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28-oji Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis" teminė konferencija
Proceedings of the 28th Conference for Junior Researchers "Science – Future of Lithuania"

DARNI APLINKA / SUSTAINABLE ENVIRONMENT

2025 m. balandžio 24 d., Vilnius, Lietuva
24 April 2025, Vilnius, Lithuania

ISSN 2029-7157 / eISSN 2029-7149
eISBN 978-609-476-390-8
https://doi.org/10.3846/da.2025.026

Pastatų energetika / Energy for Buildings

https://vilniustech.lt/346238

THE INFLUENCE OF NON-TRANSPARENT ENVELOPE INSULATION ON THE COOLING DEMAND OF RESIDENTIAL BUILDINGS IN NIGERIA

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Received 24 February 2025; accepted 17 March 2025

Abstract. A building envelope's thermal performance significantly impacts cooling energy consumption, especially in countries with very hot climates like Nigeria. Non-transparent envelope insulation, including walls, roofs, and floors, is important in reducing heat gain, improving indoor thermal comfort, and regulating indoor temperature. This study examines the traditional 3-layer uninsulated wall constructed in Nigeria. It compares it to an insulated 4-layered wall using different insulation materials to evaluate the influence of non-transparent envelope insulation on the cooling demand of residential buildings in Nigeria. By analysing different insulation materials and thicknesses, this study assesses their effectiveness in minimising cooling loads. The research considers key climatic factors such as solar radiation and ambient temperature to determine insulation strategies for energy efficiency. Findings indicate that properly insulated, non-transparent envelopes can reduce indoor temperatures and cooling energy demand in residential buildings. However, some factors like material selection and installation also influence the overall performance of these buildings. This study highlights the importance of adopting energy-efficient envelope designs to enhance sustainability and reduce dependence on mechanical cooling systems. These insights could significantly contribute to developing new practices for improving energy efficiency in Nigeria's residential building construction and renovation sector.

Keywords: Nigeria residential buildings, cooling energy consumption, energy efficiency, insulated and uninsulated envelopes.

1. Introduction

Nigeria is the most populous country in Africa and is in West Africa, covering 923.768 square kilometres with a population of approximately 223 million people (*National Bureau of Statistics, 2024*, 2024). It consists of 36 states and shares its borders with Niger Republic, Chad, Cameroon, and Benin Republic. The country is highly diverse, with over 250 ethnic groups and 500 spoken languages, although English is the official language in Nigeria. Abuja is the capital, while Lagos remains the commercial hub. Nigeria has a tropical climate due to its proximity to the equator and the Atlantic Ocean, experiencing high temperatures that can reach up to 40 °C in the dry season (NiMet, 2025). The country has two main seasons: the rainy and dry seasons. The southern region is characterised by high humidity and rainfall, while the northern region experiences an arid, desert climate with extreme heat during the day and cooler temperatures at night.

Nigerian houses are traditionally built with concrete masonry unit walls consisting of three layers: an outer layer made of cement plaster, a middle layer made of concrete block, and an inner layer made of cement plaster. These buildings are constantly exposed to solar radiation and intense heat from the sun, highlighting the need for thermal insulation to enhance occupant comfort, energy efficiency, and durability, especially given Nigeria's unreliable power supply (Building Science Concepts | WBDG - Whole Building Design Guide, n.d.).

In extreme climates like that experienced in Nigeria, insulation is essential for regulating indoor temperatures and reducing cooling energy consumption. Insulation in

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cold regions helps retain heat, reducing heating energy costs and improving comfort. Similarly, in hot climate regions, insulation can also help to minimize heat gain (Boyce et al., 2018).

Urbanisation has increased since the Industrial Revolution, with approximately 60 % of the world's population projected to reside in cities by 2030, increasing the need for efficient buildings (Abubakar & Aina, 2019). Buildings consume 35 % of global energy, with HVAC systems accounting for about 50 % of total energy use. However, modern construction often neglects local materials and climate conditions despite the importance of using local resources for thermal comfort (Kalhor & Emaminejad, 2020).

