/m-K, its properties and performance can vary slightly depending on manufacturing and method of installation.

Figure2CelluloseFiberSource: marialma.com

On the other hand, the other type of insulating material is wood wool. According to (Andrew D. Shea,2018) Current insulation materials in the construction market, which are predominantly inorganic materials, have a high performance in relation to heat transfer, i.e. high R-values, but the environmentalimpactsintheirproductionprocesses are significant. The use of bio-based natural fiber materialssuchascork,cotton,woodfiber,hemp,etc. with their lower embodied energy, moisture buffering capacity and, consequently, improved Indoor Environmental Quality have received increasing focus in both research and application, particularly amongst environmentally conscious clients and designers. [15]

Inthisstudyanaturalfibermaterialintheformof woodwasteisexaminedexperimentallytoassessits suitability for use as a thermal insulation material, without the addition of any binder, within a timber frame wall construction. The wood waste is from primaryproductionsourcesusinguntreatedmaterial. According to our experimental results, the thermal conductivity values of wood waste with different densitiesranged from0.048to 0.055W/m-K.These values are slightly higher than commonly used inorganic based insulation materials, although comparable to other natural insulation materials in the market, but have the economic advantage of being a low-cost by-product. Current insulation materialsusedinconstructionindustryaregenerally inorganic based materials such as extruded polystyrene, expanded polystyrene, and polyurethanefoam.Althoughthesematerialshavea high performance with regards to the resistance to conduction heat transfer, their environmental impacts during the building life cycle period, and especially in the production process, are generally high. [15]

Figure 3 Wood WoolSource:marialma .com

According to C. Mougel's [16], it sheds light on the multifaceted appeal of Phenolic foams (PF) within various engineering contexts. These foams offer a compelling blend of attributes, including robust fire safety measures, efficient energy absorption capabilities, excellent insulation properties, and even advantageous qualities for lighting applications. Despite these commendable traits,it'snotedthatPhenolicfoamstendtofallshort intermsofmechanicalpropertieswhencomparedto alternative foammaterials. Inparticular, issuessuch as fatigue, flexural properties, and friability pose challenges for their widespread use across diverse applications.

In a separate investigation conducted by Hosang Ahn(2022),thefocusshiftedtothebroaderrealmof foam insulation materials and their prevalent utilization within the construction industry. Ahn's study underscores the attractiveness of foam insulation materials, such as extruded polystyrene (XPS), polyisocyanurate (PIR), and phenolic foam (PF),owingtotheircost-effectiveness,utilizationof low-conductivity blowing agents, and microstructural configurations that result in low thermal conductivity. The study delved into the aging processes of these foam materials, assessing them against material-specific EN standards. [17]

The findings revealed variations in the rates of aging across different foam types. For instance, polyisocyanurate exhibited a change rate ranging from 23 to 26%, while phenolic foam showed a change of 18 to 20%. Extruded polystyrene, on the other hand, demonstrated a change rate spanning from10 to 23.8%. Notably, the studyalso observed thatslicingaccelerationledtoamorerapiddecrease in thermal resistance, approximately three times faster than aging at 70°C. [17]

Figure4FoamSource :ritemore.com

Figure5RiceStrawSource: fidepia.org

1.2.2 DifferentTypesofCelluloseanditsThermal Conductivity

Ricestrawisaleftoverproductofharvesting rice,asstatedbyMariaVictoriaMigoetal.[18].The properties of rice straw, which fall into three main categories, determine how it is used: (1) physical properties, (2) thermal properties, and (3) chemical composition. Bulk density, heat capacity, and thermal conductivity are examples of physical attributes. When it comes to handling and storing rice straw, density is most important. When converting biomass into energy, thermal characteristics and heating value are important.

A material's chemical makeup, including its lignin, cellulose,hemi-cellulose/carbohydratecontent,and nutrient contents, is important for applications like soil fertility and livestock feed. Calculating efficiency and performing life cycle analysis both benefitfromcharacterizationofricestraw.Themost popular techniques employed by the National Renewable Energy Laboratory (NREL) and the AmericanSocietyforTestingandMaterials(ASTM) provide characterizations of rice straw. A lignocellulosic biomass,ricestrawhasacomposition of 38% cellulose, 25% hemicellulose, and 12% lignin.Ricestrawhasahigherhemicellulosecontent andlesscelluloseandlignincontentwhencompared tothebiomassofotherplants,suchassoftwood.[18]

