OPTIMISING THE THERMAL PROPERTIES OF BUILDING ENVELOPES

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DEPARTMENT OF MECHANICAL ENGINEERING
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CERTIFICATION

This is to certify that this research project titled: OPTIMISING THE THERMAL PROPERTIES OF BUILDING ENVELOPES, was carried out by OSABUOHIEN STANLEY OSARO; ENG1905650, AIKHOJE GIDEON OHIMAI; ENG1905409, EYEKPIMI PHILIP OGHENERHUNA; ENG2006379, in the Department of Mechanical Engineering, University of Benin, Benin City under the supervision of Engr. Dr. H.O. Egware in partial fulfilment of the requirement for the Award of Bachelor of Engineering (B.Eng.) in Mechanical Engineering

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DEDICATION

We dedicate this report to God Almighty, whose grace has granted us the strength to accomplish all that was necessary for the success of this project. To our families, whose unwavering support and encouragement have been the foundation of our academic journey. To the Department of Mechanical Engineering, whose guidance and commitment to equipping us through extensive training and lectures have been pivotal in shaping us into who we are today. This work is also dedicated to all who have inspired and supported us along the way. Your faith in our potential has ignited our passion for learning and striving for excellence.

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ABSTRACT

Enhancing the thermal performance of building envelopes is crucial for improving energy efficiency and indoor comfort. This study examines how different material combinations influence heat transfer through composite walls.

To achieve this, we conducted both theoretical calculations and ANSYS simulations, analyzing various wall configurations. The study focused on steady-state heat transfer, considering conduction and convection while neglecting the first convective resistance. We tested multiple material setups, including Dense and Medium Dense Hollow Concrete Blocks, Fiber Glass Insulation, Rock Wool, Polystyrene Foam, Air Cavity, Agba Wood, and Mahogany. The analysis was carried out under controlled conditions, with an outer surface temperature of 35°C, an inner fluid temperature of 25°C, and a convective heat transfer coefficient of 25 W/m²·K at the inner surface.

Our findings offer valuable insights into selecting materials that can optimize building envelopes, reduce heat transfer, and enhance indoor thermal comfort. This research contributes to the development of more energy-efficient and sustainable building designs.

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q - Heat flux (W/m^2)

T1 - Outer surface temperature (°C) T2 - Inner
fluid temperature (°C) h - Convective heat
transfer coefficient ($W/m^2 \cdot K$) k - Thermal
conductivity of material ($W/m \cdot K$) L - Thickness
of material layer (m) R - Thermal resistance of a
layer ($m^2 \cdot K/W$) ρ - Material density (kg/m^3)

Cp - Specific heat capacity (J/kg·K)

$\dot{Q}$ - Heat transfer rate (W)

A - Surface area for heat transfer (m^2)

∇T - Temperature gradient (K/m)

U - Overall heat transfer coefficient

($W/m^2 \cdot K$) ΣR - Total thermal resistance

($m^2 \cdot K/W$) α - Thermal diffusivity (m^2/s) λ -

Heat conduction coefficient (W/m·K) $\dot{m}$ -

Mass flow rate (kg/s)

ΔT - Temperature difference (K)

CHAPTER 1

INTRODUCTION

1.1 Background of Study.

It is challenging to attain thermal comfort in buildings in the tropics due to high ambient temperatures, humidity, and seasonal fluctuations. Edo State, in southern Nigeria, experiences a tropical wet and dry climate with high humidity and mean temperatures of 25°C to 33°C throughout the year. The combination of the following environmental conditions often leads to indoor overheating, which has the negative effect of influencing comfort, health, and productivity of building occupants. Maximizing the building envelope is an effective solution for such issues by reducing indoor heat gain and enhancing natural ventilation

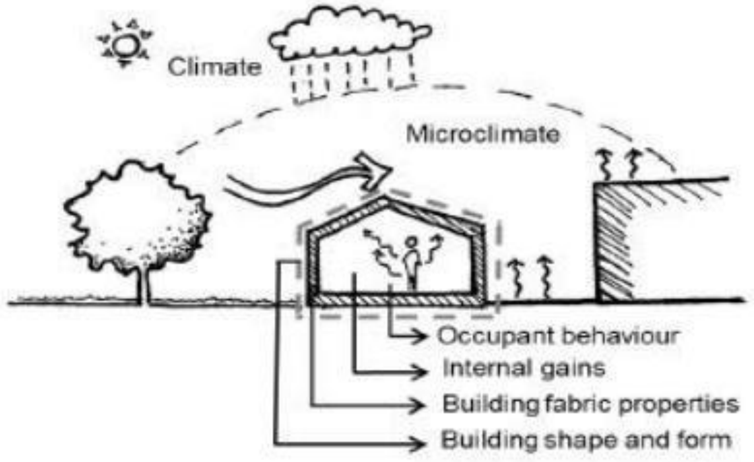


FIGURE 1.1 PARAMETERS FOR HEAT GAIN OR LOSS IN BUILDINGS

Given that building materials, like concrete, are broadly utilized for private, commercial, and regulation development, the development industry inside Nigeria contributes altogether to the economy. Additionally, Concrete is known to have critical focal points due to its solidness and ease of availability. Be that as it may, concrete's predominant application raises a few concerns, particularly in tropical ranges such as Edo State in Nigeria.

Around the world, the development division could be a driving source of carbon outflows, with around 39% of the world's CO2 outflows from vitality utilize coming from this industry. The fabricating prepare of cement—an vital fixing in concrete—is too included in this.

The generation of cement, concurring to the Worldwide Cement and Concrete Affiliation (GCCA), contributes to generally 8% of the universes CO2 emanation. Vitality utilize in these zones is crucial in moderating the extraordinary warm and stickiness caused inconvenience to tenants which raises the address of warm execution of the buildings.

FIGURE 1.2 HOUSE UNDER CONSTRUCTION

The development of building envelopes employments critical volumes of Concrete based building materials such as Thick Empty Concrete Pieces (DHCB). The extraction of limestone and clay to fabricate concrete, a non-renewable asset, postures a considerable danger to the environment. Concrete has tall warm conductivity, which suggests that warm is rapidly exchanged from the exterior to the add of buildings. Hence, indoor temperatures tend to be awkwardly tall driving to an increment in HVAC dependence. This reliance includes to the vitality utilization and natural affect as well as the financial burden for building proprietors and tenants.

These components have made an expanded requirement for the feasibility of materials having predominant warm protection properties, particularly in tropical climates like Edo State where there's tall temperature and stickiness which increments the need for solid warm cover in buildings to preserve indoor consolation for the well-being of the occupants.

Edo State, which is located in the southern part of Nigeria, experiences a tropical climate with two clear-cut seasons, which include the wet rainy season that lasts from April to October and the dry season from November till March. The range of moderate temperatures, which vary from 25 degrees to 32 degrees celsius, is always accompanied with relative humidity levels that goes over seventy percent. Because the mugginess is always too high, many newly constructed structures that are made with poor insulator materials tend to incur higher expenses in maintaining indoor warmth.

The purpose of this research is to focus on improving the energy efficiency of building envelopes using alternative sustainable materials that are energy efficient and can improve thermal comfort. The combination of Agba wood, fiberglass insulator, rock wool, and polystyrene foam as construction envelope elements can significantly improve the thermal performance of buildings in Edo State. These materials not only provide better thermal insulation, but they also help to mitigate the environmental impact of construction by reducing carbon emissions.

1.2 Statement of the problem.

Most buildings in Edo State, and without a doubt Nigeria, are confronted with issues of keeping up warm consolation as a result of tall open-air temperatures, mugginess, and the nonappearance of successful cover or shading. Most buildings are built utilizing materials that retain and hold warm, hence causing critical indoor temperature increments which have negative impacts on occupants' consolation, efficiency, and wellbeing. The non-availability of sensible, accessible inert cooling courses of action has driven an overpowering reliance on examine conditioning and other mechanical cooling systems. In any case, these are not as it were energy-intensive but moreover exceptionally costly to function, thus constituting a money related burden to families and expanding generally vitality request in Nigeria.

- Destitute warm insulation:

Concrete features a high warm conductivity, driving to destitute separator and permitting indoor temperatures to extend particularly in tropical districts like Edo State. It assists strengths the tenants to be subordinate on mechanical cooling frameworks, which may be a way of expanding vitality utilization.

- Restricted Utilization of Reasonable Options:

Though materials like Agba wood mahogany, fiberglass separator and shake downy display common warm execution and supportability; in any case, they are not however broadly utilized within the Nigeria building segment due to restricted mindfulness, accessibility, and taken a toll obstructions.

There are also problems with energy generation and distribution in Nigeria, and it would be unrealistic to have a large percentage of the population running speech conditioning systems day in and day out. This therefore calls for an urgent need for research into other alternative solutions that will be able to offer thermal comfort without relying on mechanical cooling. The research determines the ways optimization of the building envelope can reduce indoor temperatures and hence improve thermal comfort. The investigation here intends to present designs that adapt to the climate of the neighborhood, reasonable, and promote maintainable development hones through materials, separator methods, and inactive cooling procedures.

1.3 Aim and Objectives.

1.3.1 Aim.

To optimize the thermal properties of building envelopes in residential buildings within Edo state , through a comprehensive analysis of insulation materials and building design parameters to achieve enhanced energy and occupant comfort.

1.3.2 Objectives.

i) To identify materials and design strategies that can reduce heat transfer through the building envelopes in tropical climates, especially in Edo State.

Thermal conductivity (λ-value) at various temperatures.

i. Thermal resistance (R-value) per unit thickness.

ii. Specific thermal capacity (Cp).

iii. Thickness (ρ).

iv. Thermal mass calculated or obtained from literature.

ii) To evaluate the thermal performance of different types of insulation materials and assess their potential to enhance indoor temperatures. There by obtaining information on the detailed thermal properties described below for each of the given materials, namely mineral wool, EPS, specifying the type, for instance, expanded polystyrene, extruded polystyrene, and spray foam,:

iii) To provide recommendations for architects, builders, and policymakers on sustainable, climate-appropriate building practices that promote thermal comfort and reduce energy dependency.

1.4 Scope and limitations

This focus relates to residential buildings in Edo State, Nigeria, and is specifically related to Benin City.

It assesses the thermal performance of different fabric combinations in the building envelope and compares their benefits in regulating indoor temperature, energy use, and carbon emissions reduction in single-family detached houses. The materials under consideration include:

- Dense Hollow Concrete Blocks (DHCB):

One of the most common building materials in Nigeria, known for durability but not considered good insulation against thermal conditions.

- Medium-Dense Hollow Concrete Blocks (MDHCB):

An alternative to DHCB; having a far more superior warm separator characteristics due to its smaller thickness.

- Fiberglass insulation: A very commonly used material in recent times in the field of construction; it is known for its outstanding thermal performance.
- Rock wool: A fire-resistant standard mineral-based separator material with massive thermal and acoustic properties.
- Polystyrene foam: A very light, Waterproof material that always gives good outputs in hightemperature crowning.
- Agba Wood-Mahogany: An environmental-type wood found only in the South of Nigeria has easy warm crowning and imposes minimal impact to nature compared with concrete.

- Limitations

Building Demonstrate Disentanglements:

The building demonstrate utilized within the recreations could be a rearranged representation of a ordinary private building within the chosen climate zone. Whereas endeavors have been made to join practical parameters, a few rearrangements were essential, such as [specify particular rearrangements, e.g., expecting a uniform building shape, ignoring the affect of arranging, or disentangling window determinations].

These disentanglements have been made for the absolute accuracy of the simulation results, but the relative study among the different separator materials should still provide valuable insight.

Information Accessibility:

Where relevant, availability and accuracy of data regarding fabric properties, natural driving variables and retrieved data varies and similarly retrieved data depends upon [Specify Sources - i.e. local building fabric suppliers, industry averages], which may affect cost performance analysis due to price fluctuation or regional variation.

Focus on Specific Materials:

The current reflections focus on three specific cover materials:

Rockwool, DCHB,MDCHB, Fiber glass insulation, Agba wood mahogany, and polystyrene foam. Other insulation materials such as [list other materials, like cellulose] were not included in this study and may exhibit different characteristics.

Generalizability:

The results of this study pertain only to the selected climate zone and building type. The outcome cannot be applied directly to other climates or building types without further research.

1.5 Relevance of the project.

Thermal comfort is considered one of the basic needs of human beings in maintaining health and performance at work places and in private buildings. Therefore, it has become an urgent necessity in Nigeria, which has high increasing temperatures and high demands for energy consumption, to apply sustainable and energy-efficient construction methods. The present paper throws valuable light on how to optimize building envelopes to offer better thermal comfort in hot and humid climates. This therefore puts the research in better understanding of sustainable construction techniques, energy efficiency, and occupant comfort in Nigeria through assessing detached cooling strategies, separators, and suitable fabric selection. Suggestions arising from this dialogue may encourage broader building regulations and construction methods in Nigeria that lead to more sustainable and climate-resilient architectural design initiatives.

The findings have an intuitive appeal to architects, structural engineers, and builders who also, like policymakers, try to attain thermal comfort with as little reliance on mechanical cooling systems as possible. This would make sure that there is significant cost savings involved, a better environmental impact ensured, and increased wellbeing of the occupants of such buildings in tune with general principles of sustainable development for Nigeria's building sector.

CHAPTER 2

LITERATURE REVIEW

The aim of this chapter is to present the thermal characteristics of building envelopes in Edo Benin and the Southern Nigeria region. Development of thermal envelope characteristics over time; what constitutes thermal comfort and the thermal envelope characteristics of buildings, thermal comfort and performance in rooms, Thermal performance and comfort of occupants and standards for occupant comfort: Thermal performance standards.

2.1 Thermal Envelopes - Defined

A thermal envelope is the physical separator between the interior and exterior environments of a building, including walls, roofs, floors, windows, and doors. Since a building envelope separates the unconditioned exterior environment from the conditioned interior space, it is one of the key factors that impact building energy consumption. It is designed for heat transfer regulation, moisture control, and enhanced energy efficiency with minimal unwanted heat loss or gain (ASHRAE, 2019). Building envelopes in energy-efficient buildings are not simply barriers between interior and exterior but rather building systems that create comfortable spaces by means of active response to the external environment of the building and at the same substantially reduce the building's energy use (Aksamija, 2015). Energy-Efficient Building Envelopes.

i. have highly thermally resistant materials in the façade of the building, ii.
use vapor barriers and are effective in vapor control, iii. have efficient
window and door seals, iv. have effective airflow control to minimize
infiltration of outdoor air.

A well-designed thermal envelope contributes to improved indoor thermal comfort and reduced mechanical heating and cooling system reliance. This also ensures better sustainable performance in buildings. US Department of Energy, 2021.

2.2 Building Envelope Components

2.2.1 Walls

Walls are one of the main elements of the building envelope, and they play a very important role in providing structural integrity and thermal resistance. Some high-performance wall systems include ICFs, SIPs, and double-wall construction; all of these wall systems improve energy efficiency by reducing thermal bridging (Kosny et al., 2014). In hot climates, such as southern Nigeria, high thermal mass walls-for example, those made from adobe or rammed earth-can help regulate indoor temperatures by absorbing heat during the day and releasing it at night (Papadopoulos, 2005).

Development in methods of construction and building materials from pre-colonial times to the present day.

Introduction:

It is meant to show how there has been technological advancement in constructing technology and available building materials with the advent of time from before colonization times down to this time influenced by different cultural, colonial, and technology imperatives. Using Darling 1984; Ryder 1969; Ola 1977; Mabogunje 1990; Adebayo & Ayo-Vaughan, 2017 among many others, architectural tradition changes together with processes informing such changes is explored. It also tries to illustrate how the trends of economic, environmental, and urbanization factors shape the built environment in Edo State.

The land of Nigeria is so varied in climatic and cultural history that it has influenced the evolution of walling techniques since time immemorial. In this respect, Edo State, having its base in the ancient Benin Empire, therefore, provides an interesting case study, with its rich architectural heritage and influence historical transitions exert on the built environment.

This paper shall attempt a brief trace of building envelope transformation from indigenous methods employed by the Benin people to the current urbanized landscape.

Traditional building in Edo and Benin makes great use of local material-mud brick and lateritethat has a very high natural thermal mass. A combination of such materials could therefore be well adapted to the climate in the region, as they will offer a fair degree of insulation against heat. Modern applications of these materials, combined with modern insulation methods, would result in better thermal performance.

A) Pre-Colonial Era: Indigenous Building Techniques.

- Traditional Earth Construction.

FIGURE 2.1 PICTURE OF A MUD HOUSE

Optimization strategy: The materials in mud, laterite and thatch were used available locally and are renewable.

Salient Features:

- No Thermal Insulation: The thick mud walls in the majority of the tropical climates insulation, hence eliminating the need to artificially cool down the house
- Sustainability: The materials in use are renewable and require small amounts of energy in the processing and transportation activity.

Community involvement: Masters of the art pass skills down the generations, hence, guaranteeing perpetuation, thus perpetuating culture.

