

Predictive Modelling of Indoor Thermal Comfort in Selected Mixed-Mode Buildings in Caleb University, Lagos, Nigeria

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Abstract- This study investigated indoor thermal comfort in selected mixed-mode buildings at Caleb University, Lagos, Nigeria, and developed evidence-based recommendations for improving occupant comfort and building performance. Field measurements of air temperature, relative humidity, and air velocity were collected alongside 200 occupant questionnaires assessing thermal sensation, preference, and satisfaction in teaching and administrative spaces. Descriptive analysis and comparison of measured conditions with occupant responses showed that most occupants reported warm thermal sensations and a strong preference for cooler conditions; thermal satisfaction was generally moderate to low. Higher temperatures and humidity correlated with warmer sensations and reduced satisfaction, while spaces with improved airflow recorded more favourable responses, indicating that temperature, humidity, and air movement jointly shape comfort in these mixed-mode buildings. Occupant suggestions emphasized better functioning mechanical cooling, increased fans, modified window designs for cross-ventilation, shading, and landscaping to reduce solar gain. Based on these findings, the study recommends prioritized maintenance and augmentation of cooling systems, enhanced natural ventilation through window and façade modifications, localized airflow improvements, and routine monitoring using sensors, together with occupant engagement and phased predictive-modelling-guided retrofits. The results highlight the need to integrate passive and active measures tailored to tropical, university environments to achieve reliable, energy-efficient thermal comfort.

Index Terms- Caleb University, Energy Efficiency, Indoor Thermal Comfort, Mixed-Mode Buildings, Predictive Modelling.

I. INTRODUCTION

Indoor thermal comfort is a key aspect of building performance that affects occupants' health, comfort, concentration, and productivity, especially in

educational buildings where users spend long hours indoors. In tropical climates like Lagos, Nigeria, achieving comfortable conditions is challenging due to high temperatures, humidity, and rapid urban growth. Globally, buildings consume significant amounts of energy, primarily through HVAC systems, resulting in higher costs and environmental impacts (IEA, 2022). In Nigeria, reliance on mechanical cooling is common, making energy-efficient solutions increasingly important. Mixed-mode buildings, which combine natural ventilation with mechanical cooling, offer a more sustainable approach to improving comfort and reducing energy use (Gbenga-Badiwa et al., 2021). However, many buildings are not well adapted to local climate conditions, leading to frequent discomfort. Traditional models like PMV also do not always reflect real occupant experiences in tropical climates. At Caleb University, limited research exists on mixed-mode thermal performance, hence the need for this study.

1.1 STATEMENT OF THE PROBLEM

Thermal discomfort is a major issue in institutional buildings in Lagos due to high heat, humidity, poor ventilation, and non-climate-responsive designs. This leads to heavy reliance on air-conditioning systems, increasing energy consumption and operational costs. Although mixed-mode buildings aim to improve comfort and reduce energy use, occupants still experience inconsistent indoor conditions that affect learning and productivity. At Caleb University, there is limited data on their thermal performance. In addition, standards such as ASHRAE 55 may not fully represent tropical conditions due to their temperate-based development (Oselumhe et al., 2022). This creates the need for localized predictive models to better understand thermal comfort.

1.2 AIM AND OBJECTIVES OF THE STUDY

1.2.1 Aim of the Study

This study aims to investigate predictive modelling of indoor thermal comfort in selected mixed-mode buildings at Caleb University, Lagos, Nigeria, to improve indoor environmental quality, energy efficiency, and occupant well-being.

1.2.2 Objectives of the Study

- i. Assess occupants' thermal comfort perceptions and satisfaction using questionnaires and thermal sensation surveys.
- ii. Examine the relationship between indoor environmental conditions and occupants' thermal comfort perceptions.
- iii. Develop a predictive model for indoor thermal comfort in mixed-mode buildings at Caleb University, Lagos, Nigeria.

1.3 RESEARCH QUESTIONS

- i. What are the levels of indoor thermal comfort parameters in selected mixed-mode buildings at Caleb University?
- ii. How do occupants perceive and rate thermal comfort and satisfaction in these buildings?
- iii. What is the relationship between measured indoor environmental conditions and occupants' thermal comfort perceptions?
- iv. How can indoor thermal comfort in mixed-mode buildings at Caleb University be predicted using environmental variables?