According to Zhou et. al., rice straw has the advantage of low density and low thermal conductivity due to its hollow internal structure. Also, the utilization of rice straw in buildings prevents the negative environmental impact of burning straw or mixing them with soil. The composite materials are insulating with thermal conductivity values in the range of 0.039-0.045 W/(m·K) for an average density in the range of100 to 200 kg/m3. [19]

AnothertypeofCellulosematerialisbamboo fiber. Environmental and economic factors are driving a rapid evolution in the study of renewable resources.Naturalfiberswerefirstusedbypeopleto reinforce composite materials. Because of its superior mechanical strength and fatigue resistance, bamboofiber-reinforcedepoxycompositeisaviable alternativeto glass fiber- reinforcedcomposites ina variety of applications. Chiu et al. [20] describe bamboofiberasanaturalfiberthathasthefollowing benefits: low density, light texture, low energy consumption, and biodegradability. Bamboo can be harvested in short rotation periods and has good mechanical strength as a raw material. [21]

According to this study by Michael H. Ramageet al.,Afullydensifiedbamboo(i.e.,where thereisnoairorpolymermatrixandρc=ρf=1500 kg/m3) would therefore have a longitudinalthermal conductivity around k fII = 0.55–0.59 W/m K, according tothis studybyMichaelH. Ramage et al. [22]

Figure6 Bamboo FiberSource:btn-europe.com

Asperthe findingsofPatrickPereiraDiaset al. [23], Miscanthus has been applied in numerous ways. Among the intriguing products derived from Miscanthus is lightweight concrete. Research on miscanthusrevealed that it can be used for both fire and passive noise protection. The relatively high temperatureinsulationcapacityofMiscanthusfibers hasalreadybeendemonstrated.UsingMiscanthus, created inexpensive insulating particleboard panels and demonstrated their great potential due to their low density and good thermal conductivity.

The thermal conductivity of miscanthus fibers is 0.04 WmK−1, which is comparable to that of commercially available conventional insulation materials. Miscanthus fibers, when added to a concrete mixture as lightweight aggregates, increased the concrete's compressive strength by 4–28%. concluded that, considering the Miscanthus concrete'scompressivestrength,theidealtheoretical mixture would consist of 150 kg/m3 of Miscanthus and592kg/m3ofcement,withawater/cement ratio of 0.8. In addition, the pore structureof Miscanthus helps to lower the concrete's heat conductivity. The acoustic absorption qualities of the bio-based lightweight concrete containing Miscanthus were markedly improved by the addition of Miscanthus fibers.

Figure 7
MiscanthusSource:
crops4energy.co.uk

Regarding paper, the researchers concentrates on cellulosic waste made of paper. It is evidentthattheseareprimarilytheoutcomeofpeople using cardboard and paper on a daily basis[24].Byutilizingthecellulosefoundinrecycled paperandcardboard—whichbelongstothethird groupofmaterialsthatarediscardedingreaterproportion—these materials contribute to environmentalsustainability,whichjustifiestheir selection[25].Thepotentialtocreateproductive units based on waste recovery is made possible by this initiative. The goal of their project is to use the celluloseof recycledpapertocreatenewbuilding materials.AccordingtoPacheco-Torgaletal.,(2020) paper displays an apparent density of 246.54 kg/m3 and a thermal conductivity of 0.027 W/m.K. [26]

Figure8Paper
Source:petalandprint.blogspot.com

1.3 STATEMENTOFTHE PROBLEM

The Philippines is challenged with an increasing rise in temperature associated with climate change. Although various thermal insulation products exist tocounteractthistrend,theirwidespreadadoptionis hindered by affordability constraints. This research centers onaddressing the critical issue ofmitigating heat-related challenges in the Philippines by exploring accessible and cost-effective thermal insulation solutions.

1.4 OBJECTIVES

1.4.1 GeneralObjective

The main objective of this study is to develop a cellulose-based insulator with rice straw, bamboo, and miscanthus as natural additives.

1.4.2 SpecificObjectives

1. To identify the natural additives that can be added as a composite material of a cellulose based insulation.
2. ToconductacomparativeAnalysisofInsulation properties in cellulose-based composite materials with natural additives.
3. To determine the most efficient cellulose based insulation with the use of natural additives among theotherinsulationmaterials,comparedwithmarket available products.
4. Toofferalternativeinsulationmaterial.