Example of this would be the wattle and daub adobe bricks that are used to build up houses and palaces in the Benin Kingdom. **B) The Great Wall of Benin.**

These were walls that according to Darling, 1984 "were some of the largest artificial constructions of the ancient world.". Foreign visitors that included the explorers from Portuguese in the 15th Century left accounts in writing describing such complexities of those constructions, Ryder 1969.

Figure 2.2 house made out of Earth compacted walls

Optimal Solution: Advanced Method of Compacting Soil and Application of Laterite to Largescale Defense Structures by:

Salient Features:

- Structural: Earth compacted walls were firm, erosion resistant, and, therefore, very skillful, exhibiting a high order of engineering skills.
- Defensive Functionality: Serving the dual purpose, these earth heaps were territorial markers as well as protective barriers with optimum security.
- Cultural Significance: The walls revealed one of the strong and ingenuity of the Benin Kingdom and accounted for social bonding.

Example: The Great Wall of Benin was among the largest man-made structures of the time and was recorded by many European travelers.

C) Colonial Era: Introduction of European Building Materials.

The use of burnt bricks /cement blocks has gradually replaced the traditional mud walls since they are seen as stronger and more in line with West architectural construction styles (Ola, 1977).

FIGURE 2.3 HOUSE MADE OF BRICKS

British Influence on Construction (19th–20th Century)

Optimization Strategy: Maximum utilization of readily available European materials, including burnt bricks, cement blocks, and corrugated iron sheets to make buildings stood for a longer period and ensured standardization in building.

Major Features:

- Durability: The European materials were perceived as stronger, resisted processes of weathering and pests, hence could offer longer service lives.

- Standardization: Single architectural style unifying the colonies favored ease of construction by colonial authorities.

- Cultural Shift: The giving way of indigenous designs to the west in terms of aesthetics is also a representation of colonial hegemony.

Example: The use of burnt bricks /cement blocks instead of mud walls in urban areas. **D)**

Urbanization and Change of Benin City.

This state of the urbanization process completely altered direction when the city was invaded in 1897. The development which had seen local building was in decline while there was full involvement of building of houses by Western styles introduced into the setting through the Colonial rulers. Thus Ryder (1969)

FIGURE 2.4 HOUSE MADE OF SOLID BLOCKS

•Optimization Strategy: Building Western materials/ Western styles 1897 under British invasion in the rebuilding.

•Key-points

- Urban Planning: The colonial masters brought in grid patterns and housing similar to European style to maximize space and infrastructural facilities.

- Economic Focus: The application of western materials was in agreement with colonial economic focus on trade and industrialization.

- Cultural Erosion: This was followed by decaying traditional architecture into local material replacement.

•Example: Changing Benin City into an European model of house and road constructions.

E) Post-Colonial Period: Cement-Based Construction (1960–1990s) The

Rise of Sandcrete Blocks.

With the independence of Nigeria in 1960, sandcrete blocks became common, being relatively cheaper and easy to produce. Cement-based walling materials became the order of the day in urban housing, thus jettisoning the indigenous walling techniques used in the construction of traditional houses (Mabogunje, 1990).

FIGURE 2.5 PICTURE OF SANDCRETE BLOCKS

Optimization Strategy: Adopted because of its relative affordability and ease of production.

Key Features:

i) Cost-Effectiveness: Sandcrete blocks were cheaper to produce than conventional materials, and hence accessible for mass housing

ii) Efficiency: Blocks were easy to manufacture and assemble, reducing the time spent in construction.

iii) Urban Growth: The use of sandcrete favored rapid urbanization by satisfying the housing demands of a booming population.

Example: The extensive use of sandcrete blocks in urban housing projects across Edo State.

Reinforced Concrete Application.

Government policies in the post-colonial era encouraged the use of reinforced concrete for structural stability. Further, this relegated the traditional building materials to the background. Modernization swept through Benin City, and most of the old buildings were replaced with cement and concrete buildings (Ola, 1977).

Optimization Strategy: Application of reinforced concrete for structural stability and modernization.

Characteristics:

- Tensile Strength/ Resilience: Reinforced concrete has higher tensile strength, hence allowing multi-storey building construction.

- Modern Government Policies: The policies put in place post-independence favored the utilization of modern materials to help reach the goal of economic growth and development.

- Cultural Shift: The conventional materials were further confined to the background with the advent of reinforced concrete as the benchmark for urban construction.

Example: The buildings of Benin City have been replaced by the older ones with the cement and concrete ones.

F) Current Trends in Building Envelopes 2000–Present

High-Rise and Commercial Structures.

Within the last decades, high-rise buildings made from curtain wall glass with a steel frameworks started to make prominence in Nigeria's construction area. It also can be put among the list of recent latest architectural trends associated with global and urbanization shift in change Adebayo & Ayo-Vaughan 2017).

Approach towards Optimization Using Global Architecture/Use of Imported Materials for commercial and residential Existing Buildings

Key Features

- Aesthetic Appeal: Beauty to the urban centre is contributed by the glass curtain walls and a framework of steel that characterize contemporary architectural styles.
- Energy Efficiency: Modern insulation methods and materials result in higher thermal performance and thus minimize energy use.
- Economic Development: More urbanization and economic development are contributed by skyscrapers as a result of attracting investors.

Example: In Benin City, the use of modern office spaces and shopping centres made of aluminum cladding and reinforced concrete.

G) Hybrid & Sustainable Construction.

Sustainable materials like rammed earth and compressed earth blocks have revived interest in the face of environmental problems.

These will offer energy efficiency with the retention of traditional methods of construction. Adebayo & Ayo -Vaughan, 2017. In recent times, hybrid construction techniques are being advocated by researchers and developers, having modern durability with the sustainability of traditional ones.

FIGURE 2.6 PICTURE OF A RAMMED EARTH BUILDING MATERIAL

Optimization Strategy: Traditional & Modern material inclusions for sustainable building practices.

Key Features:

- Environmental Awareness: The employment of local material, such as laterite, along with modern insulation methods reduces carbon footprint.
- Cultural Revival: The hybrid design supports traditional aesthetics while adding modern functionality to maintain the culture.
- Cost-Effectiveness: It balances affordability and durability by fusing local materials with imported ones.

Example: Modern usage of mud bricks/laterite in residential buildings with added modern insulation.

2.2.2 ROOFS.

Roofs have considerable importance to the thermal performance of the building envelope mostly due to direct solar radiation in many warm and hot climates. In energy-efficient systems, roofs are cool with reflective coatings; vegetation for added insulation; and ventilated roof structure systems that minimize heat gain; U.S. Department of Energy, 2021.

Increasing the insulation layer in the roofing assembly allows for greater indoor temperature stability and maintains cooling loads at a low quantity Aksamija, 2015.

Traditional changes in construction techniques and materials from the pre-colonial era through to contemporary times. (ROOFS).

The indigeneship of the architecture in Edo State, as in much of Nigeria, is deeply rooted in the use of locally available materials and techniques adapted to the tropical climate. Roofs, which are one of the critical components of the building envelope, were designed for protection against the elements, reflecting cultural identity and social hierarchy.

The historical development of roofs in Edo State reflects a strong tradition of resourcefulness, adaptability, and cultural expression. Indigenous roofing such as thatched roofs, gable roofs, and clay tiles were not only functional but highly symbolic, representing the social and cultural values of the Benin Kingdom and the people. Where modern materials and techniques have been introduced.

A) Thatched Roofs.

FIGURE 2.7 THATCHED ROOF

One of the most adopted roofing systems within the pre-colonial period in Edo State was the thatched roof. Materials used in thatching are natural ones like grass, palm frond, or raffia palm that grow within the area. Thatch usages have been so practical and feasible in this sense for the materials happen to be renewable and biodegradable.

Climate Adaptation: Thatched roofs provided good insulation against the tropical heat; they were also effective in draining rainwater during heavy rainy seasons. Due to the slope, water runs off efficiently without collection or causing damage to the structure (Sani, 2012; Baker, 1999).

Cultural Significance: Weaving and layering thatch was an art passed from generation to generation, and the quality often mirrored the status of the homeowner. Sometimes, thickness and intricacy of thatching showed the owner's wealth and social standing of the house. Jebba 2010, Nwafor 2016.

B).Gable Roofs.

FIGURE 2.8 GABLE ROOF

The other feature that was traditionally present in the architecture of Edo State includes gable roofs, triangular in shape, having two sloping sides. Gabled roofing was majorly and highly utilized in the Benin Kingdom for residential and royal building purposes.

-Ventilation and Drainage: The design of the gable allowed for better ventilation, hence cooling, which was necessary in the hot humid climate. The steep slope thus facilitated runoff of rainwater to the ground with minimal leakage and further water-induced damages possible (Falola & Adebayo, 2008; Ikimi, 1980).

- Symbolism: The shape and decoration of gable roofs were usually symbolic in meaning. For example, the roofs of royal palaces were more complex, with intricate carvings and decorations representative of the power and prestige of the Oba (king) Okpoko, 2001; Nigerian National Commission for Museums and Monuments, 2005.

C). Clay tiles.

FIGURE 2.9 CLAY TILES

While thatched roofs were very common, there is also the use of clay tiles in certain areas of Edo State, including the Benin Kingdom. Such types of tiles would generally be found on very important buildings like palaces, temples, and other rich peoples' houses.

- Durability and Aesthetics: These were more durable than thatch; clay tiles offered very good protection against fire and harsh weather conditions. The material was fairly attractive, though, given the reddish-brown colored tile which would add to the look of the buildings; Sani 2012, Ikimi 1980.

Cultural Prestige: the use of clay tiles acted and still acts like a marker for status and wealth. Among them, in the royal palaces of Benin, the widely timbered clay tile roofs are widely manifesting the kingdom's technical ability and resource positions (Baker, 1999). **D). Doomed and curved roofs.**

FIGURE 2.10 DOOMED AND CURVED ROOF

In fact, some of the conventional buildings in Edo State have curved or domed roofs, as in the case of religious and ceremonial buildings, made from a wooden frame with thatch or palm fronds.

Aesthetic and Functional Design: Thus, these arc-shaped roofs had a number of functions, providing a very striking aesthetic and improved ventilation for both the interior spaces and the air in the houses.

In religious contexts, it evoked a bond between the natural and spiritual spheres of human reality. Nigerian National Commission for Museums and Monuments 2005; Falola & Adebayo 2008.

Eco-cultural Factors

Roof construction in Edo State was strongly influenced by environmental and cultural concerns. Adaptation to Climate: The tropical climate of southern Nigeria, with high temperatures and heavy rainfall, imposed demands on roofing systems for insulation and ventilation as well as effective water drainage.

Native techniques were functional and provided comfort in regard to these conditions (Sani 2012; Ikimi 1980).

Sustainability: Thatch, bamboo, and clay were some of the commonly used local materials in traditional building practices. These materials were friendly to the environment; they are costeffective and inexpensive to maintain, as remarked by Jebba (2010) and Nwafor (2016).

-Cultural Identity: The form and material applied for roofing developed to become the symbol of cultural identity and social class. An elaborated palace and temple roof served as an indicator of the strength and

prestige of a kingdom, whereas more modest roof design for dwellings in the countryside served practical and customary needs of the people (Baker, 1999; Okpoko, 2001).

E) Transition into colonial and modern roof types.

This brought an enormous transformation into the architectural environment of Edo State through to the 19th and 20th century with the arrival of the colonial masters. Colonial architects introduced the use of corrugated iron sheets, concrete, and imported timbers. With time and in many places, these had overgrown and surpassed traditional roofing systems.

Introduction of Corrugated Iron Sheets: Corrugated iron sheets were popular in the colonial period because they were tough, cheap, and easy to install.

These sheets allowed very minimal insulation, hence raising internal temperatures in the tropics (Falola & Adebayo, 2008; Smith, 2010).

FIGURE 2.11 CORRUGATED IRON SHEETS

- Modernization and Urbanization: With the rapid urbanization of Nigeria in the post-colonial era, modern roofing materials and techniques were increasingly adopted. Such changes brought improvement in durability and fire resistance but resulted in losses of traditional architectural practices and their cultural heritage (Nwafor 2016; Sani 2012).

Thatched roofing and corrugated metal sheets are very traditional roofing materials. Even today, they are fairly common in southern Nigeria. Where the thatch provides some natural insulation, the metal roofs contribute to heat gain inside the home. Modern solutions include reflective coatings and insulated roof panels.

2.2.3 Floors

Floors contribute to the thermal envelope of a building through heat loss to the ground. Insulated slab foundations, raised floors, and radiant floor heating systems enhance thermal efficiency more. For tropical climates, raised floors with ventilation gaps help lower indoor heat gain according to ASHRAE 2019. In addition, thermally mass materials like concrete and stone further the passive cooling strategies in hot climate regions as indicated by Kosny et al. 2014.

Pre-colonial Floor Indigenous Building Techniques in Edo State).)

Chronology of the floors in Edo State, Nigeria, demonstrates an adaptive indigenous building technique to the prevalent environmental and sociocultural circumstances. These coincidentally optimized the thermal envelope in the use of local materials while enhancing durability and sustainability.

Indigenous Flooring Techniques and Thermal Optimization **A)**

Earth and Clay Floors.

FIGURE 2.12 EARTH AND CLAY FLOORS

Compacted earth and clay were the two main methods of flooring, cooling the ground naturally.

Earth Compacted Floors: Laterite was mixed with water and then compacted using wooden pounders or stone slabs to achieve a smooth and firm surface. According to Okpoko (2001), this dense composition naturally kept the indoor temperatures cool by absorbing heat at a slow rate.

- Cow Dung and Palm Oil Application: Application of cow dung or palm oil provided water resistance and prevented termite infestation and also enhanced the thermal mass of the floor (Baker, 1999).

-Polished Clay Floors: High-status buildings used polished clay with potash or ash, making the surface reflective that reduced heat absorption (Sani, 2012).

B).Palm Kernel Shell and Pebble Flooring.

FIGURE 2.13 PALM KERNEL SHELL AND PEBBLE FLOORING

Use of reinforced floors with palm kernel shells and pebbles in areas experiencing heavy traffic conditions improved their resistance and durability towards maintaining heat: it

- Aesthetic Pebble Floors: The pebble layers on top of the clay floors improved reflectivity of surface due to low absorption of the heat; and that allowed gaps for natural ventilation. Nigerian National Commission for Museums and Monuments, 2005 **C).**

Wooden and Elevated Floors.

The wooden and raised floors were primarily adopted in swampy or flood-prone areas to achieve better ventilation and thermal efficiency.

Wooden Floors on Stilts: A stilted wooden floor prevented the accumulation of moisture, enabled air to pass underneath the structure, and prevented heat gain inside the space (Falola & Adebayo, 2008).

Smoothened Wooden Floors: Smoothened wood flooring was treated with palm oil for insulation against cold and heat oscillations in high-class houses (Ikimi, 1980). **D). Stone and Coral Floors.**

Stone and coral floor usages signified wealth and trading influences with the added benefit of heat resistance.

Stone Slabs: Stone floorings in royal settings had the effect of providing a heat-resistant surface and hence reduced indoor temperature extremities (Jebba, 2010).

- Coral Flooring: Crushed coral obtained through coastal trading produced naturally cool floors, whose porous structure trapped cool air and minimized the absorption of heat (Sani 2012).

Impact of Environment and Culture on Thermal Efficiency

Climate Adaptation: The use of clay and laterite achieved the needed passive cooling, which is very necessary in the tropics of Edo State. (Nwafor, 2016)

Sustainability: The use of local materials reduced environmental degradation so that most of the structures survived long. (Baker, 1999).

- Social Significance: The material of the floor was a show of status, and the high class used polished clay and stone on the floors while compacted earth remained the staple for most rural dwellings. (Ikimi 1980)

Transition to Colonial and Modern Floors.

The colonial influence erased the indigenous techniques of cement, concrete, and ceramic tiles flooring in areas of urbanization. However, to date, the traditional techniques are relevant to optimize thermal envelopes for energy-efficient and ecologically friendly solutions in contemporary architectural design. Smith, 2010.

These raise the floor and provide natural ventilation gaps in both the traditional building designs of Edo and Benin, which agree considerably with the passive cooling principles of today. These could be optimized further by the addition of insulation materials for enhanced thermal performance.

2.2.4 Windows and Doors.

Glazing and air leakage can frequently render the windows and doors the weakest link in the thermal envelope. Some energy-efficient options involve double- or triple-glazed windows with low-emissivity coatings, or argon-filled insulating glass units, to restrict heat gains and losses (Carmody et al., 2004). The correct sealing and insulation of the doors will further provide indoor temperature stability (Lstiburek, 2005).

Pre-Colonial Era: Indigenous Building Techniques

In Edo State, traditional architecture incorporated locally available materials such as wood, clay, bamboo, and palm fronds for constructing windows and doors. These elements were designed for ventilation, security, and cultural expression (Jebba, 2010; Nwafor, 2016). **A). Traditional Window and Door Designs•**

Small Openings for Ventilation: The small, rectangular, or circular openings in old buildings allowed ventilation to take place while reducing heat penetration and improving security Okpoko, 2001).