1.4 SIGNIFICANCE OF THE STUDY

This study is important to architects, engineers, facility managers, and researchers as it provides data for improving building design and operation. It supports energy-efficient and climate-responsive design while reducing reliance on mechanical cooling (Chen et al., 2023; Adeyemi et al., 2024). It also promotes sustainability by reducing energy use and emissions (IEA, 2022). Academically, it bridges gaps in thermal comfort research in Nigerian mixed-mode buildings and supports adaptation of international standards to tropical climates (Oselumhe et al., 2022).

1.5 SCOPE OF THE STUDY

This study focuses on predictive modelling of indoor thermal comfort in selected mixed-mode buildings at Caleb University, Lagos. It examines key parameters such as air temperature, humidity, air velocity, and mean radiant temperature, along with occupants' perceptions (ASHRAE, 2023). It is limited to mixed-mode buildings and excludes residential, commercial, fully air-conditioned, and purely naturally-ventilated buildings.

II. LITERATURE REVIEW

Thermal comfort is a vital aspect of building performance because it directly affects the health of occupants, their productivity and overall well-being (Kim et al., 2021). In recent years, there has been growing concern about indoor environmental quality due to increasing global temperatures, rapid urbanization, and rising energy consumption in buildings (Perez et al., 2023). Mixed-mode buildings, which refer to the combination of natural ventilation with mechanical cooling systems, have emerged as a sustainable strategy for achieving thermal comfort while reducing energy demand (Heiselberg et al., 2021). Studies have shown that mixed-mode ventilation systems can improve occupants' satisfaction while reducing dependence on fully mechanical cooling systems (Bouda et al., 2026). In addition, predictive modeling techniques are increasingly being used to determine indoor thermal conditions and optimize building performance in sustainable architecture (Merabet et al., 2021). Within Sub-Saharan Africa, thermal comfort studies have gained attention due to the region's tropical climate, rapid urban growth, and energy challenges (Widera, 2021). This chapter therefore reviews existing literature on thermal comfort, mixed-mode buildings, predictive modeling, and thermal comfort studies within Sub-Saharan Africa.

2.1 CONCEPT OF THERMAL COMFORT

Thermal comfort is known as the condition in which individuals feel comfortable and satisfied with their surrounding thermal environment. According to recent studies, thermal comfort is dependent on environmental conditions such as air temperature, humidity, air velocity, and radiant temperature, it is also dependent on personal factors like clothing insulation and metabolic rate (Bouda et al., 2026).

Uncomfortable indoor conditions can affect concentration, learning and productivity hence why it has become a major concern in building design. Previous studies have shown that occupants in buildings that are naturally ventilated or mixed-mode buildings often adapt to wider temperature ranges compared to occupants in fully air-conditioned buildings. Kim et al. (2021) explained that adaptive thermal comfort theories observed occupants' behavioral adjustments such as opening windows, changing clothing, or using fans to achieve comfort. Furthermore, thermal comfort standards such as ASHRAE Standard 55 and EN 16798 are commonly used globally; however, research indicates that these standards may not completely reflect occupants' thermal preferences in Sub-Saharan African climates (Bouda et al., 2026). Therefore, there is a need for region-specific thermal comfort studies.

2.2 MIXED-MODE BUILDINGS

Mixed-mode buildings are buildings that integrate natural ventilation and mechanical cooling systems to attain acceptable indoor thermal conditions while reducing energy consumption. These buildings allow flexibility by allowing occupants to switch between natural and mechanical ventilation depending on outdoor climatic conditions. The growing adoption of mixed-mode buildings is connected to the global push for sustainable development and energy efficiency. Perez, Hernández, and López (2023) expressed that mixed-mode systems significantly reduce reliance on air-conditioning systems in warm climates by employing natural airflow during favorable weather conditions. Research by Heiselberg, Toftum, and Andersen (2021) showed that mixed-mode buildings can reduce energy consumption by over 50% in comparison to buildings that are fully air conditioned. Their study also revealed that occupants in mixed-mode environments generally reported higher levels of thermal satisfaction because of increased control over their indoor environment. In tropical climates, features such as building orientation, shading devices, natural ventilation strategies, and façade design play critical roles in the success of mixed-mode systems.

Studies associated with the Department of Architecture at Caleb University highlight sustainable architectural practices and environmentally responsive design approaches for the African context.