1.5 SCOPEANDLIMITATIONS

The focus of this study is to conduct a comprehensivecomparisonofthethermalinsulation properties of cellulose-based materials, including bamboo fiber, rice straw, and miscanthus, to understand their intrinsic ability to resist heat transfer.

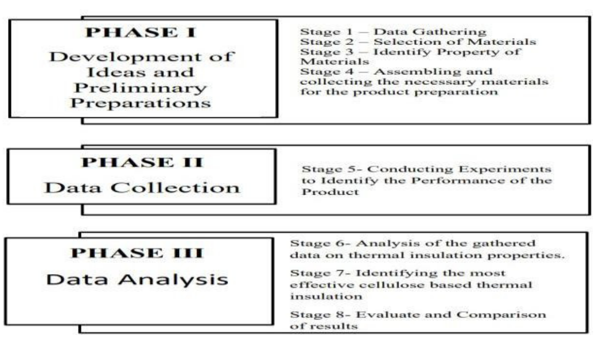
The study also considers a combination of factors toidentifythemosteffectivematerialineachcontext.

The goalis to evaluate the thermalconductivity(K) of each cellulose-based material to understand their effectivenessinimpedingheatflow.ToExaminethe densityof bamboo fiber, rice straw, and miscanthus to identify their structural characteristics and potential impact on insulation performance. To investigatethematerials'waterabsorptionproperties toassesstheirresiliencetomoisture,acriticalfactor in real-world applications. And measure how each material swells when immersed in water to understand its dimensional stability, which is essential for long-terminsulationperformance. [27][28]

The study has delimited in-depth material testing due to financial constraints and lack of testing apparatus.Thus,utilizingscaled-downstructurescan be cost-effective, making it a viable option when financial constraints limit access to more sophisticated thermal insulation apparatus. While scaled models maynotpreciselyreplicatereal-world conditions, they can still provide a relative comparison of materials' thermal conductivity, offeringinsightsintotheircomparativeeffectiveness. Scaled-down testing is generally quicker and more accessible, allowing for a timely assessment of the thermal performance of different materials. [29]

2. METHODS

In order to obtain the desired results and accomplish the specified objectives. The approach was divided into three stages: gathering and preparing materials to be utilized, performing trials to assess the effectiveness of the product, and analyzingandcomparingdataacquiredwithcurrent thermal insulation products, mostly cork thermal insulators.



2.1 ResearchDesign

Experimental research design for testing three cellulose-based materials with natural additives, using a small-scaled structure, and comparing their thermal insulationeffectiveness is driven by several key advantages. This design allows for precise control over variables, ensuring consistent testing conditions, and facilitating the systematic manipulation of materials for meaningful comparisons. The experimental approach supports causalinference, helpingresearchersunderstandnot only which material performs best but also why it does so under specific conditions. Quantitative data collection is a strength of this design, enabling rigorous assessments ofproperties like heat transfer rates and thermal conductivity.

Moreover, the use of a small-scaled structure enhances practicality and cost-effectiveness while still providing valuable insights. The findings derived from this experimental design can be extrapolated to real-world scenarios, such as building insulationapplications. Overall, thechosen research design offers a structured and controlled framework to systematically evaluate the thermal insulationeffectiveness ofcellulose-based materials with natural additives, contributing valuable knowledge to the field of construction materials.

2.2 Phase 1 - Development of Ideas and Preliminary Preparations

2.2.1 Stage1:DataGathering Stage

In this stage, the researchers collected information and evidence relevant to the Research studyorproject.Thedatagatheringprocessinvolves systematically gathering, documenting, and organizing information to address the research objectives or answer specific research questions by means of experimentation in this specific research.

2.2.2 Stage2: Selection ofMaterials

In this stage, the Researchers carefully chose the materialsmainlybamboo[21],giantmiscanthus[23], and rice straw [18]as natural additives; paper [24] as its base; and boric acid as its binder [30]. The materials mentioned earlier are going to be used for data collection, analysis, and documentation. The specificmaterialsselectedwasdependonthenature ofthe research,the researchquestionsorobjectives, the methodology employed, and ethical considerations base on the past researches that are connected to this study.