Timber and Bamboo Frames: The doors were solid timber, but the windows were made from bamboo or raffia palm so as to control the amount of air entering the building for cooling Baker, 1999).

Ornate Carvings: In the royal palaces and the houses of the elite, there were intricately carved wooden doors reflecting social status and artistic heritage (Sani, 2012; Nigerian National Commission for Museums and Monuments, 2005).

Colonial Era: Introduction of European Influence

During the colonial era, new materials and design principles were introduced that gradually replaced indigenous methods (Falola & Adebayo, 2008).

Glass Panes and Metal Frames: Glass for windows became common in elite structures for aesthetics and daylight penetration. This is according to Ikimi 1980.

Louvre Wood Windows: They allowed ventilation with a semblance of privacy and security. According to Jebba, 2010

Mass-produced Doors: The colonial administration promoted mass-produced wooden and metal doors. These eventually replaced traditional handcrafted ones. According to Nwafor 2016. **B) Post-Colonial and Modern Innovations.**

Large expanses of glass for windows and doors have also been introduced with modernity and industrialization within the post-colonial context of Nigeria's gaining independence (Smith, 2010).

i) Aluminum and Steel Frames: The framing in the building replaced wood and gave the advantage of durability, termite resistance amongst other factors (Nigerian National Commission for Museums and Monuments, 2005).

ii) Sliding and Casement Windows: Further functional designs include sliding and casement windows in use (Okpoko, 2001).

FIGURE 2.14 SLIDING AND CASEMENT WINDOW -

Safety doors and reinforcement glasses:

more aware of safety has led to increased application of reinforced steel inputs and frantic glasses for windows, both in the population and commercial structure (Sani , 2012).

current trends: Currently, technology continues to have an impact on contemporary Nigeria building envelopes (Jebba, 2010).

- Energy efficiency window: smoked glass windows and double offer heat reduction and improving internal comfort (Smith, 2010).

smart doors and Windows:biometric safety and remote control are highly required with automated systems. . (Falola and Adebayo, 2008).

In hot and humid climates, an appropriate mark of the window and doors to promote diagonal ventilation, thus reducing mechanical cooling requirements. Large windows and awnings in traditional conceptions to southern Nigeria allows an airflow in a construction space while reducing heat increases.

2.3 Thermal Comfort in Tropical Climates

2.3.1 Definition of Thermal Comfort

Thermal comfort is a fundamental need in the design of buildings and environmental engineering, particularly for regions with extreme climatic conditions such as Edo State, Nigeria. It is that state of mind that expresses satisfaction with the thermal environment. Attainment of thermal comfort is quite vital to the well-being, productivity, and quality of life of the occupants. This perception is a result of both environmental and personal parameters as defined by ASHRAE Standard 55 and other international standards.

Key Factors Influencing Thermal Comfort

There are six key elements that define thermal comfort and are classified into two broad categories, namely, environmental factors and personal factors:

1. Air Temperature:

   i) Air temperature: One of the main parameters that most influences thermal discomfort is constituted by the general temperature that characterizes surrounding air.
   ii) In the region of the tropics, so to say, uncomfortably high temperatures in excess of 30°C are often felt, especially in regions such as Edo State, where poor insulation may have occurred.

It is of paramount importance that, for thermal comfort, air temperature should be maintained within the optimum range of 23°C to 26°C in tropical countries.

2. Radiant Temperature:

Radiant temperature is the temperature of the surfaces in the environment, such as walls, floors, and ceilings.

   i) In buildings with high thermal conductivity materials, like concrete, radiant temperatures can rise substantially by absorbing heat from solar radiation.
   ii) High radiant temperatures can result in discomfort, even when air temperature is within the acceptable range.

3. Air Velocity:

I. Air velocity: It is the speed of the air movement around the occupant. Air velocity is an important factor in the thermal comfort of a person, particularly when it's hot and humid.

II. Good air movement can enhance dissipation of heat and reduce discomfort in naturally ventilated buildings. However, too much air velocity creates drafts and hence discomfort.

- The optimum air velocity for thermal comfort in tropical climates lies between 0.1 m/s and 0.3 m/s.

4. Humidity:

i) Humidity is the amount of moisture in the air. In tropical climates, such as Edo State, the relative humidity mostly exceeds 70%, especially during the rainy season.

ii) High humidity decreases the capacity of the human body to cool itself by evaporation, creating discomfort and a sticky sensation.

- The best range for relative humidity that can offer thermal comfort is between 40% and 60%.

5. Clothing Insulation:

i) The insulation of clothing is an indicator of levels worn. This acts to interrupt the transmission of heat flow from the human body to and from the ambient.

ii) Lightweight and very permeable dressings are widely worn in a tropical climate due to the inability of the dressed-up person to hold much more heat.

Clothing insulation is quantified in clo units, where 1 clo is the insulation from a typical business suit.

6. Metabolic Rate:

Metabolic rate refers to the amount of physical activity of the occupant. It quantifies the amount of heat generated by the body.

i) Higher metabolic rates, such as during physical activity, raise the body's heat production and thus require cooler environments for comfort.

ii) The metabolic rate is usually measured in met units, where 1 met is the amount of heat produced by a seated person at rest.

2.4 Thermal Comfort Models.

Several models have been developed to predict and assess thermal comfort. These include:

1. Predicted Mean Vote (PMV) Model:

Among the most used models for thermal comfort prediction, the PMV model was developed by Fanger (1970). It calculates the average thermal sensation of a group of people along a sevenpoint scale ranging from -3 (cold) to +3 (hot), where 0 means neutral comfort.

- The PMV model covers all six factors affecting thermal comfort, which include air temperature, radiant temperature, air velocity, humidity, clothing insulation, and metabolic rate.

2. Adaptive Comfort Model:

- This model is developed on the basis of ASHRAE Standard 55, following the principle that occupants are able to adapt themselves to their thermal environment through behavioral adjustments such as changing clothes or opening windows.

The adaptive model, thus, will find its particular relevance for naturally ventilated buildings within tropical climates, as the occupants of such areas are usually habituated to high temperature and moisture content in air. This indicates that through acclimatization, the tropical occupants will accept a much higher indoor temperature-as high as 28 degrees Celsius-than people of the temperate climate regions.

2.5 Thermal Comfort in Tropical Climates.

Thermal comfort is very difficult to achieve in tropical climates like Edo State due to the combination of high temperatures, high humidity, and strong solar radiation. Key considerations include:

1. Heat Gain:

- Buildings in tropical climates have a great potential for heat gain through walls, roofs, and windows. This may raise indoor temperatures and make them uncomfortable.

- Materials with low thermal conductivity, such as Agba wood mahogany and fiberglass insulation, will reduce heat gain and give better thermal comfort.

2. Natural Ventilation:

Natural ventilation is one of the important strategies for maintaining thermal comfort in tropical climates. Natural ventilation dissipates heat and decreases humidity levels.

Large windows, open plans in building design further enhance cross-ventilation flow and comfort levels.

3. Shading:

Shading devices such as overhangs, awnings, vegetation, etc. can reduce solar radiation and heat gain in buildings.

Another essential factor of the orientation of buildings, which would contribute to the least amount of heat gain from the sun, relates to the minimum share of east and west orientation for windows. Conclusion.

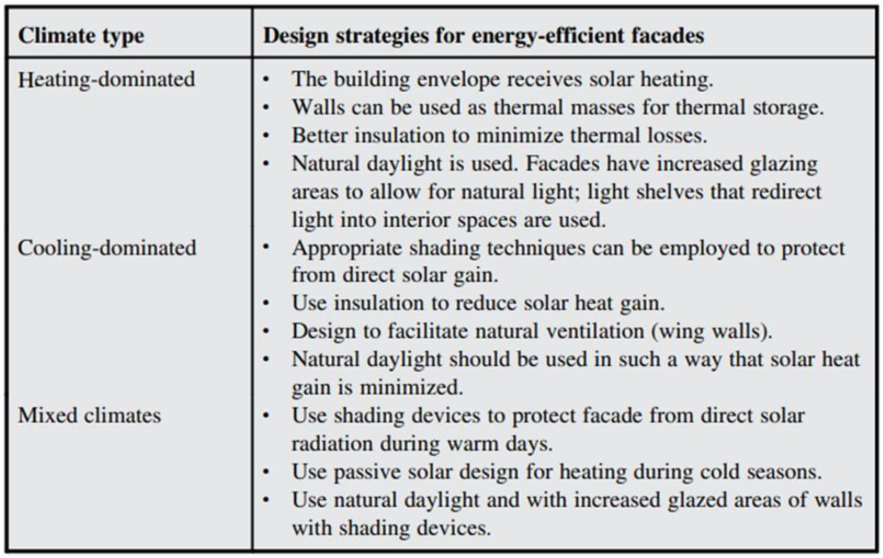
It is a complex and multi-dimensional concept because thermal comfort shall depend on several environmental and personal factors. Therefore, thermal comfort would be achievable only when this tropical climate provides ample consideration of high air temperature, humidity, and solar radiation factors.

It follows that in employing such low-conductivity material, the integration of passive designs for natural ventilation and shading shall be of immense importance in offering indoor comfort coupled with the economy in energy utilization. Understanding the principles of thermal comfort is important in the design of comfortable and energy-efficient buildings within the tropics.

2.6 Increasing thermal resistance of the building envelope.

The simplest method of increasing the thermal resistance of a facade consists of using an increased thickness of insulating material. The method was highly popular, especially in Northern Europe.

This is evidenced by the fact that since the early 1970s, the thickness of insulation in buildings has increased with almost a doubling in Northern Europe, Papadopoulos, 2005. Increasing insulation thickness results in increased energy performance of the building envelope and hence (Energy Services Fundamentals and Financing).



Climate type	Design strategies for energy-efficient facades
Heating-dominated	• The building envelope receives solar heating. • Walls can be used as thermal masses for thermal storage. • Better insulation to minimize thermal losses. • Natural daylight is used. Facades have increased glazing areas to allow for natural light; light shelves that redirect light into interior spaces are used.
Cooling-dominated	• Appropriate shading techniques can be employed to protect from direct solar gain. • Use insulation to reduce solar heat gain. • Design to facilitate natural ventilation (wing walls). • Natural daylight should be used in such a way that solar heat gain is minimized.
Mixed climates	• Use shading devices to protect facade from direct solar radiation during warm days. • Use passive solar design for heating during cold seasons. • Use natural daylight and with increased glazed areas of walls with shading devices.

FIGURE 2.15 ENERGY PERFORMANCE OF BUILDING ENVELOPES

The increased use of insulation leads to the following benefits:

Reduced heat loss and gain, hence reduced heating and cooling demands.

- Improved indoor comfort, with relatively stable indoor temperatures.

- Energy cost reduced due to reduction in the operation of HVACs.

The integration of high-performance insulation materials like aerogels, vacuum insulation panels, and phase change materials can help improve thermal resistance with minimal thickness (Kosny et al., 2014). In tropical regions such as southern Nigeria, the application of insulation materials is limited by the need for natural ventilation. This is quite effective in hybrid solutions that combine insulation with ventilated façades or roofs.

2.7 Climate-Specific Design of Energy-Efficient Envelopes.

The thermal envelope efficiency is a function of the specific climate design strategy adopted. Buildings in hot and humid weather, an example of which is Southern Nigeria, need different envelopes from others that may be located in cold regions. According to Energy Services Fundamentals and Financing, 2019, in climate-responsive envelope designs:

1) Hot and Humid Climates:

The roofs should have heat-reflective roofing material to reduce heat absorption. I.

Large roof overhangs and shading devices to reduce solar heat gain.

Natural ventilation strategies enhance passive cooling.

2) Temperate Climates:

I. Optimized thickness of insulation with regard to balanced seasonal energy efficiency.
II. Double glazing with Low-E coating for thermal control.

3) Cold Climates:

I. High-performance insulation reduces heat loss.
II. Triple-glazed windows to avoid thermal bridging.
III. Airtight construction to avoid cold air infiltration.

This therefore, upon considerations of such design principles, guarantee that the buildings in Edo, and rest of the regions in Nigeria shall be highly energy efficient and indoors comfortable; definitely reducing operational cost.

2.8 Economic and Affordability Issues.

Costs of the imported building materials make them unaffordable to people of low incomes; this calls for a hybrid approach in the integration of traditional materials with modern ones (Ola, 1977). This will bridge the gap between affordability and sustainability with the production of local materials.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Materials

Each composite structure is modeled using SOLIDWORKS software and the steady state thermal analysis is done using ANSYS software.

The first step was selecting the range of materials commonly used in building envelopes. These materials were chosen based on their thermal conductivity. Industry standards and energy efficiency guidelines were also considered to ensure practical relevance.

The temperature transfer through steady state thermal analysis is done between the range of 35°C and 25°C

The proposed materials intended for all composite structures are

I. Dense Hollow Concrete Block
II. Medium Dense Hollow Concrete Block
III. Fiber Glass Insulation
IV. Rock Wool
V. Polystyrene foam
VI. Agba Wood
VII. Mahogany

3.2Simulation and Modeling

To predict how different materials in each composite design affect thermal performance, ANSYS simulation software is used. Various building composites are modeled, and their thermal behavior is analyzed. This helped in identifying materials and design that minimize heat gain since we live in the hot climate region.

Conceptual models will be considered from which the most effective based on real-time cost and thermal behaviors will be selected

3.2.1 Conceptual Models

The method of design approach for each composite structures will be an adaptive design where each proposed structure will be a modification to already existing building structures with improvements.