Sustainable and locally sourced materials enhance energy efficiency in residential buildings. Using local materials can improve thermal comfort without excessive reliance on air conditioning (Bencheikh & Bederina, 2020). Materials such as wood, bamboo, straw bales, earth, clay bricks, and tiles reduce environmental impact and support sustainable development (Orhon & Altin, 2020).

Sustainable development in construction focuses on economic, social, and environmental benefits. Economic sustainability promotes cost-effective, energy-efficient buildings. Social sustainability emphasises safe environments, while environmental sustainability reduces waste and energy consumption (Manandhar et al., 2019).

2. Statement of the problem

Residential buildings in Nigeria face significant challenges in maintaining indoor comfort due to poor insulation. The use of materials such as zinc and aluminium roofing sheets, which conduct heat, results in excessive indoor temperatures (Ponni M & Baskar Rajaram, 2015). Concrete block walls absorb and retain heat, further exacerbating thermal discomfort. This research aims to provide better building construction techniques and materials with better cooling energy consumption in Nigeria, that can withstand the harsh and hot climate. The idea is to introduce insulation materials with low thermal conductivity to the building envelope, which should help increase the heat resistance and slow the transfer of heat through the building wall, thereby ensuring maximum indoor comfort for the building occupants by reducing the need for cooling.

The construction sector struggles with thermal inefficiency due to outdated building materials and techniques. This leads to high energy consumption for cooling, increased household energy costs, and added pressure on the country's already strained power grid. Additionally, the lack of knowledge, skilled professionals, and guidelines on innovative building materials and construction methods further hinders the adoption of energy-efficient practices (Bentoumi et al., 2024).

Addressing these challenges requires targeted research and implementation of modern materials and advanced construction techniques to improve thermal efficiency in Nigerian residential buildings. Without such efforts, energy inefficiency and poor indoor comfort will persist, affecting the environment and residents' quality of life.

The construction of building walls is a fundamental aspect of building design, influencing structural integrity, thermal performance, and energy efficiency. The characteristics and performance of wall systems can vary significantly based on geographic location, material availability, and climatic conditions. This analysis aims to reduce cooling energy consumption and dependence on cooling (air conditioning) and enhance indoor comfort for building residents in Nigeria. It will focus on building houses that maintain indoor temperatures at approximately 24 °C and outdoor temperatures up to 40 °C.

3. Choice of insulation material based on Nigeria's climate

The hot weather climate in Nigeria makes the selection of insulation material crucial for maintaining indoor comfort and reducing the energy consumption associated with artificial cooling in residential buildings. Both organic and inorganic materials possess different advantages and disadvantages that make them suitable for several applications in hot climates.

Organic materials, especially cork and hemp, are known for their excellent thermal insulation properties. Organic thermal insulation materials can also be subdivided into organic and synthetic materials. A good example of a synthetic insulation material is the closed-cell spray polyurethane foam (ccSPF), which is potentially the most effective and efficient thermal insulation material because of its extremely low thermal conductivity, moisture resistance, and high energy efficiency, making it very suitable for Nigeria's hot and humid climate (Elrayies, 2017).

Studies carried out on ccSPF have shown that it can significantly reduce cooling demand, providing approximately a 55 % reduction in cooling energy requirements in hot desert climates like northern Nigeria (Reyes-Barajas et al., 2021). Another excellent organic thermal insulation material is the phenolic-silica aerogel, which also exhibits low thermal conductivity and high thermal resistance, enhancing its applicability in thermal insulation (Yu et al., 2018).

The insulation materials, like mineral wool and perlite, are widely known for their durability and high resistance. Mineral wool has high thermal performance and is non-combustible, making it a better choice than fire hazards are of concern (Raimundo et al., 2023). Materials like perlite have low thermal conductivity while being lightweight, which is advantageous for wall construction in hot climates in Nigeria (Liu et al., 2022). Research has indicated that the use of mineral wool and other inorganic materials can effectively reduce heat transfer in a wall, hence improving the thermal comfort of buildings in a hot environment like Nigeria (Raimundo et al., 2023).