Figure9Selected Materials

2.2.3 IdentifythePropertyofMaterials

In this stage, the researchers determined the propertiesofthematerialsintendedtobeusedonthe product, for instance, its thermal conductivity. Mentioned below are the thermal conductivity of each material:

a) bamboothermalconductivityaround=0.55–0.59 W/mK. [22]

b) Giant Miscanthus- thermal conductivity of miscanthus fibers is 0.04 WmK–1. [23]

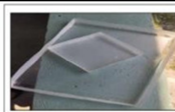
c) Rice Straw- with thermal conductivity values in the range of 0.039-0.045 W/(m·K) for an average density in the range of 100 to 200 kg/m3 [19]

d) Paper-AccordingtoPacheco-Torgaletal.,(2020) paper displays an apparent densityof246.54 kg/m3 and a thermal conductivity of 0.027 W/m.K. [26]

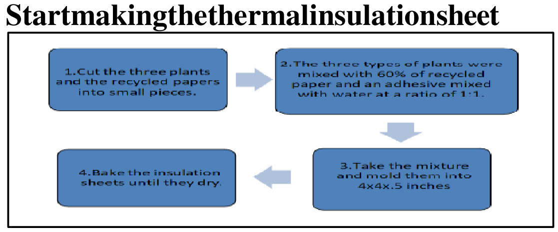
2.2.4 Stage4:AssemblingandCollectingthe NecessaryMaterialsfortheProductPreparation

Inthisstage,theresearcherscollectedandprepared resources, tools, and equipment necessary to conduct the studyand assemble the product.This process is crucial for ensuring that researchers have access to the instruments and materials to carry out theirinvestigationseffectively.Assemblingthe productcanbeachievedbyfollowingthesteps below:

Table1. Toolsand Equipment

	LAMINATING SHEET (MOLDER) is a thing that molds, shapes, or forms something.
	MEASURING CUP used to accurately measure liquid or dry ingredients.
	WEIGHING SCALE It provides a numerical value representing the amount of force exerted by the object due to gravity.
	CALIPER is a measuring tool used to accurately measure the distance between two opposite sides of an object.
	DRYING OVEN is a type of oven used for drying or removing moisture from substances or materials.
	SMALL SCALED STRUCTURE

Startmakingthethermalinsulationsheet



a) Thecollectednaturaladditivesandrecycledpaper was cut into small pieces.

Figure9CuttingoftheMaterials

b) The studyemployed a trial-and-error approach to systematicallyexploredifferentproportionsaimedat achievingtheresearchobjectives.Thefirsthurdle we had to overcome was how to dissolve the wood glueand mix it wellinthewater.The initialattempt failed because the wood glue solidified before we hadthechancetomix it,butthesecondattempt was successful because we mixed it immediately after pouring water on it. Regarding the proportioning of substrates,the initialapproach involved trying a 1:1 ratio, which resulted in the products not combining well.Onour second attempt, wetried a 60% to 40% proportion and achieved the desired result. Each iteration was accompanied by monitoring, data collection, and analysis to evaluate the efficacy of the approach. Insights gained from failed attempts wereutilizedtorefinesubsequentiterations,leading to the eventual development of the product. This iterative process allowed for the optimization ofthe insulator and ensured the robustness of the study's conclusions.

Table2.ExperimentalSampleProportion

PROPORTION	PAPER(%)	NATURAL ADDITIVES (40%)
Proportion 1	60	Rice Straw
Proportion 2	60	Bamboo
Proportion 3	60	Miscanthus

Figure11MixingandProportions

c) Thesamplesweresun-driedforandovendriedfor 30 minutes.

Figure10DryingandHeating

2.2.5COSTING

	(ESTIMATED)	
WOOD GLUE	PHP 140/ 500g	PHP 35/ 125g
BORIC ACID	PHP 80/ 1kg	PHP 4/ 50g
PAPER	PHP 9/ 1kg	PHP 4/ 375g
RICE STRAW	PHP 5/ 1kg	PHP 1/ 200g
BAMBOO	PHP 292/ 1kg	PHP 37/ 125g
MISCANTHUS	PHP 5/ 1kg	PHP 1/ 200g

PROPORTION	AREA	TOTAL COSTING
Proportion 1	0.87 sqm	PHP 40
Proportion 2		PHP 76
Proportion 3		PHP 40
Foam Insulator Board	50 sqm	PHP 5700

2.3 Phase2– DataCollection

After completing the data gathering and product assembly phases, researchers are now ready to advance to the next stage. In this phase, they conducted various experiments to collect the necessary data for the subsequent processes. By thesesimplefactorswecancollectivelyassessedthe materials.