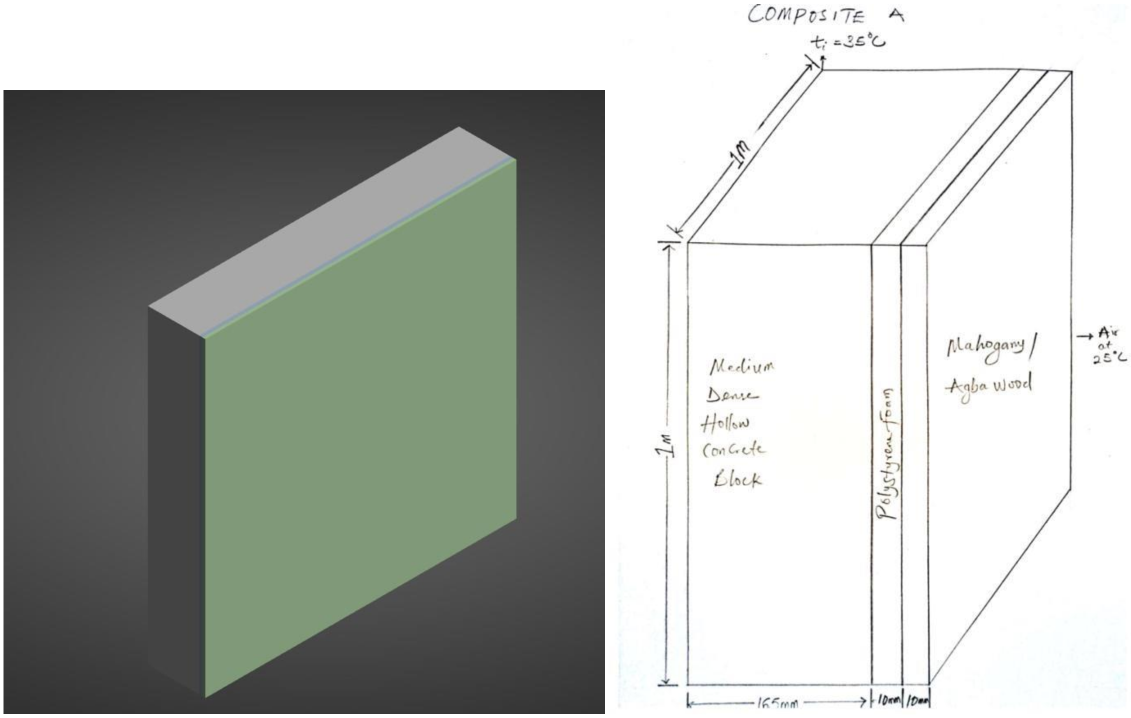


FIGURE 3.1 COMPOSITE A SOLID WORKS MODEL AND DEVELOPED DRAWING IN 3D

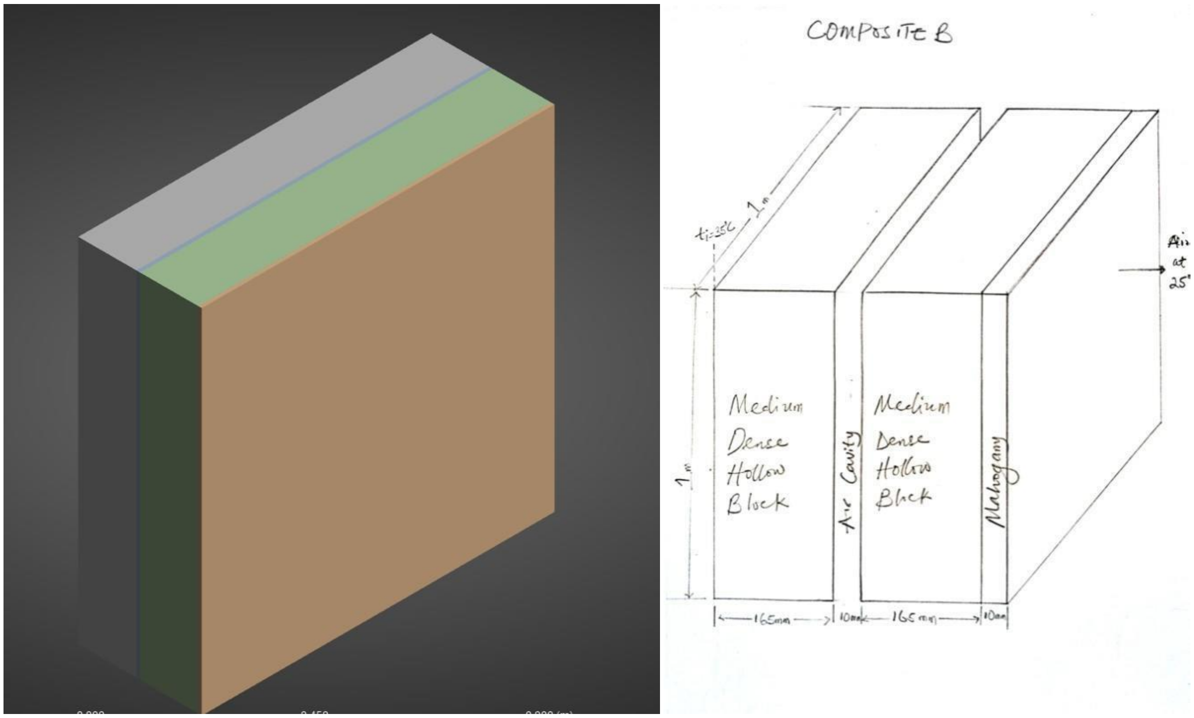


FIGURE 3.2 COMPOSITE B SOLID WORKS MODEL AND DEVELOPED DRAWING IN 3D

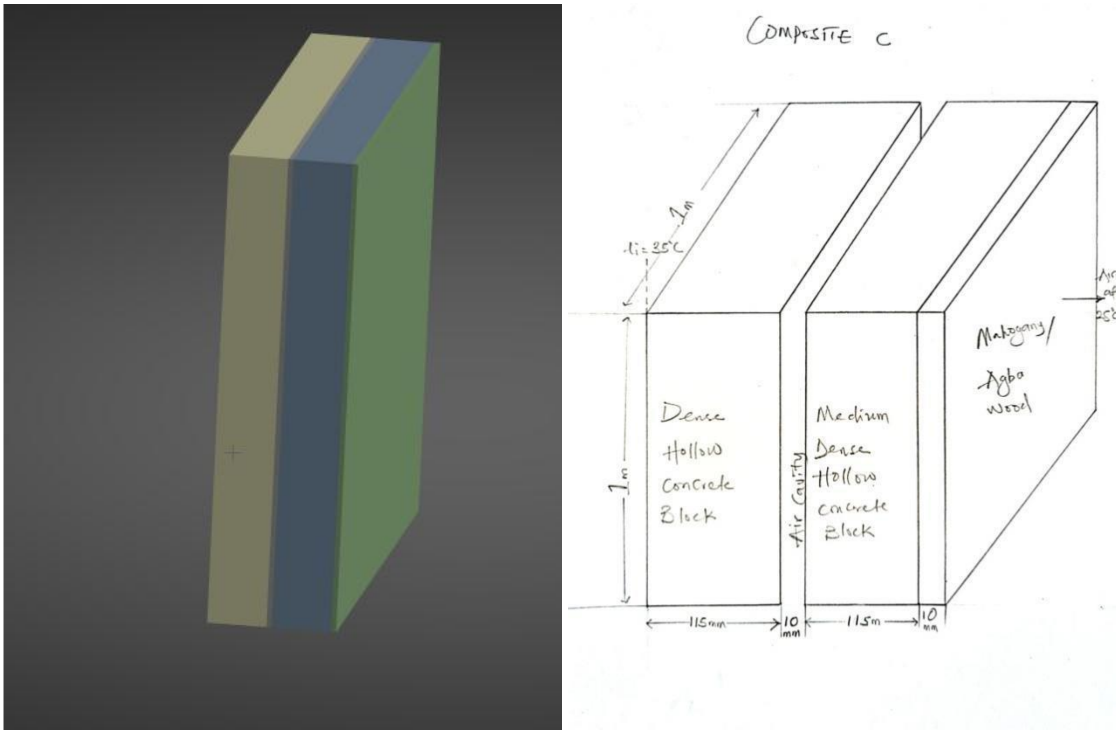


FIGURE 3.3 COMPOSITE C SOLID WORKS MODEL AND DEVELOPED DRAWING IN 3D

Figure 3.1 has three parts that makes up the composite. The first part which is 165mm thick can either be made of Dense Hollow Concrete Block or Medium Hollow Concrete Block. The last two parts are made of insulating materials of size 10mm but with the last material as wood(either Agba wood or Mahogany) to maintain structural integrity.

Figure 3.2 has four parts that makes the composite. The first part is 165mm which will be the hollow block also with the third part. The second and fourth part is made of insulating materials which is 10 mm each, also with the last material being wood

Figure 3.3 also has four parts but the first and third part is reduced to 115mm due to cost of producing the structure in Figure3.2

3.3 Methods

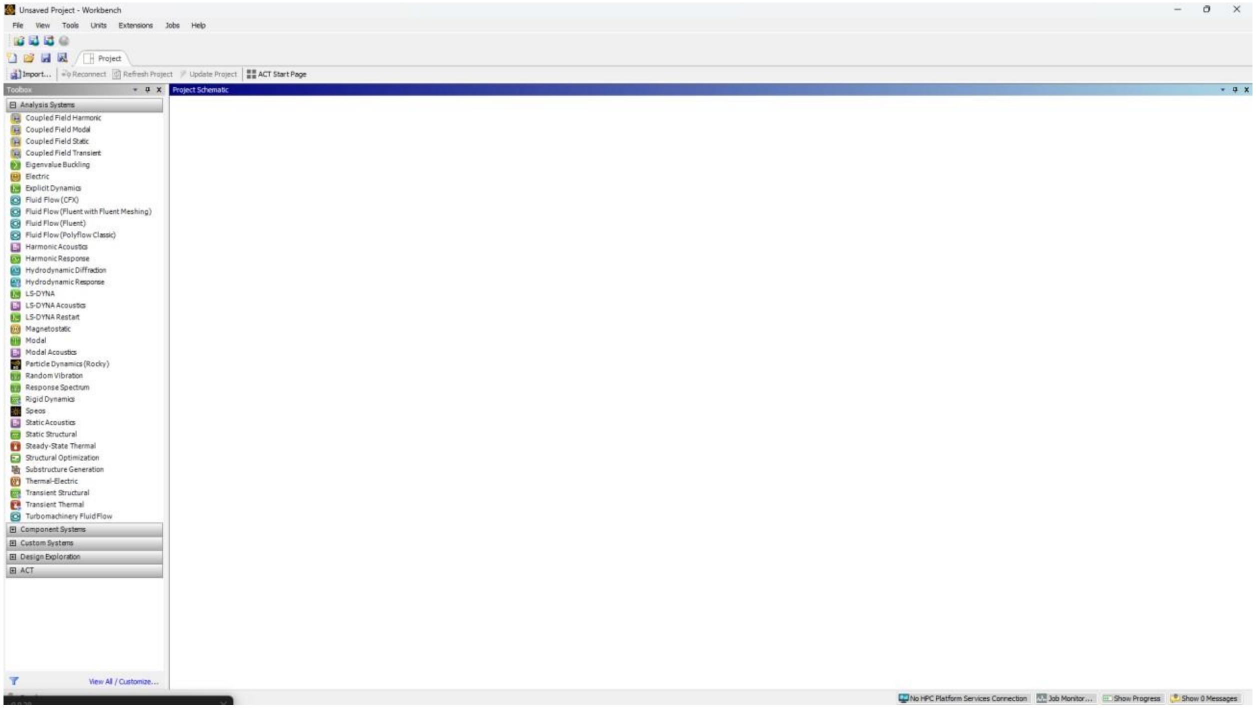
To optimize the thermal properties of each composite structure, the study combines material analysis, modeling, simulation, and data evaluation. This approach ensures a comprehensive understanding of how different materials and design strategies influence heat transfer and energy efficiency.

Below are the steps to which the steady state thermal analysis is carried out using the ANSYS simulation tool

3.3.1 Locate the solver tool

Open the ANSYS project workbench and on the left, the toolbox is displayed

Locate the Steady state thermal tool amongst all solvers and drag to the right display page


Unsaved Project - Workbench
File View Tools Units Extensions Jobs Help
Project
Import... Reconnect Refresh Project Update Project ACT Start Page
Toolbox
Project Schematic
Analysis Systems
Coupled Field Harmonic
Coupled Field Modal
Coupled Field Static
Coupled Field Transient
Eigenvalue Buckling
Electric
Explicit Dynamics
Fluid Flow (CFX)
Fluid Flow (Fluent with Fluent Meshing)
Fluid Flow (Fluent)
Fluid Flow (Polyflow Classic)
Harmonic Acoustics
Harmonic Response
Hydrodynamic Diffraction
Hydrodynamic Response
LS-DYNA
LS-DYNA Acoustics
LS-DYNA Restart
Magnetostatic
Modal
Modal Acoustics
Particle Dynamics (Rocky)
Random Vibration
Response Spectrum
Rigid Dynamics
Speos
Static Acoustics
Static Structural
Steady-State Thermal
Structural Optimization
Substructure Generation
Thermal-Electric
Transient Structural
Transient Thermal
Turbomachinery Fluid Flow
Component Systems
Custom Systems
Design Exploration
ACT
View All / Customize...
No HPC Platform Services Connection
Job Monitor...
Show Progress
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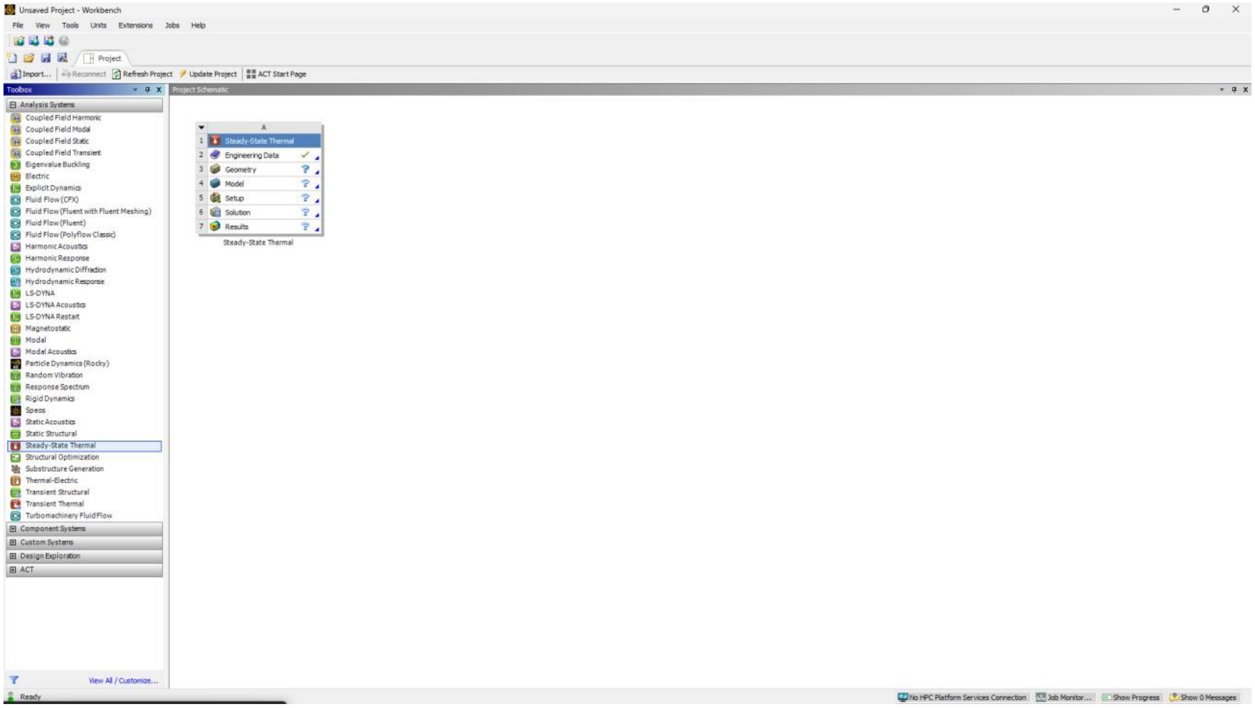
Unsaved Project - Workbench
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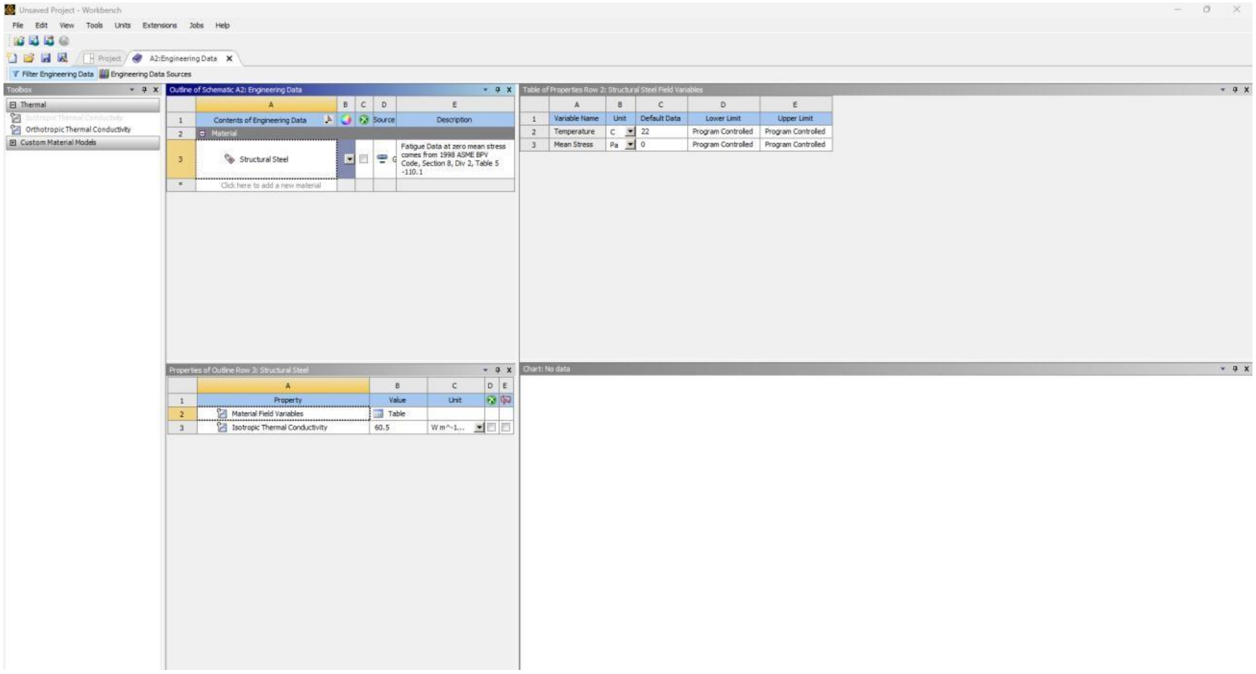
Toolbox
Project Schematic
Analysis Systems
Steady-State Thermal
A
1 Steady-State Thermal
2 Engineering Data
3 Geometry
4 Model
5 Setup
6 Solution
7 Results
Steady-State Thermal
Component Systems
Custom Systems
Design Exploration
ACT
View All / Customize...
Ready
No HPC Platform Services Connection
Job Monitor...
Show Progress
Show 0 Messages

3.3.2 Select the materials

On the displayed solver, locate the **engineering data** and double click to open the list of materials available

Locate the materials needed for the analysis and add to the material library



Outline of Schematic A2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	Material				
3	Structural Steel		☐		Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5 -110.1
*	Click here to add a new material				

Table of Properties Row 2: Structural Steel Field Variables

	A	B	C	D	E
1	Variable Name	Unit	Default Data	Lower Limit	Upper Limit
2	Temperature	C	22	Program Controlled	Program Controlled
3	Mean Stress	Pa	0	Program Controlled	Program Controlled