4. Methodology

This analysis will be conducted using simulation software IDA-ICE to run simulations for the traditional 3-layered and 4-layered walls with organic, inorganic, and synthetic insulation materials. This would provide the best material with effective thermal insulation capabilities for the Nigerian climate. These simulations would be done using the same input data for weather and climatic conditions for the building walls and roof to simulate the same environment. The data collection method and subsequent analysis will be obtained from the data and resources in the IDA-ICE software. It will comprise the model formulation, analysis, and simulation of all four types of walls and the results observed and recorded. The results obtained will be analysed to determine which building has the least cooling energy consumption and ensure the comfort of the building occupants. The analysis process and proper interpretation and computation of results would be ensured.

The typical building in Nigeria is not constructed with an insulation layer. Therefore, an insulated layer will be introduced to the traditional building wall and roof unit to determine how well it would perform given the harsh climate. The information and deductions from the research would be implemented into building construction and renovation techniques and practices to reduce the dependence on artificial cooling and increase energy saving in Nigerian houses. The study was conducted for Nigerian houses. Therefore, the simulation's climate conditions would mimic the Nigerian climate on a typical day. The climatic data for Nigeria was obtained from the IDA-ICE database, and since Nigeria's climatic data is not currently available, data for the Benin Republic was used as it borders Nigeria to the West, and they have similar weather and climate. Some scientific assumptions would be made to ensure the results' accuracy. Some of these are the thickness of the insulation materials used and the position of the building wall for best performance. Mineral wool was chosen for its low thermal conductivity and high moisture resistance for inorganic thermal insulation. Cork was chosen for organic thermal insulation because of its low thermal conductivity and moisture resistance. Another analysis would be carried out with a synthetic material known as closed-cell spray polyurethane foam (ccSPF), and the results obtained would be analysed and compared. IDA-ICE would be used to measure the building's energy consumption and indoor temperature.

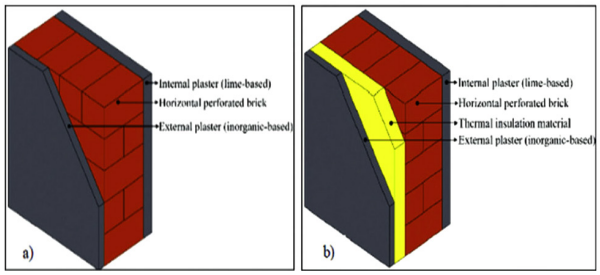


Figure 1. Analysed constructions



Figure 2. A typical building in Nigeria

The simulated building covers an area of 200 m^2 and has a flat roof. It also has one floor, and the simulation used the same materials traditionally used in Nigeria. It is 2.6 m high, has three regular-sized windows for ventilation, and has one door. The building has an open floor space inside.

5. Analysis using IDA-ICE simulation software

The simulations were carried out for one year, showing monthly results, and simulations would be done with cooling.

These parameters would help analyse the cooling energy consumption of the building, which uses the traditional 3-layer wall construction technique and various insulation materials to improve thermal comfort. All simulations would be done using the same weather and climatic data to ensure the accuracy of results. Weather and climate data for Cotonou were used as yearly data.

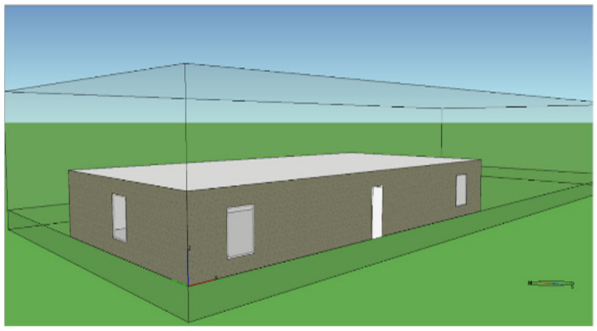


Figure 3. View of the building being analysed

6. Results

The material thicknesses used to simulate these insulated building walls are mineral wool 0.1 m, cork insulation 0.07 m, and closed-cell spray polyurethane foam insulation 0.07 m.