2.3.1 Stage5: ConductingExperiencestoIdentify the Performance of the Product

Inthisstage,theResearchersareaimingtoidentify the following data:

1) Determinationofdensity

a) Measurethelength, width, andthicknessofthe sheet using appropriate instruments.

b) Calculate the volume of the sheet by multiplying its length, width, and thickness.

c) Weigh the sheet using a scale with sufficient precision.

d) Divide the mass of the sheet by its volume to calculate the density. The formula is density = mass/volume.

2) DeterminationofWater Absorption

To determine the waterabsorptionofa sheet thermal insulator, you can use the ASTM C209 standardtestmethod[28].Thismethodiscommonly employed for measuring water absorption of cellulose fiber insulating board. Here's a simplified overview of the procedure:

a) Cut representative samples of the thermal insulator sheet.
b) Measure the thickness of the specimen with reasonable accuracy and calculate the volume therefrom.
c) Then carefully weigh the specimen and submergeithorizontallyunder1in.(25mm)offresh tap water.

d.)After2hofsubmersion,placethespecimenon end to drain for 10 min; at the end of this time remove the excess surface water by hand with a blotting paper or paper towel, and immediately weigh the specimen.

e) Calculate and report the amount of water absorbedfromtheincreaseinweightofthespecimen during the submersion, and the water sorption shall be expressed as the percentage by volume based on the volume after conditioning.

2.3.2 Evaluatetheheatprotectioneffectivenessof thermal insulation sheets using scaled down structure

Determining the thermal insulation effectiveness of a roof using a scaled-down structure involves simulating heat transfer within a controlled environment [29]. Here's a basic process:
a) Build a scaled-down model of the roof and the roomit covers. Ensure thatthe materialsused inthe model accurately represent those of the actual structure.
b) Place the model in a controlled environment, minimizing external factors that could affect temperature.
c) Introduce a controlled heat source to simulate conditions similar to those in a real-world scenario. Thiscouldbeaheatlamporanothercontrolled heatingelement.Forthisstudy,theresearchersused 50 Watts bulbs as the heating element.

d) Recordtemperaturedata.

e) Calculate the thermal resistance of the roof material. Thermal Conductivity is calculated using $k = Qd/A\Delta T$, where ΔT is the temperature difference,Qistheheattransferrate,disthickness and A is Area. (Joseph Fourier's Law). According to the Fourier's law of heat conduction, the rateof heat transmission through a material is directly is directly proportional to the temperature gradient andcross-sectionalarea,but inverselyproportional to its thickness.

f) Compare the thermal resistance of the scaled-downstructurewiththeexpectedordesiredthermal resistance. This provides insight into the effectiveness of the roof insulation.

g) Documentyourexperimentalsetup,procedures, and results for future reference.

2.4 Phase3-DataAnalysis

After obtaining the necessary data, theresearchersarepreparedtoadvancetothenextphase. During this stage, the researchers analyzed and compared the data and determined which has the optimal performance among the three thermal insulators. The insulator with the best performance was compared with the existing thermal insulator in the market. The third phase is broken into three stages.

2.4.1 Stage6:Analysisofthegathereddataon thermal insulation properties

In this stage, the researchers analyzed the gathered data on thermal insulation properties involving various factorsthat affect the abilityofa materialto resist heat transfer. Below arethe importance ofthe data'sthattheresearchersareaimingtofindinphase II;

Density

Densityiscrucialforthermalinsulatorperformance, affecting thermal conductivity (higher density insulates better, lower density conducts heat more), weight and thickness (higher density is heavier but needs less thickness for insulation, lower density is lighter but requires greater thickness), and cost (higher density may be pricier but more energy-efficient, lower density could be cost-effective but mayneedmoreextensiveusefordesiredinsulation). [29]

Water Absorption

Water absorption can greatly affect a thermal insulator's performance, with outcomes varying basedontheinsulationmaterial.Whenmaterialslike fiberglassandfoamboards,typicallyeffectivewhen dry, absorb water, their thermal performance can decline.Thisisbecausewater,havinghigherthermal conductivity than air, can boost heat transfer within the insulation, diminishing its overall effectiveness. [29]

2.4.2 Stage7:Identifyingthemosteffective cellulose based thermal insulation.

In this stage, the researchers assessed the results through a comparative analysis to identify the most effectivethermalinsulationamongthethreeoptions. Acomprehensivetable, comprisingtheoutcomesof diversetestsconductedinphaseII,wasconstructed. This table will facilitate the differentiation of gathered data, aiding in the selection of the most optimal thermal insulator. [31] [32]

2.4.3 Stage8:Evaluateandcomparisonofresults.

Inthisstage,uponchoosingthemostsuitableand high-performingmaterialfromtheavailableoptions, the researchers compared it with the current insulation material on the market, specifically focusing on foam thermal insulation.