Properties of Outline Row 3: Structural Steel

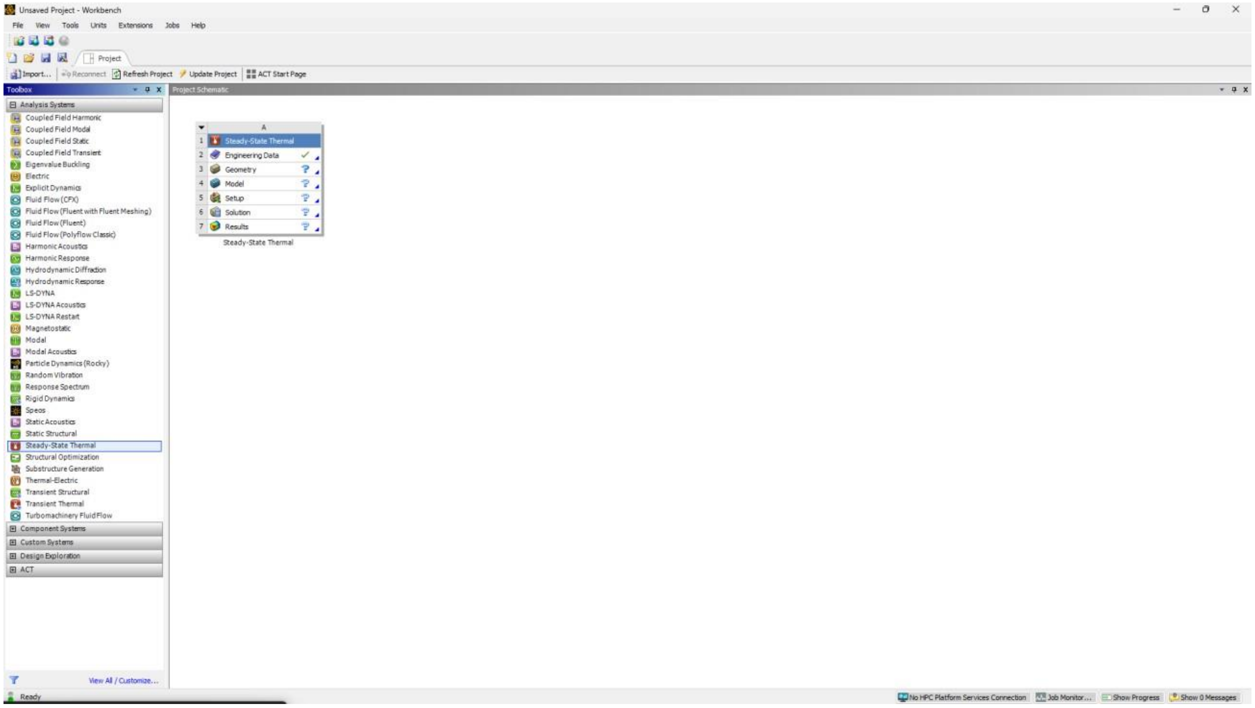
	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Isotropic Thermal Conductivity	60.5	W m^-1...	☐	☐

OR

Click on the **add materials** and add the materials manually and its respected properties

3.3.3 Select the Model/Design

Click on **geometry** and navigate to the solid work design file path and click on **select** to import the solid work or CAD design model to the ANSYS workbench



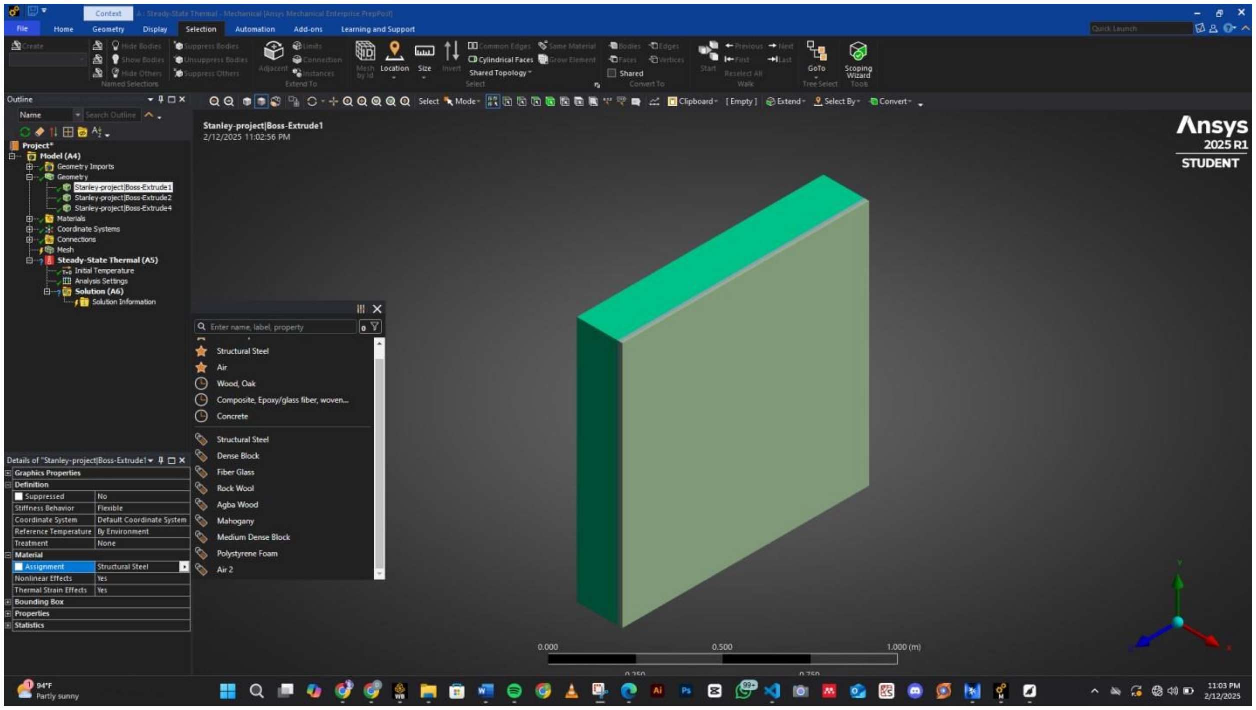
3.3.4 Select the Materials

Double click on **model** and the ansys mechanical page opens

On the left side, the mechanical model tree opens up

Click on **geometry** to open each part of the model design

Click on each part and assign a material suitable for the analysis

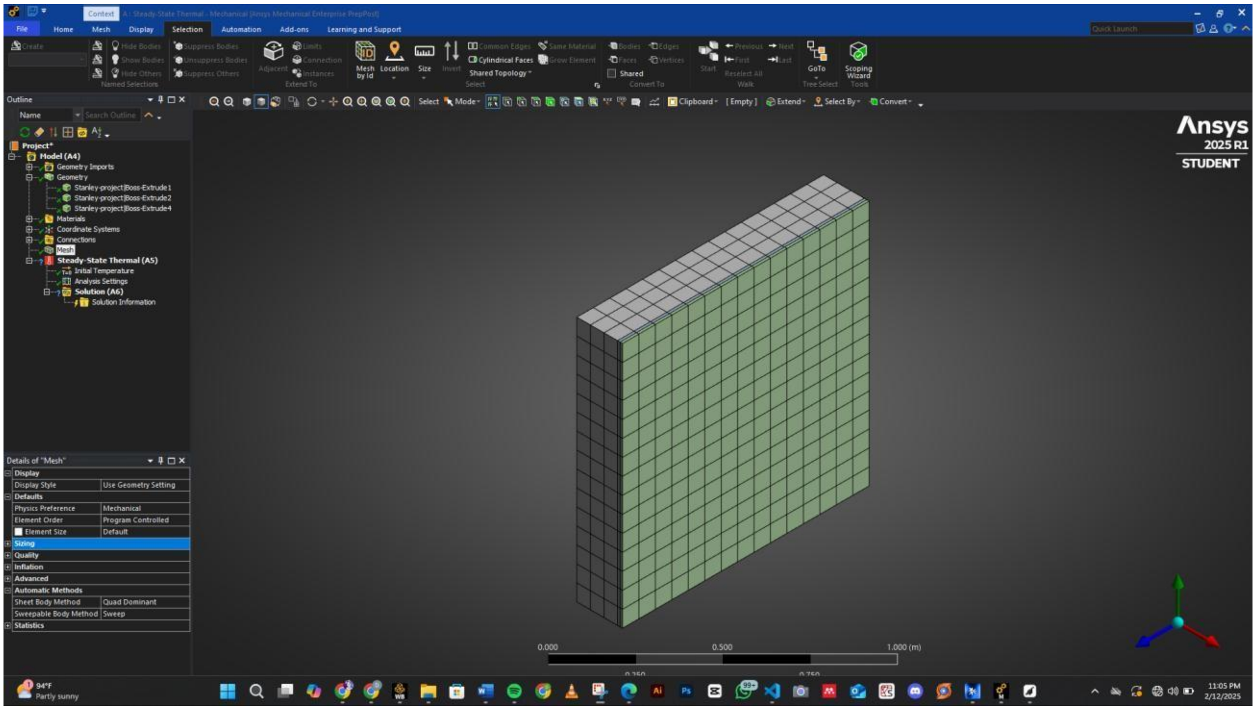


Details of "Stanley-project|Boss-Extrude1"

Suppressed	No
Stiffness Behavior	Flexible
Coordinate System	Default Coordinate System
Reference Temperature	By Environment
Treatment	None
Assignment	Structural Steel
Nonlinear Effects	Yes
Thermal Strain Effects	Yes

3.3.5 Generate Mesh

Right click on **mesh** and click on **generate mesh**



Details of "Mesh"

Display Style	Use Geometry Setting
Physics Preference	Mechanical
Element Order	Program Controlled
Element Size	Default
Sheet Body Method	Quad Dominant
Sweepable Body Method	Sweep

3.3.6 Boundaries/Constraints

After generating mesh, right click on **steady state thermal (A5)**

Select **insert**

Select **temperature**

Click on the surface to apply the temperature and click on **apply**

Insert the temperatures on the surfaces we're constraining

3.3.7 Generating the solution

After inputting the boundaries/constraints, we right click on **solution**

Click on **solve**

Then the result will be generated

3.4 Governing Equations of Heat Transfer

Heat transfer is the procepess by which thermal energy moves between systems due to temperature differences. It occurs through three primary modes which are **conduction, convection and radiation**.

In the context of optimizing the thermal properties of building envelopes, we will focus mainly on **conduction** and **convection** as the composites are all solid materials and the ambient environment is made of fluids (air)

Following fundamental laws, the equation governing heat transfer through the mode of conduction include

i. First Law of Thermodynamics (Energy Conversation in Conduction)
ii. Second Law of Thermodynamics (Direction of Heat Flow in Conduction)
iii. Fourier's Law of Heat Conduction
iv. Newton's Law of Cooling

The **First Law of Thermodynamics**, or the principle of energy conservation, states that the rate of change of internal energy within a control volume must equal the net heat conduction into the volume plus any internal heat generation.

For a differential control volume in a solid, the energy balance equation is:

$$\frac{\partial}{\partial t}(\rho c_p T) = \nabla \cdot (k\nabla T) + q^{\cdot}$$

where:

ρ is the material density $\left(\frac{kg}{m^3}\right)$,

c_p is the specific heat capacity at constant pressure $\left(\frac{J}{kg} \cdot K\right)$,

T is the temperature field (K),

k is the thermal conductivity $(W/m \cdot K)$,

$q^{\cdot}$ is the internal heat generation per unit volume $\left(\frac{W}{m^3}\right)$.

This equation forms the basis of the general heat conduction equation, which describes how temperature evolves within a solid over time.

The **Second Law of Thermodynamics** states that heat flows spontaneously from regions of higher temperature to regions of lower temperature, ensuring that thermal energy moves in a well-defined direction. This concept is implicit in Fourier's Law, where the negative sign ensures that heat flows **down the temperature gradient**.

In mathematical terms, entropy generation due to heat conduction is given by:

$$\sigma = \frac{k}{T^2}(\nabla T \cdot \nabla T) \geq 0$$

where σ represents entropy generation. This equation ensures that conduction is an **irreversible process**, meaning thermal equilibrium is achieved when temperature gradients vanish.

Fourier's Law provides the fundamental relationship between heat flux and temperature gradient in conduction. It states that the heat flux (q) is proportional to the negative of the temperature gradient:

$$q = -k\nabla T$$

where

q is the heat flux vector $\left(\frac{W}{m^2}\right)$ k is the thermal conductivity $\left(\frac{W}{m} \cdot K\right)$,

∇T is the temperature gradient $\left(\frac{K}{m}\right)$.

This law forms the basis of all conduction-related heat transfer equations.

For **one-dimensional steady-state conduction**, Fourier's Law simplifies to:

$$q = -k\frac{dT}{dx}$$

Where q is the heat transfer rate per unit area.

Newton's Law of Cooling describes the convective heat transfer, where heat is transferred between a surface and a moving fluid:

$$q = h(Ts - T\infty)$$

where:

q is the convective heat flux,

h is the convective heat transfer coefficient,

Ts is the surface temperature,

$T\infty$ is the ambient fluid temperature.

For a **composite wall** with multiple layers, the total thermal resistance approach is used:

$$q = \frac{T1 - T2}{\sum Rthermal}$$

where thermal resistance for a layer of thickness L is:

$$R = \frac{k}{LA}$$

This analogy is useful in **thermal insulation design** for building envelopes.

Table 3.1. Properties of the materials used for Steady State Thermal Analysis

Name	**Properties**
Dense Hollow Concrete Block	Thermal Conductivity: 1.4W/mK Specific heat: 1000J/kgK
Medium Dense Hollow Concrete Block	Thermal Conductivity: 0.5 W/mK Specific heat: 1000J/kgK
Fiber Glass Insulation	Thermal Conductivity: 0.04 W/mK Specific heat: 900J/kgK
Rock Wool	Thermal Conductivity: 0.037 W/mK

	Specific heat: 900$J\ /kgK$
Polystyrene Foam	Thermal Conductivity: 0.033W/mK Specific heat:1131J/kgK
Agba Wood	Thermal Conductivity: 0.08 W/mK Specific heat: 1550 J/kgK
Mahogany	Thermal Conductivity: 0.10 W/mK Specific heat: 1561 J/kgK
Air	Thermal conductivity: 0.04 W/mK Convective Heat Transfer coefficient: 25 W/m^2K

3.5 Theoretical Analysis of Each Composite Modification

For Figure3.1, we will calculate the **heat flux** for different composite wall modification using steady-state heat conduction.