Additionally, contemporary African architecture increasingly incorporates traditional passive cooling principles into modern buildings. Courtyards, perforated facades, shading devices, and naturally ventilated circulation spaces are now commonly used in institutional and educational buildings to improve thermal performance.

2.3 PREDICTIVE MODELING OF INDOOR THERMAL COMFORT

Predictive modeling refers to the use of mathematical, statistical, and computational techniques to foretell indoor environmental conditions and occupants' thermal responses (Merabet et al., 2021; Akhtar et al., 2025). Predictive models are progressively vital in building performance analysis because they help architects and engineers enhance energy use while maintaining acceptable comfort levels. Recent advancements in predictive modeling have prioritized machine learning and artificial intelligence techniques. Akhtar et al. (2025) developed an artificial intelligence model capable of foretelling indoor temperatures across naturally ventilated schools and homes in Sub-Saharan Africa. Their findings demonstrated that predictive models can improve thermal comfort management in resource-constrained environments. In Nigeria, the growing adoption of Building Information Modeling (BIM) and digital environmental simulation tools has improved opportunities for predictive building analysis. Furthermore, predictive thermal comfort studies support evidence-based architectural design by enabling designers to test building performance before construction.

2.4 THERMAL COMFORT STUDIES IN SUB-SAHARAN AFRICA

Thermal comfort studies in Sub-Saharan Africa have increased due to concerns about climate change, rapid urbanization, and inadequate energy infrastructure. Several African cities experience high temperatures and humidity levels that adversely affect indoor comfort conditions. Bouda et al. (2026) studied mixed-mode office buildings in Burkina Faso and found that occupants would rather be in naturally ventilated environments despite higher indoor temperatures. The study also showed that occupants' adaptive behavior strongly influenced their thermal comfort perception. Eyiah-Botwe (2026) carried out a systematic review of

passive cooling strategies in African architecture and established that natural ventilation, shading systems, courtyards, and thermal mass remain essential methods for enhancing thermal comfort in tropical climates. Similarly, Widera (2021) overviewed vernacular dwellings in Western Sub-Saharan Africa and found that traditional architectural features such as thick walls, courtyards, and shaded outdoor spaces significantly improved indoor thermal performance. These findings imply that traditional African architectural principles remain applicable for modern sustainable building design.

Despite these studies, there remains limited research focusing specifically on predictive modeling of indoor thermal comfort in mixed-mode institutional buildings within Nigeria. Most existing studies concentrate on residential or naturally ventilated buildings rather than educational facilities that combine natural and mechanical ventilation systems.

2.5 LITERATURE GAP

The reviewed literature reveals that thermal comfort is shaped by environmental factors, occupant behavior and building design techniques. Existing studies have demonstrated the benefits of mixed-mode buildings in enhancing thermal comfort while reducing energy consumption. Research has also highlighted the importance of adaptive comfort theory and predictive modeling techniques in sustainable building performance analysis.

However, several gaps remain within existing literature. Firstly, most predictive thermal comfort studies have been carried out outside Sub-Saharan Africa, specifically in developed countries with different climatic conditions. Secondly, existing thermal comfort standards are majorly based on European and North American studies, making them unsuitable for tropical African environments. Thirdly, limited studies have examined predictive thermal comfort modeling within mixed-mode institutional buildings in Nigeria, particularly university environments where occupants experience varying indoor thermal conditions. There is also inadequate integration of local climatic realities and occupant adaptive behavior into predictive models used within African contexts.

Therefore, this study seeks to bridge this gap by investigating predictive modeling of indoor thermal comfort in selected mixed-mode buildings within Caleb University, Lagos, Nigeria.

III. METHODOLOGY

This study adopted a quantitative survey research design using questionnaire to investigate indoor thermal comfort conditions in selected mixed-mode buildings at Caleb University, Lagos, Nigeria which were the Architecture department and the A' level building. The survey approach was considered appropriate because it enabled the collection of occupants' perceptions and experiences regarding thermal comfort within the selected buildings. The study focused on understanding how environmental conditions such as temperature, humidity, and airflow influence thermal sensation, thermal preference, and overall thermal satisfaction.

3.1 STUDY AREA

The research was conducted within the Architecture Department and A' level buildings at Caleb University, Lagos State, Nigeria. Lagos experiences a humid tropical climate characterized by high temperatures and elevated humidity levels throughout most of the year. These climatic conditions make thermal comfort an important factor in educational buildings where students and staff spend long periods indoors.