3. RESULTSANDDISCUSSIONS

Thischapter includesthedatadescription,analysis, findings, and interpreted results based on the study objective.Theresultsfromtheproceduresperformed inthepreviouschapterarepresentedusingtablesand graphs.

3.1 DataDescription

The results from the experimental variable group were considered in this study. The determination of density was computed using mass over volume, while the water absorption was calculated by the difference of the initial and final volume after immersed in water [28]. Conversely, thermal conductivity was based by getting the difference of temperature using the small scaled structure and calculated by Fourier’s Law. [29]

3.1.1 DeterminationofdensityTable

Table 4. Calculated density of each proportion

INSULATOR SPECIMEN	WEIGHT(Kg)	AREA (m2)	THICKNESS (m)	DENSITY (kg/cu.m)	DENSITY (kg/cu.m)
Proportion 1	.0525	0.4064	.010	12.9 (9)	117
Proportion 2	.072	0.4064	.010	18 (9)	160
Proportion 3	.043	0.4064	.010	11 (9)	96

As shown in table the analysis of insulator specimens reveals notable differences among them. According to the ASTM standard a cellulose insulation board minimum density is 160 kg/cu.m with the area of 0.0929 m2 that is why the sample sheet density is multiplied by 9 to get the value in accordancewiththeASTMstandard.TheProportion 1 specimen weighs 0.0525 kilograms, resulting in a densityof117 kg/m³. Incomparison, the Proportion 2, weighing 0.072 kilograms and sharing the same dimensions and thickness, demonstrates a higher densityof 160 kg/m³. Conversely, the Proportion 3, weighing 0.043 kilograms under identical dimensions and thickness, presents a lower density of96kg/m³.Theresultsshowsthatthedensityofthe Proportion2 is greater thanthe two proportions and reached the ASTM C208 standard. [27]

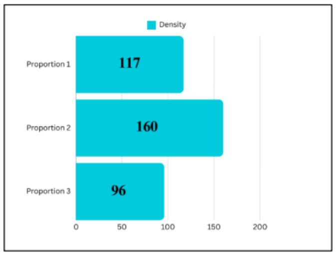


Figure 13 Density Results

As depicted in Figure 13, the properties of each cellulose fiber have an impact onthe densityresults ofthethreeproportions.Thegraphillustratesthatthe highest density is achieved by Proportion 2, which consists of a 60% Paper and 40% Bamboo fiber mixture. Bamboofiberoffersexcellent physicaland mechanicalproperties,ashighlightedinthestudyby Haitao Li [37]. This implies that when paper and bamboo fiber are combined, the resulting density is higher**.**

3.1.2 Determinationofwaterabsorption

Table 5. Calculated Water Absorption

INSULATOR SPECIMEN	INITIAL VOLUME (m^3)	FINAL VOLUME (m^3)	INCREASE IN VOLUME (%)
Proportion 1	0.0001032256	0.0001135816	10
Proportion 2	0.0001032256	0.0001238707	20
Proportion 3	0.0001032256	0.0001032256	0

Utilizing the formula ((V2 - V1) / V1) x 100 to calculate the volume change, the evaluation of insulator specimens reveals varying responses to Figure13DensityResults32Proportion1 Proportion 2 Proportion 3 volume alterations. Proportion 1, starting with an initial volume of 0.0001032256 m³, expanded to 0.0001135816 m³, reflecting a 10% increase in volume. In contrast, Proportion 2, sharing the same initial volume, expanded more significantly to 0.0001238707 m³, markinga20% increase. Conversely, the volume of Proportion3remainedconstantat0.0001032256m³, showcasing no change. The table indicates that Proportion 3 does not experience as much of an increase as the other two proportions.

3.1.3 PhysicalThermalTest

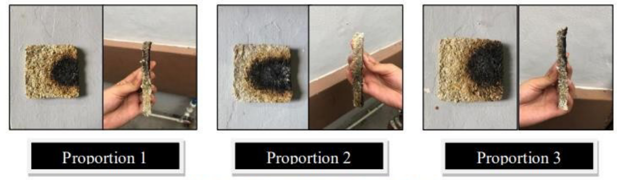


Figure 14 Two Minutes Direct Heat

Atwominutesdirect heat wasconducted[33].As shown in Figure 8, the difference of the cross sections of each proportions. The three proportions did resist the fire but among the three, Proportion 2 show less burnt. This suggests that the Proportion 2 performance in this test was ideal in terms of its thermal behavior and has a resistance to fire.