Since heat flows through the three materials in series, the total thermal resistance is the sum of the individual resistances:

i.e $\mathrm{R_{total}} = \mathrm{R_1} + \mathrm{R_2} + \mathrm{R_3}$

where the resistance of each layer is given by:

$$\mathrm{R} = \frac{\mathrm{k}}{\mathrm{L}}$$

Using **Fourier's Law**, the heat flux is:

$$q = \frac{T_1 - T_2}{R_{total}}$$

where:

Hot side temperature: T_1=35∘C

Cold side temperature: T_2=25∘C

Layer thicknesses:

First material: L_1=0.165m

Second material: L_2=0.010m

Third material: L_3=0.010m

Case 1,

Dense Hollow Concrete Block + Fiber Glass Insulation + Agba Wood

First layer (Dense Hollow Concrete Block):k_1 = 1.4 W/m·K

Second layer (Fiber Glass Insulation): k_2 = 0.04 W/m·K

Third layer (Agba Wood):k_3 = 0.08 W/m·K

$$\mathrm{R}_1 = \frac{k_1}{L_1} = \frac{1.4}{0.165} = 0.11786\ \mathrm{m}^2 \cdot \frac{\mathrm{K}}{\mathrm{W}}$$

$$\mathrm{R}_2 = \frac{k_2}{L_2} = \frac{0.04}{0.010} = 0.2500\ \mathrm{m}^2 \cdot \frac{\mathrm{K}}{\mathrm{W}}$$

$$\mathrm{R}_3 = \frac{k_3}{L_3} = \frac{0.08}{0.010} = 0.1250\ \mathrm{m}^2 \cdot \frac{\mathrm{K}}{\mathrm{W}}$$

$$\mathrm{R}_{\mathbf{total}} = 0.11786 + 0.2500 + 0.1250 = 0.49286\ \mathrm{m}^2 \cdot \frac{\mathrm{K}}{\mathrm{W}}$$

$$\mathrm{q} = \frac{35 - 25}{0.49286}$$

$$\mathrm{q} = 20.29\ \mathrm{W/m^2}$$

Case 2,

Dense Hollow Concrete Block + Fiber Glass Insulation + Mahogany,

the total resistance is:

$$\mathrm{R}_{\mathbf{total}} = 0.11786 + 0.2500 + 0.1000 = 0.46786\ \mathrm{m}^2.\mathrm{K/W}$$

$$\mathrm{q} = \frac{10}{0.46786} = 21.37\mathrm{W/m^2}$$

Case 3,

For **Dense Hollow Concrete Block + Rock Wool + Agba Wood**,

the total resistance is:

$$\mathrm{R}_{\mathbf{total}} = 0.11786 + 0.2703 + 0.1250 = 0.51316\ \mathrm{m}^2.\mathrm{K/W}$$

$$\mathrm{q} = \frac{10}{0.51316} = 19.49\mathrm{W/m^2}$$

Case 3,

For **Dense Hollow Concrete Block + Rock Wool + Mahogany**,

the total resistance is:

$$\mathrm{R_{total}} = 0.11786 + 0.2703 + 0.1000 = 0.48816\ \mathrm{m^2.K/W}$$

$$\mathrm{q} = \frac{10}{0.48816} = 20.49\mathrm{W/m^2}$$

Case 4,

For **Dense Hollow Concrete Block + Polystyrene Foam + Agba Wood**,

the total resistance is

$$\mathrm{R_{total}} = 0.11786 + 0.3333 + 0.1250 = 0.5761\ \mathrm{m^2.K/W}$$

$$\mathrm{q} = \frac{10}{0.57619} = 17.36\mathrm{W/m^2}$$

Case 5,

For **Dense Hollow Concrete Block + Polystyrene Foam + Mahogany**,

the total resistance is:

$$\mathrm{R_{total}} = 0.11786 + 0.3333 + 0.1000 = 0.5511\ \mathrm{m^2.K/W}$$

$$\mathrm{q} = \frac{10}{0.55119} = 18.14\ \mathrm{W/m^2}$$

Case 6,

For **Medium Dense Hollow Concrete Block + Fiber Glass Insulation + Agba Wood**, the total resistance is:

$$R_{total} = 0.33000 + 0.2500 + 0.1250 = 0.7050\ m^2.K/W$$

$$q = \frac{10}{0.70500} = 14.18\ W/m^2$$

Case 7,

For **Medium Dense Hollow Concrete Block + Fiber Glass Insulation + Mahogany**,

the total resistance is:

$$R_{total} = 0.33000 + 0.2500 + 0.1000 = 0.68000\ m^2.K/W$$

$$q = \frac{10}{0.68000} = 14.71W/m^2$$

Case 8,

For **Medium Dense Hollow Concrete Block + Rock Wool + Agba Wood**,

the total resistance is:

$$R_{total} = 0.33000 + 0.2703 + 0.1250 = 0.7253\ m^2.K/W$$

$$q = \frac{10}{0.72530} = 13.79\ W/m^2$$

Case 9,

For **Medium Dense Hollow Concrete Block + Rock Wool + Mahogany**,

the total resistance is:

$$R_{total} = 0.33000 + 0.2703 + 0.1000 = 0.7003\ m^2.K/W$$

$$q = \frac{10}{0.70030} = 14.28 W/m^2$$

Case 9,

For **Medium Dense Hollow Concrete Block + Polystyrene Foam + Agba Wood**,

the total resistance is:

$$R_{total} = 0.33000 + 0.3333 + 0.1250 = 0.78833\ m^2.K/W$$

$$q = \frac{10}{0.78833} = 12.68 W/m^2$$

Case 10,

For **Medium Dense Hollow Concrete Block + Polystyrene Foam + Mahogany**,

the total resistance is:

$$R_{total} = 0.33000 + 0.3333 + 0.1000 = 0.76333\ m^2.K/W$$

$$q = \frac{10}{0.76333} = 13.10 W/m^2$$

For Figure 3.2, same principle apply but layer thickness and number of layers changes

First layer: 165 mm = 0.165 m
Second layer: 10 mm = 0.01 m
Third layer: 165 mm = 0.165 m
Fourth layer: 10 mm = 0.01 m

We will be running only two cases with two material modifications with the lowest thermal conductivity

Case 1,

Medium Dense Hollow Concrete Block + Polystyrene Foam + Medium Dense Hollow Concrete Block + Mahogany

$$\mathrm{R_{total}} = 0.33 + 0.333 + 0.33 + 0.1 + 0.04 = 1.133\mathrm{m^2.K/W}$$

$$\mathrm{q} = \frac{35 - 25}{1.133} = 8.82\ \mathrm{W/m^2}$$

Case 2,

Medium Dense Hollow Concrete Block + Air Cavity + Medium Dense Hollow Concrete Block + Mahogany

$$\mathrm{R_{total}} = 0.33 + 0.25 + 0.33 + 0.1 + 0.04 = 1.05\ \mathrm{m^2.K/W}$$

$$\mathrm{q} = \frac{35 - 25}{1.05} = 9.52\ \mathrm{W/m^2}$$

For Figure 3.3, we follow same principles

First Layer: 0.115m (Dense Hollow Concrete Block)

Second Layer: 0.010m (Insulation: Fiber Glass, Rock Wool, Polystyrene Foam, or Air Cavity)

Third Layer: 0.115m (Dense Hollow Concrete Block)

Fourth Layer: 0.010m (Wood: Agba Wood or Mahogany)

Resistance of Fixed Layers

$R_1 = \frac{0.115}{1.4}$ = 0.0821 m²·K/W (Dense Hollow Concrete Block)

$R_3 = \frac{0.115}{1.4}$ = 0.0821 m²·K/W (Dense Hollow Concrete Block)

$R_{conv} = \frac{1}{25}$= 0.04 m²·K/W

Case 1: Fiber Glass Insulation + Agba Wood

$R_2 = \frac{0.010}{0.04}$ = 0.25 m²·K/W

$R_4 = \frac{0.010}{0.08} = 0.125$ m²·K/W

$\text{Total Resistance} = 0.0821 + 0.25 + 0.0821 + 0.125 + 0.04 = 0.5792\ \text{m}^2 \cdot \text{K/W}$

Heat Flux q = $\frac{35-25}{0.5792} = 17.27$ W/m²

Case 2: Fiber Glass Insulation + Mahogany

$R_4 = \frac{0.010}{0.1}$ = 0.1 m²·K/W

$Total\ Resistance = 0.0821 + 0.25 + 0.0821 + 0.1 + 0.04$ = 0.5542 m²·K/W

Heat Flux q = $\frac{35-25}{0.5542}$ = 18.05 W/m²

Case 3: Rock Wool + Agba Wood

$R_2 = \frac{0.010}{0.037} = 0.2703$ m²·K/W

R_4 = 0.125 m²·K/W

Total Resistance = $0.0821 + 0.2703 + 0.0821 + 0.125 + 0.04$ = 0.5995 m²·K/W

Heat Flux q $= \frac{35-25}{0.5995} = 16.68$ W/m²

Case 4: Rock Wool + Mahogany

R_4 = 0.1 m²·K/W

Total Resistance = $0.0821 + 0.2703 + 0.0821 + 0.1 + 0.04$ = 0.5745 m²·K/W

Heat Flux q = $\frac{35-25}{0.5745} = 17.41$ W/m²

Case 5: Polystyrene Foam + Agba Wood

$R_2 = \frac{0.010}{0.03} = 0.3333$ m²·K/W

$R_4 = 0.125$ m²·K/W

Total Resistance = $0.0821 + 0.3333 + 0.0821 + 0.125 + 0.04$ = 0.6625 m²·K/W

Heat Flux q $= \frac{35-25}{0.6625} = 15.09$ W/m²

Case 6: Air Cavity + Agba Wood

$R_2 = \frac{0.010}{0.04} = 0.25$ m²·K/W

$R_4 = 0.125$ m²·K/W

Total Resistance = 0.5792 m²·K/W

Heat Flux q = 17.27 W/m²

Case 7: Polystyrene foam + Mahogany

$R_2 = \frac{0.010}{0.033} = 0.30$ m²·K/W

$R_4 = \frac{0.010}{0.1} = 0.1$ m²·K/W

Total Resistance = 0.7552 m²·K/W

Heat Flux q = 13.24 W/m²

Case 9: Air Cavity + Mahogany

$R_2 = \frac{0.010}{0.04} = 0.25$ m²·K/W

$R_4 = \frac{0.010}{0.1}$ = 0.1 m²·K/W

Total Resistance = 1.992 m²·K/W

Heat Flux q = 5.02 W/m²

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

In this study, both theoretical calculations and numerical simulations were carried out to analyze heat transfer through different composite wall configurations. The goal was to evaluate how various material combinations influence the thermal performance of building envelopes.

1. Theoretical Analysis

The heat transfer through the composite walls was analyzed using steady-state thermal equations. The total thermal resistance of each configuration was calculated by summing up the resistances of individual layers, while the convective heat transfer at the inner surface was also considered. The heat flux for each wall configuration was determined based on the applied temperature difference. Different insulation materials were tested to examine their effect on reducing heat transfer through the structure.

2. ANSYS Simulation

To complement the theoretical calculations, a numerical analysis was conducted using ANSYS. The simulation provided a detailed visualization of temperature distribution and heat flux across the composite walls. The results were used to compare and validate the theoretical predictions. By analyzing the heat flow patterns and thermal gradients, the impact of each material combination was assessed, highlighting the effectiveness of different insulation materials in improving thermal resistance.

By combining both approaches, this analysis provides a well-rounded evaluation of the thermal performance of building envelopes, ensuring both accuracy and practical relevance.

4.1 RESULTS

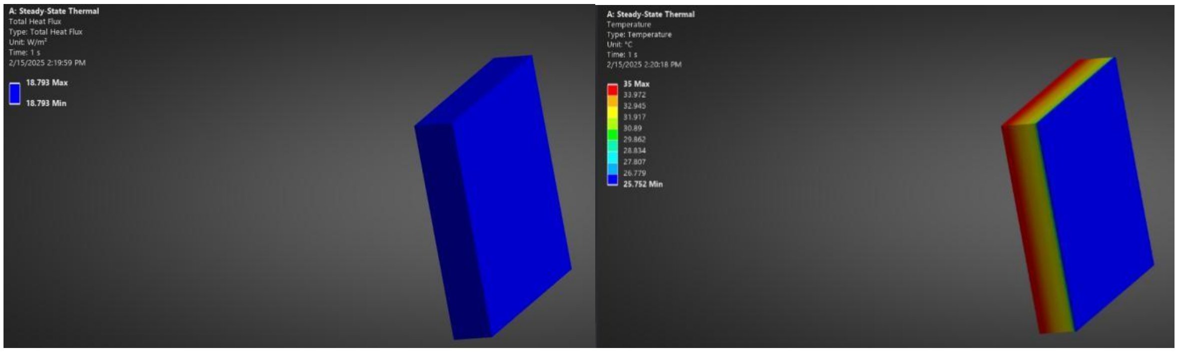


FIGURE 4.1 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + FIBER GLASS INSULATION + AGBA WOOD Theoretical

Heat Flux: 18.793 W/m^2

ANSYS Simulated Heat Flux: 20.29 W/m^2

Difference: 1.497 W/m^2 (7.38% deviation)

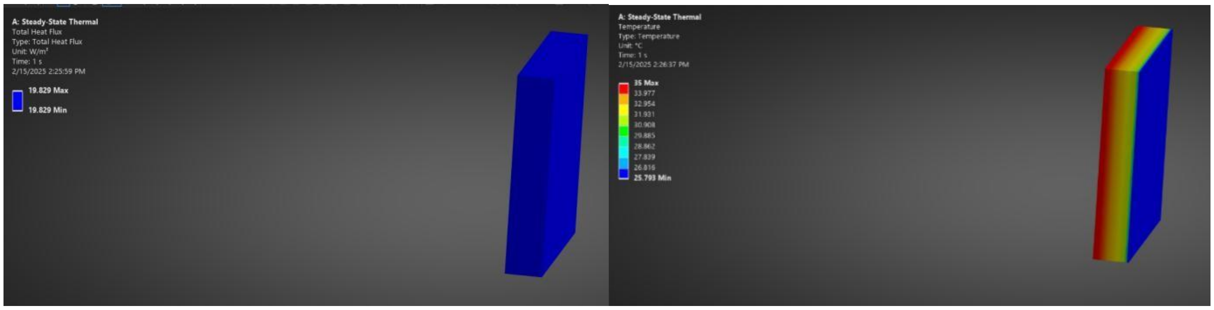


FIGURE 4.2 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + ROCK WOOL + AGBA WOOD

Figure 4.2 represents Dense Hollow Concrete Block + Rock wool + Agba Wood

Theoretical Heat Flux: 19.29 W/m^2

ANSYS Simulated Heat Flux: 19.829 W/m^2

Difference: 0.001 W/m^2 (0.1% deviation)

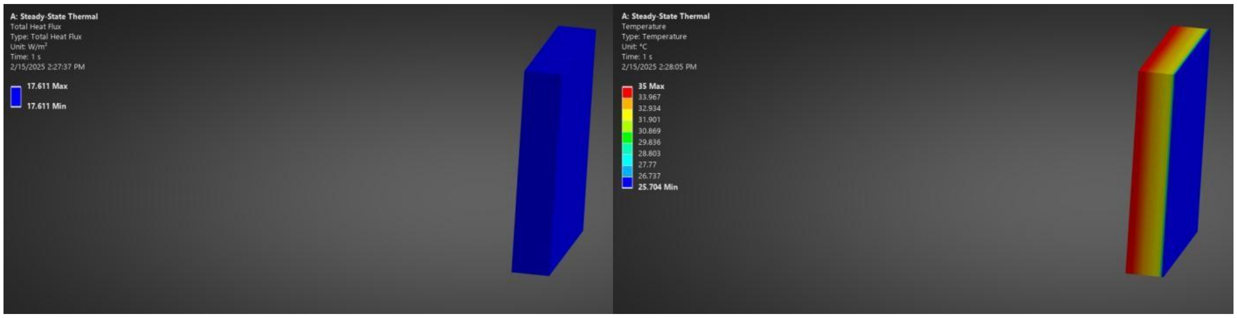


Figure 4.3 ANSYS results for Dense Hollow Concrete Block + Polystyrene Foam + Agba Wood

Theoretical Heat Flux: 17.36 W/m²

ANSYS Simulated Heat Flux: 17.61 W/m²

Difference: 0.25 W/m² (1.44% deviation)

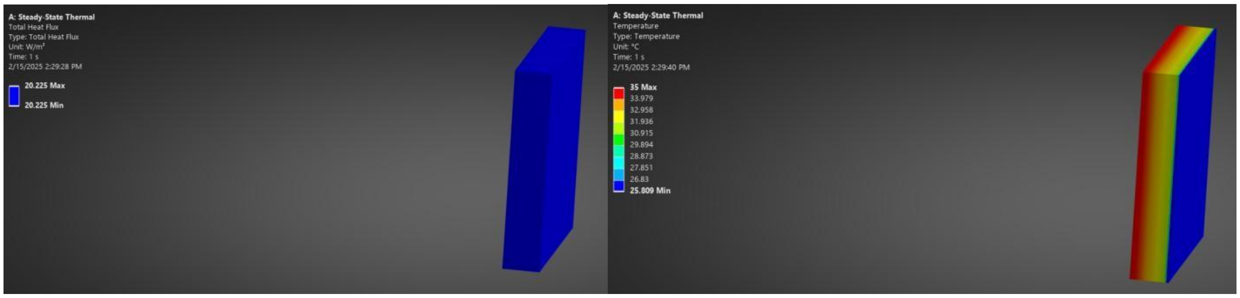


Figure 4.4 ANSYS results for Dense Hollow Concrete Block + Fiber Glass Insulation + Mahogany

Theoretical heat flux: 21.37 W/m²

ANSYS heat flux: 20.225 W/m²

Difference: 1.145 W/m² (5.4% deviation)

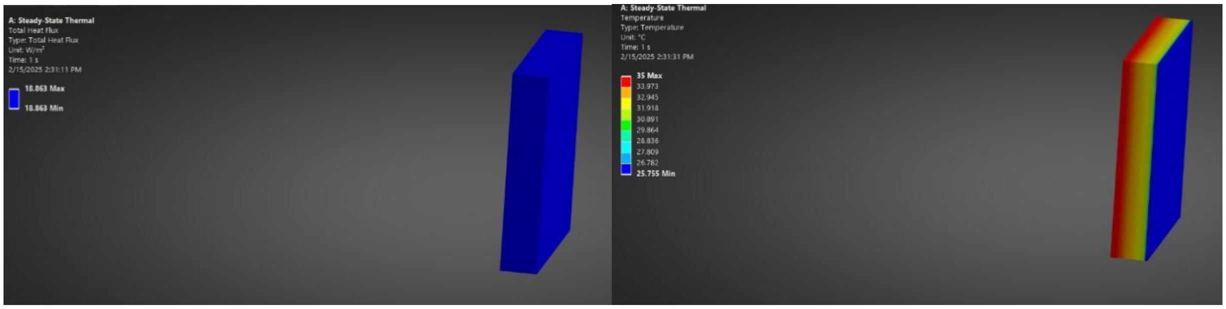


Figure 4.5 ANSYS results for Dense Hollow Concrete Block + Polystyrene Foam + Mahogany