3.2 POPULATION AND SAMPLE SIZE

The target population comprised students, academic staff, and non-academic staff occupying the selected mixed-mode buildings. A total of 200 respondents participated in the study through questionnaire administration. The sample size was considered adequate for assessing occupants' perceptions of indoor thermal comfort and identifying prevailing comfort trends within the buildings.

3.3 DATA COLLECTION INSTRUMENT

Data were collected using a structured questionnaire divided into sections covering:

1. Demographic characteristics of respondents.
2. Thermal sensation perceptions.
3. Thermal preference responses.
4. Thermal satisfaction levels.

5. Recommendations for improving indoor thermal comfort.

Respondents were asked to indicate how they felt about the thermal conditions within their buildings and to suggest possible improvements that could enhance comfort.

3.4 DATA ANALYSIS

The collected data were analyzed using descriptive statistical techniques including frequencies, percentages, charts, and tables. Responses were summarized to identify patterns in thermal sensation, thermal preference, thermal satisfaction, and recommendations for thermal comfort improvement. The findings were presented using charts and interpreted in relation to indoor environmental conditions within the selected buildings.

IV. RESULT AND DISCUSSION

4.1 THERMAL SENSATION RESPONSES

The findings revealed that a significant proportion of respondents perceived the indoor environment as slightly warm, warm, or hot. Only a small percentage reported feeling thermally neutral. This indicates that many occupants experienced some degree of thermal discomfort during occupancy periods.

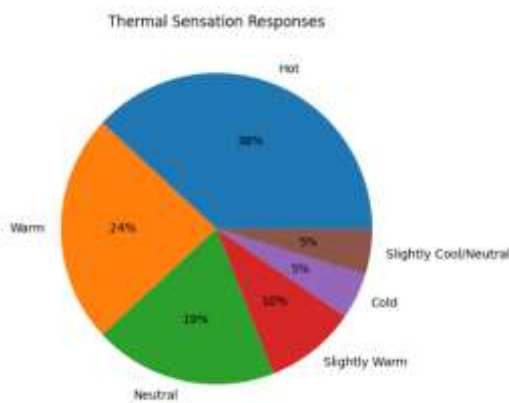


Fig 1 showing responses to thermal sensation

The predominance of warm thermal sensation responses suggests that indoor temperatures within the buildings frequently exceeded occupants' preferred comfort range. The findings further indicate that high

humidity and inadequate airflow contributed to these thermal perceptions.

4.2 THERMAL PREFERENCE RESPONSES

Results showed that most respondents preferred cooler indoor conditions. A large proportion indicated that they would prefer the environment to be slightly cooler or much cooler than the current condition. Only a few respondents desired warmer conditions, while some expressed satisfaction with the existing thermal environment.

The preference for cooler conditions suggests that the existing ventilation and cooling systems were not fully meeting occupants' comfort expectations. The findings further imply that excessive indoor heat accumulation affected occupants' comfort and productivity.

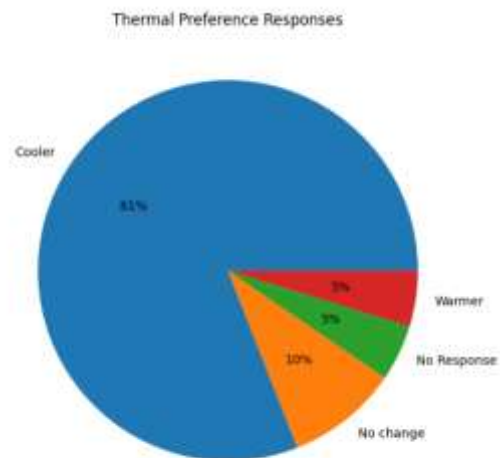


Fig 2 showing responses to thermal preference

4.3 THERMAL SATISFACTION LEVELS

Analysis of thermal satisfaction responses revealed moderate to low satisfaction levels among building occupants. While some respondents reported acceptable comfort conditions, a larger proportion expressed dissatisfaction with the indoor thermal environment.

The dissatisfaction observed among respondents was associated with excessive heat, poor air circulation, inconsistent airflow, and inadequate cooling performance. These factors collectively reduced

indoor environmental quality and negatively affected comfort during academic activities.