3.1.4 ThermalConductivity

Table 6. Thermal Conductivity Results

TYPE OF INSULATOR	HEAT TRANSFER (watts)	THICKNESS (m)	AREA (m^2)	INITIAL TEMPERATURE (K)	FINAL TEMPERATURE (K)	THERMAL CONDUCTIVITY (W/m-K)
Proportion 1	200	0.0127	0.0452	314.25	310.25	0.36
Proportion 2	200	0.0127	0.0452	314.25	310,05	0.34
Proportion 3	200	0.0127	0.0452	314.25	311.85	0.60

The comparison of different types of insulators reveals their respective abilities to manage heat transfer under similar conditions. For instance, despite each type conducting 200 watts of heat througha0.0127mthicknessacrossa0.0452m²area, the Proportion1, witha thermalconductivityof0.36 W/m·K, reduced the initial temperatureof 314.25 K to a final temperature of 310.25 K. Meanwhile, the Proportion 2, possessing a higher thermal conductivity of 0.34 W/m·K, resulted in a final temperatureof311.85K.Similarly,theProportion3, with a thermal conductivity of 0.60 W/m·K, achieved a final temperature of 310.05 K. These outcomes highlight the varying efficacy of the insulators in mitigating heat transfer while demonstrating distinct thermal conductivity levels and shows that the proportion2 achieved the ASTM C208 standards. [27]

Table 7. Summary of Results

PROPORTION	1	2	3	STANDARD
DENSITY (kg/cum)	117	160	96	ASTM C208, C209 ≥ 160, < 497
WATER ABSORPTION	9%	16%	0	ASTM C208, C209 0 – 10%
k (W/m-K)	0.36	0.34	0.60	ASTM C208, C209 ≤ 0.38

As shown in table 7, Proportion 2 performed the bestamong the restin each test conforming to the ASTMstandards[27],[28].Proportion2showedthe bestresistanceinfireamongthethreeaswellin thermalconductivity.Proportion2appearedtobe lesseffectiveintermsofwaterabsorption,having its volume increase in 20%. According to the study of Hongyan Chen et. Al [36], because of its structure and composition, bamboo absorbs moisture when it isexposedtohumidconditionsorimmersedinwater. Thatexplains why Proportion 2 had the 34 largest percentageintermsofwaterabsorption.However,in real usageof roofinsulatoritwillbeconditional. There are many causes for wet insulation, like attic insulationthat getswetfroma leakingroof. Because celluloseinsulationistypeofinsulationfeatures plant fibers, that means it can pick up moisture likea sponge. If a small section of the insulation is wet, you might be able to get away with replacing only the affected area. It might also be possible to dry it out.If thewater leakissignificant,you'll needto replace the entire section [34]. The insulating board usageisinadryenvironmentwhereexposureto moisture is minimal.

Table 8. Comparing to market available insulation board

Insulation Board	Cost per 50 sqm	Thermal conductivity W/m-K
Proportion 2 (Bamboo fiber and Recycled Paper)	4408 PHP	0. 34
Foam Insulator (market available)	5700 PHP	0.032

As shown in table 8, Proportion 2 has high thermal conductivity than the foam insulator in the marketwith0.032W/m-K.Still,Proportion2canbe offered as an alternative as it conform the ASTM standard and at the same time it cost lower than the market available insulation boards

4. CONCLUSIONSANDRECOMMENDATION

Thischapterpresentsasummaryofallthefindings, conclusion,aswellastherecommendationsfromthe researchers that may be used as a guide for future researchersconductingresearchwithinthesame line fortheimprovementofthesubjectofstudyandother methods to enhance the paper and background.

4.1 SummaryofFindings

The Researchers conducted an investigation into the thermal properties of three natural additives suitable for composite materials in paper as cellulose-based insulation. Bamboo demonstrated a moderatethermal conductivity rangingfrom0.55to 0.59W/mK.GiantMiscanthusfibersexhibiteda notablylowthermalconductivityof0.04W/mK, indicating strong potential for enhancing insulation effectiveness. Ricestrawshowedpromisingthermal conductivityvaluesrangingfrom0.039to0.045 W/(m·K) at average densities of 100 to 200 kg/m3. Thesefindingshighlightthesuitabilityofthesenaturala dditivesforimprovingthe insulation propertiesofcompositematerialsbasedoncellulose. Thestudyextensivelycomparesthethermal insulationpropertiesofcellulose-basedmaterials, incorporatingnaturaladditivessuchasbamboofiber, rice straw, and miscanthus, to assess their inherent heat resistance. Utilizing ASTM standards 208 and 209,theresearchevaluatesvariousfactorsincluding thermalresistance,density,waterabsorption,and responsetodirectheatovertwominutesto determinethe most effective material. These factors collectivelymeasuretheperformance,durability, andsafetyoftheproduct,providinginsightscrucial foroptimizinginsulationsolutions.