Theoretical Heat Flux: 18.14 W/m²

ANSYS heat flux; 18.863 W/m²

Difference: 0.723 W/m² (3.99% deviation)

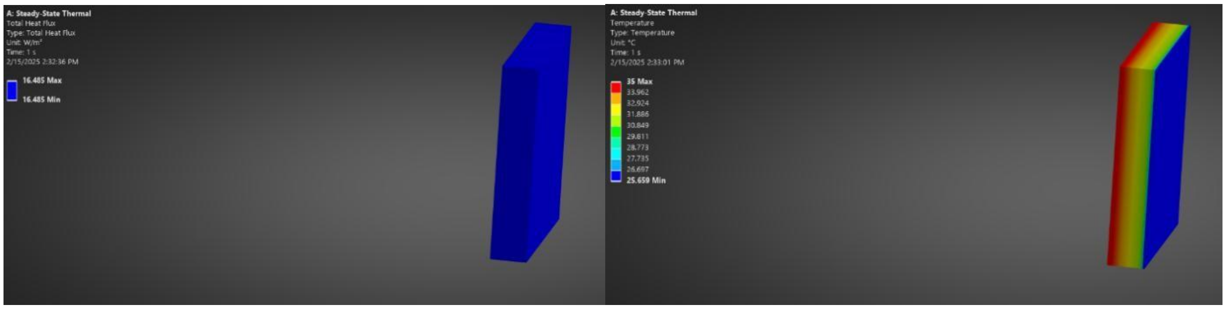


FIGURE 4.6 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + FIBER GLASS INSULATION + AGBA WOOD

Theoretical Heat Flux: 14.18 W/m²

ANSYS heat flux; 16.485 W/m²

Difference: : 2.305 W/m² (16.26% deviation)

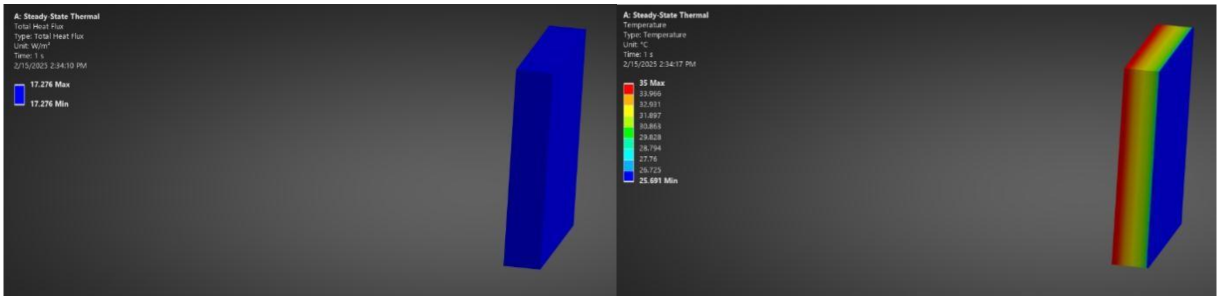


FIGURE 4.7 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + ROCK WOOL + AGBA WOOD

Theoretical Heat Flux: 13.79 W/m²

ANSYS heat flux; 17.276 W/m²

Difference: 3.486 W/m² (25.28% deviation)

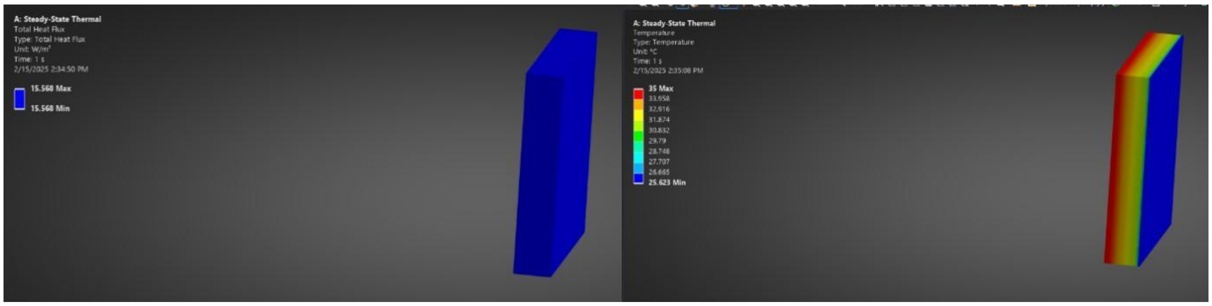


Figure 4.8 ANSYS results for Dense Hollow Concrete Block + Polystyrene Foam + Agba Wood

Theoretical Heat Flux: 12.68 W/m²

ANSYS heat flux; 15.568 W/m²

Difference: 2.888 W/m² (22.78% deviation)

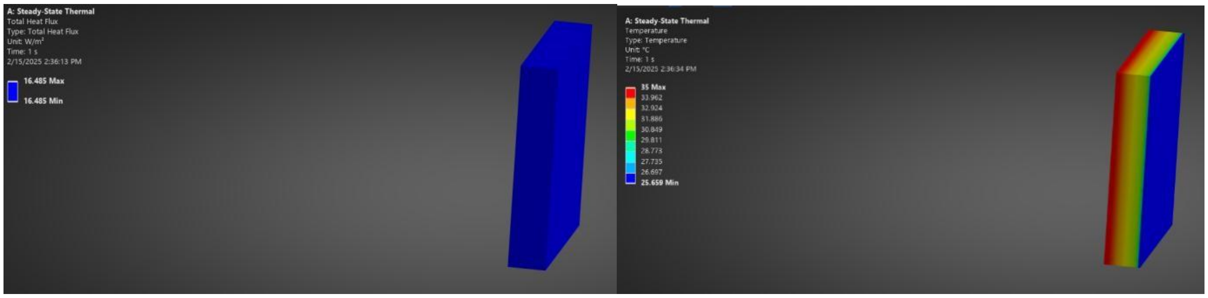


Figure 4.9 ANSYS results for Dense Hollow Concrete Block + Fiber Glass Insulation + Mahogany

Theoretical Heat Flux: 14.71 W/m²

ANSYS heat flux; 16.485 W/m²

Difference: 1.7775 W/m² (12.07% deviation)

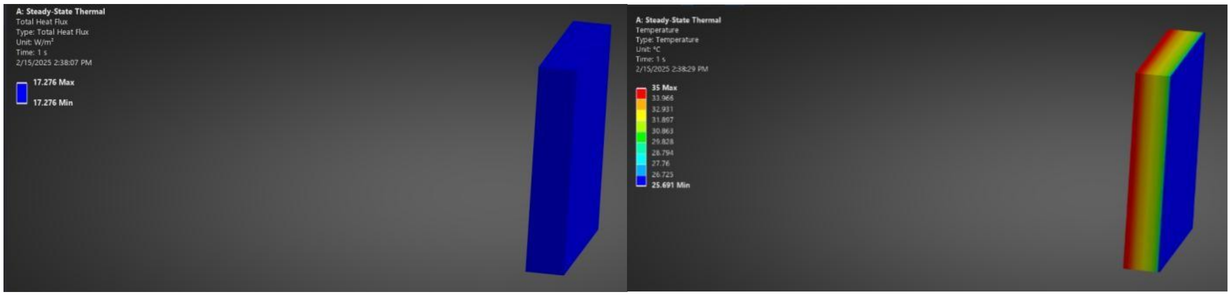


Figure 4.10 ANSYS results for Dense Hollow Concrete Block + Rock wool + Mahogany

Theoretical Heat Flux: 14.28 W/m²

ANSYS heat flux; 17.276 W/m²

Difference: 2.996 W/m² (20.98% deviation)

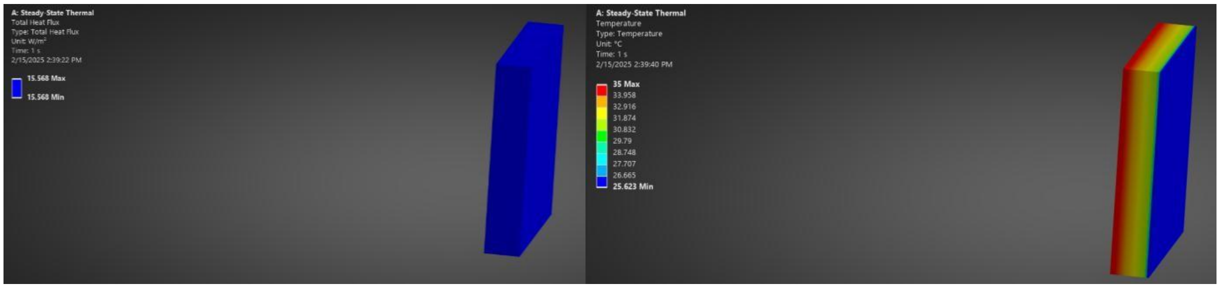


FIGURE 4.11 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + POLYSTYRENE FOAM + MAHOGANY

Theoretical Heat Flux: 13.10 W/m²

ANSYS heat flux; 15.568 W/m²

Difference: 2.468 W/m² (13.84% deviation)

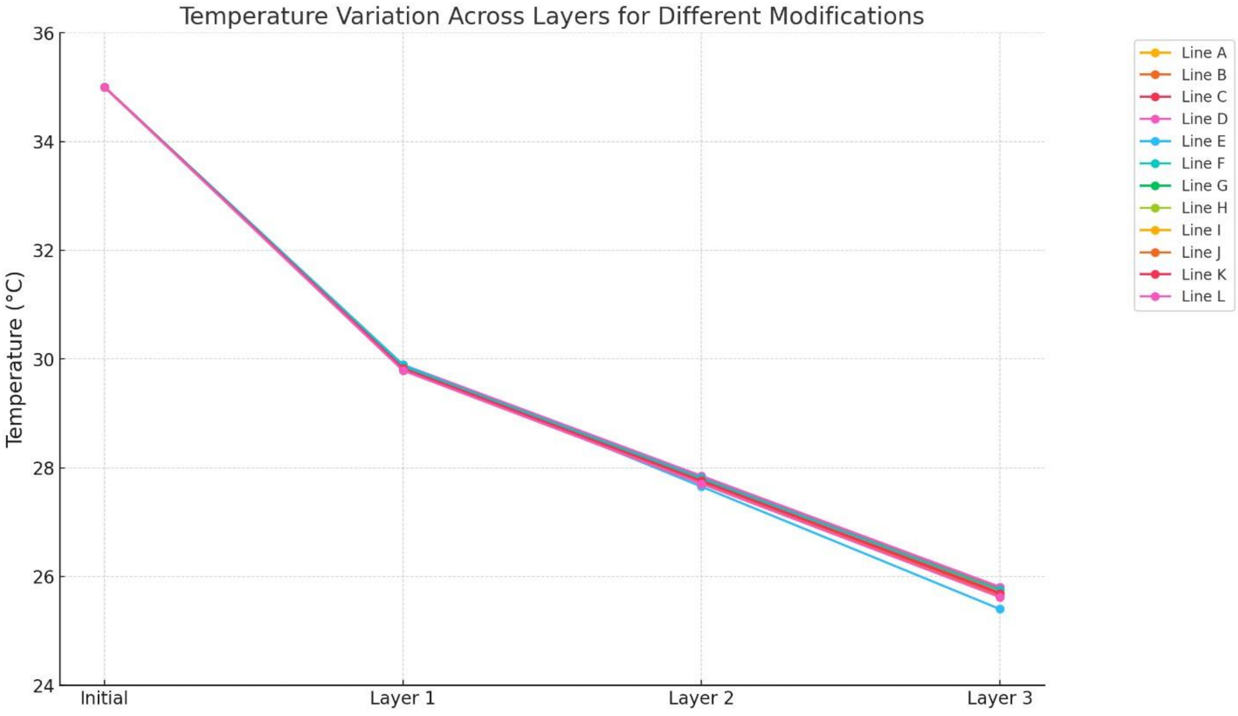


FIGURE 4.12 GRAPH OF TEMPERATURE GRADIENT ACROSS DIFFERENT LAYERS FOR FIGURE 3.1 MODIFICATIONS

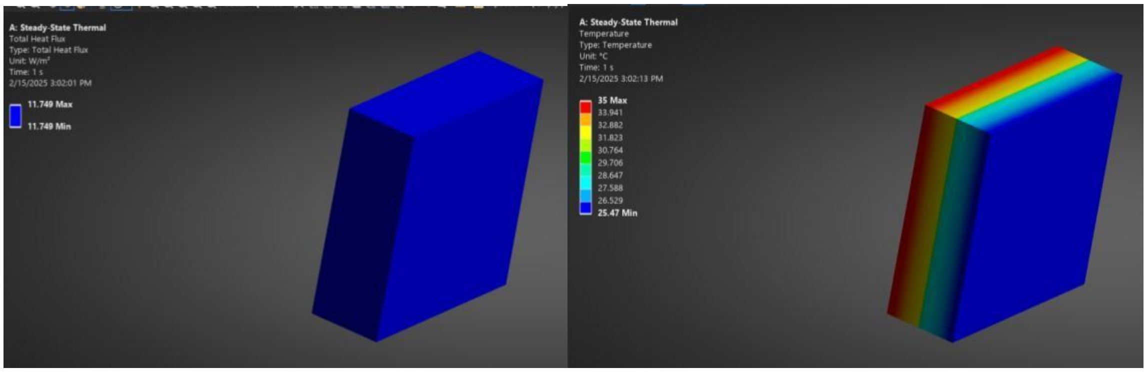


FIGURE 4.13 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + POLYSTYRENE FOAM + MEDIUM DENSE HOLLOW CONCRETE BLOCK + MAHOGANY

Theoretical Heat Flux: 8.82 W/m^2

ANSYS heat flux; 11.749 W/m^2

Difference: 2.929 W/m^2 (33.21% deviation)

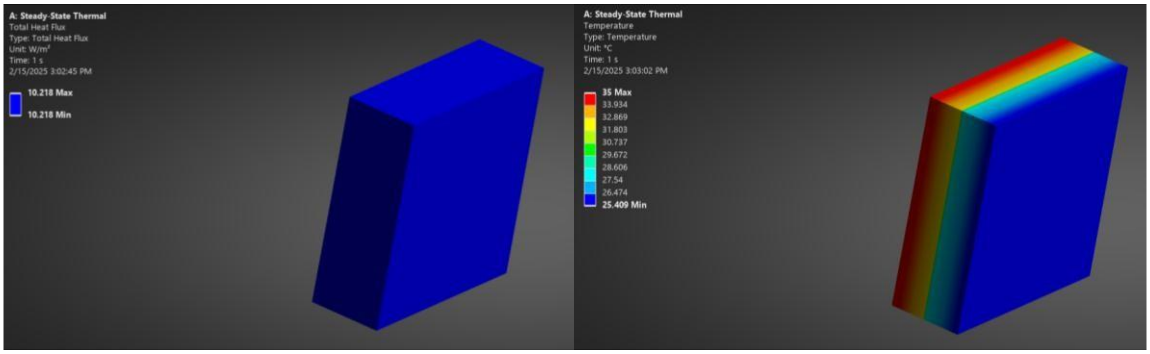


FIGURE 4.14 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + AIR CAVITY + MEDIUM DENSE HOLLOW CONCRETE BLOCK + MAHOGANY

Theoretical Heat Flux: 9.52 W/m^2

ANSYS heat flux; 10.218 W/m^2

Difference: 0.698 W/m^2 (7.33% deviation)