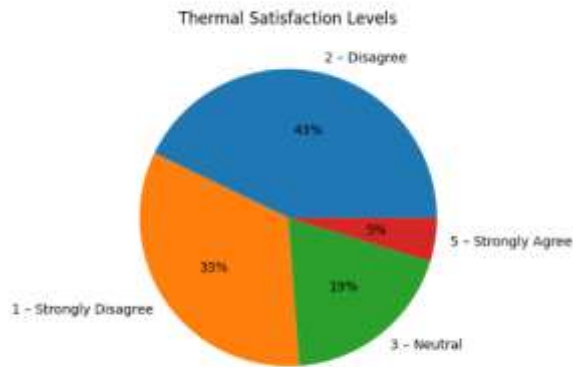


Fig 3 showing responses to thermal satisfaction

4.4 OCCUPANTS' RECOMMENDATIONS FOR IMPROVING THERMAL COMFORT

The recommendation responses provided valuable insights into occupants' expectations regarding thermal comfort improvements.

The most frequently suggested improvements included:

- Installation of additional air conditioners.
- Repair and maintenance of existing air conditioning systems.
- Provision of more fans within indoor spaces.
- Improved ventilation systems.
- Better airflow distribution.
- Modification of window designs to enhance natural ventilation.
- Installation of shading devices.
- Planting of trees around buildings to provide shade and reduce solar heat gain.

Several respondents specifically emphasized that functioning air conditioners are essential for maintaining comfort during lecture periods. Others highlighted the importance of improving natural ventilation through better window configurations and increased airflow.

4.5 RELATIONSHIP BETWEEN ENVIRONMENTAL CONDITIONS AND THERMAL COMFORT

The findings demonstrated a clear relationship between indoor environmental conditions and occupants' thermal comfort perceptions. Higher temperatures and humidity levels were associated with warmer thermal sensation responses and lower satisfaction levels. Conversely, spaces with better airflow generally recorded more favourable comfort responses.

This suggests that thermal comfort within the selected buildings is influenced by the combined effects of temperature, humidity, and air movement rather than any single environmental factor.

4.6 SUMMARY OF FINDINGS

The study revealed that:

- Most occupants experienced warm thermal conditions.
- A majority preferred cooler indoor environments.
- Thermal satisfaction levels were generally moderate to low.
- Temperature, humidity, and airflow significantly influenced comfort perceptions.
- Improved ventilation and cooling systems were the most frequently recommended solutions.
- Occupants recognized the importance of both natural ventilation and mechanical cooling in achieving comfortable indoor environments.

Overall, the results indicate that thermal comfort remains a significant concern within the selected mixed-mode buildings at Caleb University and that improvements in ventilation design and cooling system performance are necessary to enhance occupants' comfort and well-being.

V. CONCLUSION AND RECOMMENDATION

The study revealed that occupants of the selected mixed-mode buildings at Caleb University predominantly experienced warm indoor conditions and generally preferred cooler environments. Thermal satisfaction across the sampled spaces was moderate to low, a condition closely linked to elevated indoor temperatures, high relative humidity, and inadequate

airflow. Where air movement was better, occupants reported more favourable comfort, indicating that thermal perception in these buildings is governed by the combined effects of temperature, humidity, and air velocity rather than any single factor. Although occupants value both natural ventilation and mechanical cooling, the existing systems and building configurations were insufficient to deliver consistent comfort during typical occupancy periods.

To address the identified issues, building operators should prioritize reliable cooling by repairing and maintaining existing air-conditioning equipment and augmenting capacity where necessary, while also improving localized air distribution through additional fans and better ducting or grille placement to raise air velocity in occupied zones. Window designs and operable openings should be reconfigured to facilitate cross-ventilation and give occupants easier control over airflow; complementary passive measures such as external shading devices and increased perimeter vegetation will reduce solar heat gain and lower indoor temperatures. A routine monitoring and maintenance program using temperature, humidity, and airflow sensors is recommended to detect performance shortfalls and guide timely interventions, and predictive modelling (BIM or machine-learning simulations) should be used to evaluate phased retrofits and low-cost passive strategies before major investments. Finally, engage occupants through education on adaptive behaviours (window operation, fan use, clothing adjustments) and incorporate their feedback into operational schedules to achieve more acceptable, resilient indoor comfort.

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