The findings highlight that Proportion 2, comprising60%paperand40%bamboo,emergedas the most efficient cellulose-based insulator. Proportion 2 achieved a density of 160 kg/m³, meetingASTMC208standards[27],indicatingits structuralintegrity.Withwaterabsorptionincreasing by only 20%, it demonstrated superior durability, crucial for long-term performance. Proportion 2 exhibited remarkable fire resistance and sustained theleastdamageduringthermalanalysis.Moreover, its thermal conductivity of 0.34 W/m-K surpassed that of Proportion 1 and Proportion 3, making it highly effective in impeding heat transfer. Proportion2'sadherencetoASTMstandards[27], [28] further underscores its suitabilityfor insulation applications,emphasizingitsroleasaleadingchoice in cellulose-based insulation.

The investigation highlights cellulose-based insulation with natural additives as a compelling alternative, emphasizing its economic advantages and environmental benefits. The estimated cost of thesamplesheet,rangingfrom44to76pesosper 0.87 sqm, significantly undercuts foam insulating boardscommonlyusedinthePhilippines,whichcan costupto5,700pesosper50sqm.Despiteitsslightly higher thermal conductivity of 0.34 W/m-K compared to foam boards at 0.032 W/m-K, the sample sheet meets ASTM standards [27]-[28], making it a viable alternative. Additionally, its renewable sourcing and reduced environmental impactcontributetosustainability.Theaffordability ofthis optionfurther enhances its appeal, offering a cost-effective solution for both initial installation and long-term energy savings.

4.2 Conclusion

As global temperatures continue to rise and the callfor sustainablesolutions intensifies,thisresearch standsasabeaconofhopeinaddressingthepressing challenge of climate change. Through rigorous examinationandtesting,itunveilsthemostefficient composite material for thermal insulation applications, weighing crucial factors like performance, cost-effectiveness, and environmental sustainability. The pursuit of developing a thermal insulation board using agricultural fibers and recycledpapermarksaboldstridetowardsproviding an accessible and environmentally friendly alternative to conventional insulation materials.

The potential impact ofthis research is profound, especially in regions like the Philippines, where extremeheatamplifiestheneedforeffectivethermal insulation. By championing the use of agricultural waste or by-products over foam and plastics, this study underscores the diverse advantages of sustainable alternatives. These materials not only offer comparable, if not superior, insulation properties but also address the critical issues of affordability and environmental preservation.

Astheurgencyforsustainabledevelopmentgrows, thesignificanceofthisresearchcannotbeoverstated. Beyondmerelyidentifyingpracticalsolutions,it servesasacatalystforpromotingsustainable practiceswithin insulationtechnology. Inthe Philippines and beyond, the pursuit of efficient and eco-friendly thermal insulation materials transcends necessity; it becomes a moral imperative in shapingamoresustainablefutureforallgenerationstoco me.

4.4 Recommendations

Thisstudyispursuedtoidentifythemostefficient thermalinsulatorusingcellulosebasedmaterialsthat can be an alternative use. In terms of the result the Proportion2, whichisthe mixofpaperand bamboo fiber results the best among the standard tests. The researchers of this study were confident enough to recommend using the cellulose based insulation boardmadeofpapermixedwithbamboofiber[21], [24] as an alternative for insulating boards in the market. It is economical, accessible, and achieved the ASTM (C208, C208) standards [27], [28]. After thorough research and testing for this study, the researchers recommend the following to improve and expand the scope of the study.

1. Further study and testing on the physical properties of the said cellulose-based insulation board.
2. Lower the ratio of the paper that is mixed with the natural additives.
3. Useandtestdifferent samplesizes.
4. Abetter methodofextracting the fiber fromthe natural additives.
5. Exposingthesampletotheheatlonger.
6. Researchothercellulosebasedmaterialsthatcan be used as an alternative.

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