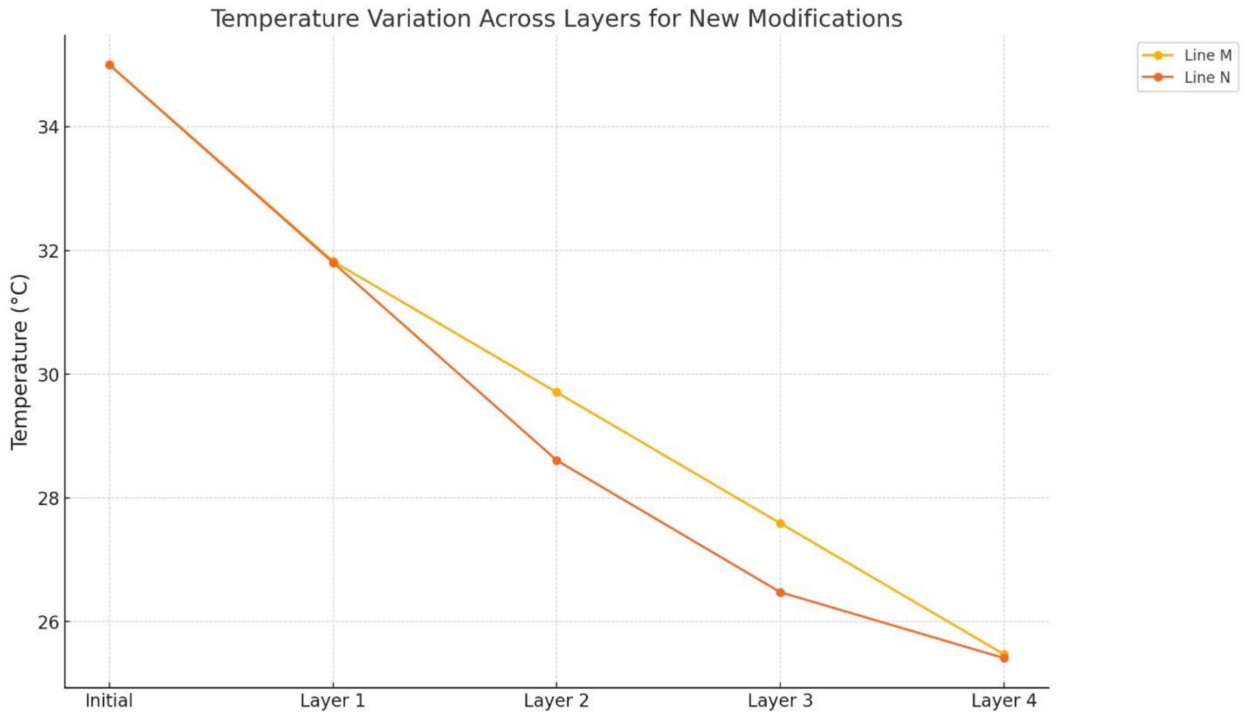


FIGURE 4.15 GRAPH OF TEMPERATURE GRADIENT ACROSS DIFFERENT LAYERS FOR FIGURE 3.2 MODIFICATIONS

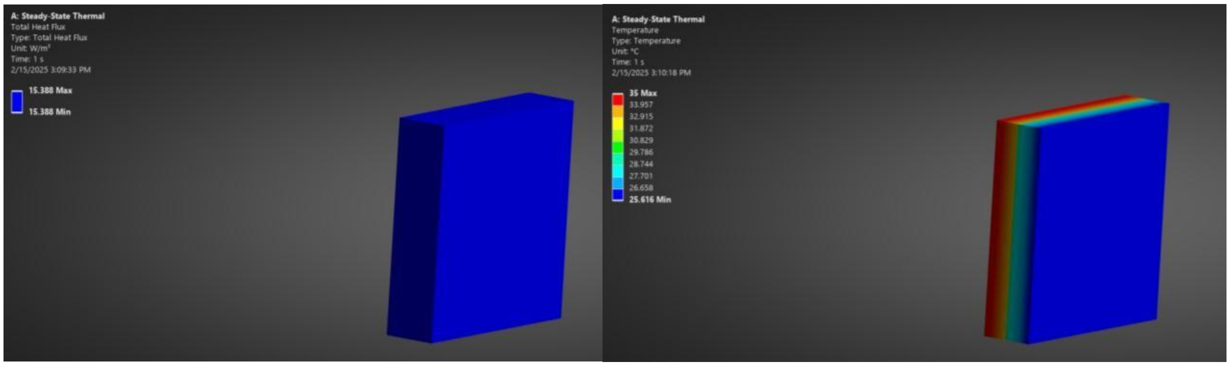


FIGURE 4.16 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + POLYSTYRENE FOAM + MEDIUM DENSE HOLLOW CONCRETE BLOCK + MAHOGANY Theoretical

Heat Flux: 13.24 W/m²

ANSYS heat flux; 15.388 W/m²

Difference: 2.148 W/m² (16.22% deviation)

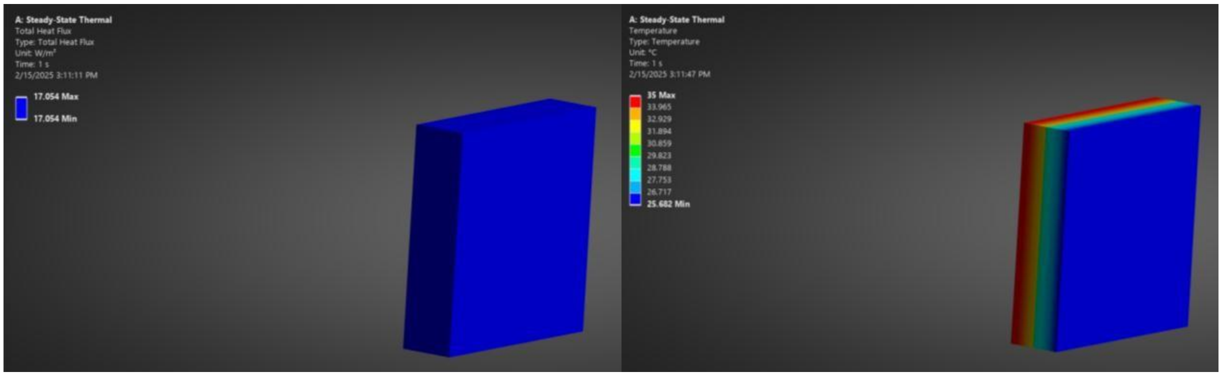


Figure 4.17 ANSYS results for Dense Hollow Concrete Block + Rock Wool + Medium Dense Hollow Concrete Block + Mahogany Theoretical Heat Flux: 15.09 W/m^2

ANSYS heat flux; 17.054 W/m^2

Difference: 1.964 W/m^2 (13.02% deviation)

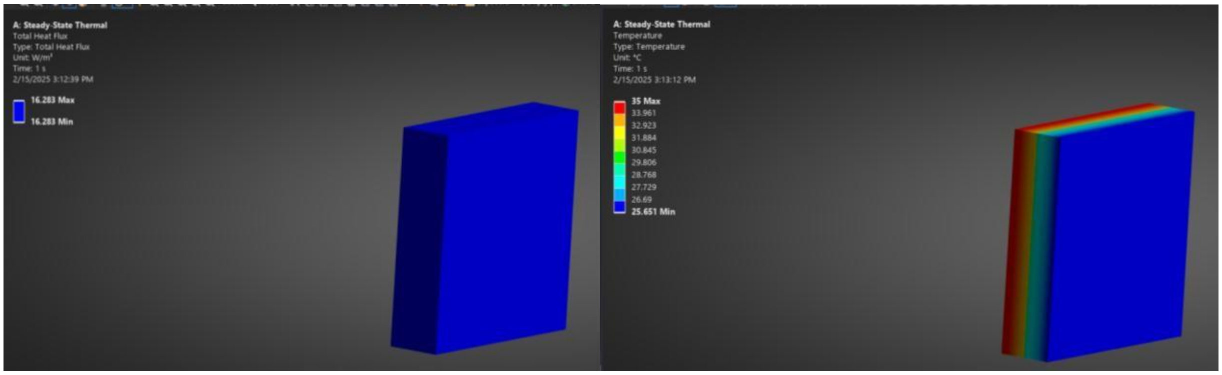


Figure 4.18 ANSYS results for Dense Hollow Concrete Block + Fiber Glass Insulation + Medium Dense Hollow Concrete Block + Mahogany

Theoretical Heat Flux: 18.05 W/m^2

ANSYS heat flux; 16.283 W/m^2

Difference: 1.767 W/m^2 (9.79% deviation)

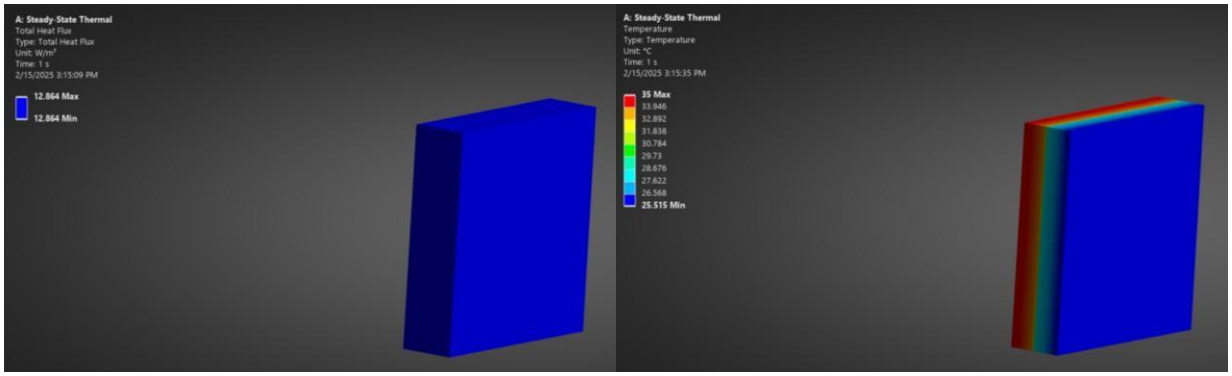


FIGURE 4.19 ANSYS RESULTS FOR DENSE HOLLOW CONCRETE BLOCK + AIR CAVITY + MEDIUM DENSE HOLLOW CONCRETE BLOCK + MAHOGANY

Theoretical Heat Flux: 5.02 W/m²

ANSYS heat flux; 12.864 W/m²

Difference: 7.844 W/m² (156.25% deviation)

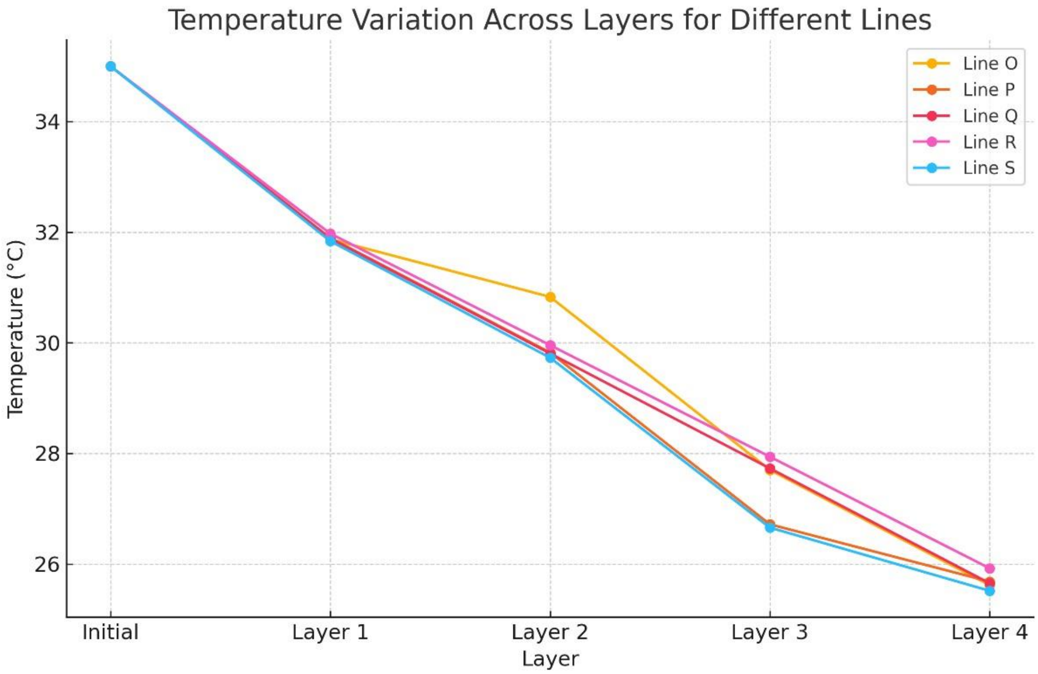


FIGURE 4.20 GRAPH OF TEMPERATURE GRADIENT ACROSS DIFFERENT LAYERS FOR FIGURE 3.3 MODIFICATIONS

4.2 DISCUSSION

This study aimed to analyze the thermal performance of different composite wall configurations using both theoretical calculations and ANSYS simulations. The results provide insight into how material selection influences heat transfer and energy efficiency in building envelopes.

4.2.1 Comparison between Theoretical and Simulated Heat Flux

The theoretical and simulated heat flux values show a close correlation, with deviations varying across different configurations. In some cases, the difference was minimal, such as Dense Hollow Concrete Block + Rock Wool + Agba Wood, where the deviation was just 0.1%, indicating strong agreement between both methods. However, for some configurations, larger deviations were observed. For example, the Dense Hollow Concrete Block + Air Cavity + Medium Dense Hollow Concrete Block + Mahogany combination showed the highest deviation (156.25%). This significant difference is likely due to the difficulty in accurately modeling air cavities, as they involve convective and radiative heat transfer, which are not fully accounted for in steady-state conduction calculations.

Most other configurations had moderate deviations between 3% and 25%, which can be attributed to factors such as computational approximations in ANSYS, material property variations, and boundary conditions in the simulation.

4.2.2 Effectiveness of Insulation Materials

The choice of insulation material had a clear impact on heat transfer. Among the three insulation types analyzed:

Polystyrene Foam (Thermal Conductivity: 0.033 W/m·K) proved to be the most effective in reducing heat flux.

Rock Wool (0.037 W/m·K) and Fiber Glass Insulation (0.04 W/m·K) also performed well, significantly lowering heat transfer.

Air Cavity, which was assumed to have a thermal conductivity of 0.04 W/m·K, showed inconsistent results due to its tendency to introduce convective effects that were not fully captured in the theoretical model.

The results confirm that using insulation materials with lower thermal conductivity effectively minimizes heat loss and improves energy efficiency in building envelopes.

4.2.3 Influence of Concrete Block Type

Comparing the two types of concrete blocks used:

Dense Hollow Concrete Block (1.4 W/m·K) led to higher heat flux values.

Medium Dense Hollow Concrete Block (0.5 W/m·K) consistently reduced heat transfer, making it a better choice for energy-efficient designs.

For instance, the theoretical heat flux for Dense Hollow Concrete Block + Fiber Glass Insulation + Agba Wood was 18.79 W/m², while the same configuration with Medium Dense Hollow Concrete Block resulted in 14.18 W/m²—a 24.5% reduction. This demonstrates that selecting materials with lower thermal conductivity can significantly improve thermal resistance.

4.2.4 Structural vs. Thermal Performance Considerations

While Mahogany and Agba Wood were primarily included for structural integrity, their thermal properties also influenced the overall heat flux. Configurations using Mahogany generally showed slightly higher heat transfer than those using Agba Wood, since Mahogany has a slightly higher thermal conductivity (0.10 W/m·K vs. 0.08 W/m·K). Although this difference is relatively small, it suggests that material selection should consider both structural and thermal performance.

4.2.5 Implications for Energy Efficiency

The findings reinforce the importance of selecting the right materials to minimize heat gain in buildings. The best-performing configurations—those with Medium Dense Hollow Concrete

Blocks and Polystyrene Foam—achieved the lowest heat flux values, making them ideal for improving energy efficiency in hot climates.

CHAPTER FIVE

CONCLUSION

This study focused on optimizing the thermal properties of building envelopes by evaluating various material combinations for their heat transfer performance. Through both theoretical calculations and ANSYS simulations, the results provided a comprehensive understanding of how different materials influence the thermal resistance of building walls.

The findings confirmed that the selection of insulation materials significantly affects heat flux, with Polystyrene Foam proving to be the most effective among the tested insulation materials due to its lowest thermal conductivity. Similarly, Medium Dense Hollow Concrete Blocks exhibited better insulation performance compared to Dense Hollow Concrete Blocks, making them a preferable option for energy-efficient building envelopes.

The results also highlighted the importance of choosing materials that balance structural integrity and thermal efficiency. While Mahogany and Agba Wood contributed to structural stability, their thermal conductivities slightly influenced heat transfer. Among these, Agba Wood performed slightly better in minimizing heat flux.

One of the key takeaways from the study is that incorporating insulation materials with low thermal conductivity can significantly reduce indoor heat gain, thereby decreasing reliance on mechanical cooling systems. This is particularly relevant for hot and humid climates like Edo State, Nigeria, where energy-efficient building designs can improve occupant comfort while lowering energy costs and environmental impact.

RECOMMENDATIONS

i. Adopt Energy-Efficient Wall Configurations

The study suggests using Medium Dense Hollow Concrete Blocks combined with Polystyrene Foam insulation for optimal thermal performance. This combination demonstrated the lowest heat flux values, making it an ideal choice for improving indoor thermal comfort in tropical climates.

ii. Promote the Use of Sustainable Insulation Materials

Fiberglass and Rock Wool also showed good insulation properties and should be considered as alternatives, especially where cost or availability is a concern. Efforts should be made to increase awareness and accessibility of these materials in the Nigerian construction industry.

iii. Encourage the Integration of Passive Cooling Strategies

In addition to selecting better insulation materials, building designs should incorporate natural ventilation, shading techniques, and reflective surfaces to further reduce heat gain and improve overall thermal comfort.

iv. Update Building Regulations and Standards

The findings of this research support the need for revised building codes in Nigeria that encourage the use of energy-efficient materials in construction. Policies should incentivize the adoption of sustainable materials and construction practices to reduce overall energy consumption.

v. Future Research and Material Testing

Additional studies should explore the long-term performance of these materials under real-world conditions, including factors such as moisture absorption, durability, and cost-effectiveness. Testing hybrid configurations combining modern and traditional materials could further enhance thermal efficiency while maintaining affordability.

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