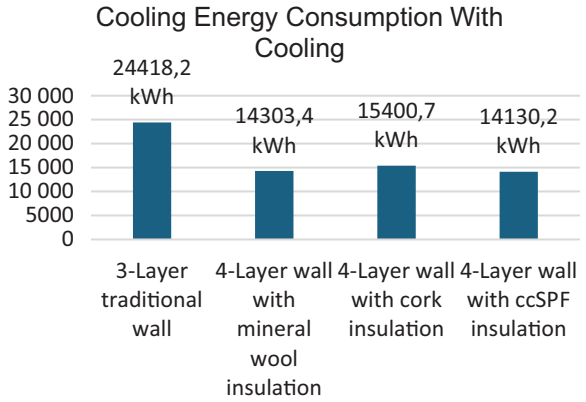


Figure 4. The yearly energy consumption for cooling

The figure above shows that the 3-layer wall consumed 24 418.2 kWh, twice that of other walls with an insulated layer. The chart shows that the building with ccSPF insulation consumed just 14 130.2 kWh, less than the other two building models, making the closed-cell polyurethane foam a superior alternative. This result indicates that using the closed-cell spray polyurethane foam insulated layer in the building wall and roof would have a significant positive effect in reducing the thermal discomfort in residential houses by reducing the heat transfer rate through the building wall and roof, thereby ensuring indoor comfort compared to other insulation materials.

According to this analysis, the closed-cell spray polyurethane foam would save 42.14% of cooling energy when applied instead of the traditional 3-layer uninsulated wall, as shown in the figure below.

The simulation also showed results for the main temperatures. These simulations were also performed with and without a cooler, and the results are analysed below.

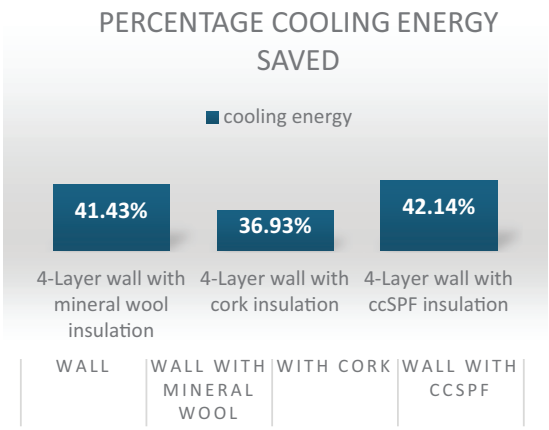


Figure 5. Percentage of cooling energy savings with the insulated walls

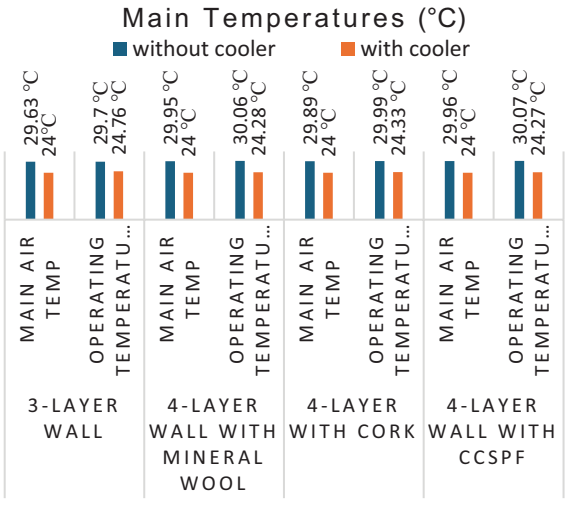


Figure 6. The main operating temperature of the building

The *main temperatures* show the mean air temperature and the operating temperature of each building wall in the room. The main air temperature refers to the air temperature within a space, while the operating temperature refers to the air temperature and radiant temperature. This means the operating temperature considers the air temperature and the effects of the surrounding surfaces (walls, windows, and floors). It shows the mean temperature value and operating temperature, and from the chart, they all performed poorly without the cooler but improved when the cooler was installed, as shown in the figure below.

7. Conclusions

In conclusion, this analysis aimed to analyse the influence of non-transparent envelope insulation on the indoor temperature and cooling energy consumption of residential buildings in Nigeria. It focused on building

houses that maintain indoor temperatures at approximately 24 °C and outdoor temperatures up to 40 °C. This was achieved by analysing a traditional 3-layer wall unit in Nigeria and substituting a 4-layer wall with insulation. Three distinct materials were chosen and analysed, and the following conclusions were made from the analysis.

1. It was discovered that using a 4-layer wall with synthetic closed-cell spray polyurethane foam performed best compared to other insulation materials studied in ensuring indoor thermal comfort. It maintained indoor temperature inside the building at recommended levels for comfort, approximately 24 °C, with less cooling energy consumption.

2. The closed-cell spray polyurethane foam is more energy efficient, requiring 42.14% less cooling energy to maintain indoor comfort levels than other alternatives using other insulation materials. This makes it a superior material in terms of insulation for the Nigerian climate and reduces cooling energy consumption. If applied in construction practices in Nigeria, this research would significantly improve the indoor comfort of residential houses in Nigeria, thereby reducing or eliminating the need for cooling.

Using other insulation materials that might be cheaper to purchase, have better thermal insulation properties suited for the Nigerian climate, and are easily accessible for further analysis or by conducting an economic or environmental impact assessment using these materials. By doing these, better options for improving indoor thermal comfort and energy efficiency in Nigeria's buildings would be discovered.

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NESKAIDRIŲ ATITVARŲ APŠILTINIMO ĮTAKA GYVENAMŲJŲ PASTATŲ VĖSINIMO POREIKIAMS NIGERIJOJE

E. AIGBODION, K. VALANČIUS

Santrauka. Pastato atitvarų šiluminės charakteristikos daro reikšmingą poveikį vėsinimo energijos suvartojimui, ypač šalyse, kuriose vyrauja labai karštas klimatas, pavyzdžiui, Nigerijoje. Neskaidrių pastato atitvarų - sienų, stogų ir grindų -

apšiltinimas yra svarbi priemonė šilumos prieaugiui mažinti, patalpų šilumos komfortui gerinanti ir vidaus temperatūrai reguliuoti. Šiame tyrime lyginama tradicinė trijų sluoksnių neapšiltinta siena su izoliuota keturių sluoksnių siena, naudojant skirtingas izoliacines medžiagas. Tikslas – įvertinti neskaidrių atitvarų apšiltinimo įtaką gyvenamųjų pastatų vėsinimo energijos sąnaudoms Nigerijos. Analizuojant skirtingas izoliacines medžiagas ir storius, vertinamas jų efektyvumas mažinant vėsinimo apkrovas. Tyrimo rezultatai rodo, kad tinkamai izoliuotos neskaidrios atitvaros gali sumažinti patalpų temperatūrą ir vėsinimo energijos poreikį gyvenamuosiuose pastatuose. Vis dėlto galutinį efektyvumą taip pat lemia tokie veiksniai kaip medžiagų pasirinkimas ir jų montavimo kokybė. Tyrimas pabrėžia, kad energiją taupančių konstrukcijų taikymas yra būtinas siekiant didesnio tvarumo bei mažesnės priklausomybės nuo mechaninių vėsinimo sistemų.

Reikšminiai žodžiai: Nigerijos gyvenamieji pastatai, vėsinimo poreikiai, energijos vartojimo efektyvumas, atitvarų apšiltinimas.