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EFFECTS OF WALL MATERIAL TYPE ON TEMPERATURE VARIATION IN PRIMARY SCHOOLS IN ANAMBRA STATE, NIGERIA

Anthony I.V. Maduabum[1], Charles C. Munonye[2]

[1]*Leicester School of Architecture, Institute for Sustainable Futures, De Montfort University, Leicester, UK*

[2]*Department of Architecture, Chukwuemeka Odumegwu Ojukwu University, Uli Campus*

Email: p2679031@my365.dmu.ac.uk, aiv.maduabum@coou.edu.ng

Abstract

Providing conducive learning environments is essential for enhancing educational quality. Suboptimal indoor environments negatively influence students' performance. This study examined the impact of wall material type on temperature variation in three primary schools, using a purposive sampling technique. The indoor thermal comfort within the three primary schools in Anambra State, Nigeria, comparing Sandcrete Block (SCB) and Interlocking Compressed Earth Block (ICEB) classroom constructions was studied. Classroom temperature data were collected and analysed to evaluate the thermal performance of each material. Result indicated that classrooms constructed with ICEB exhibited lower average temperatures in all the three schools than those constructed with SCB. Although the difference was not statistically significant in one of the schools investigated, the variability in thermal performance between ICEB and SCB classrooms underscores the necessity for location-specific design considerations to achieve optimal thermal comfort. It is recommended that ICEB should be tried in construction of new primary school classrooms henceforth in the warm-humid region of South East Nigeria. Addressing this issue requires concerted efforts from government agencies, educational institutions, and relevant stakeholders to improve infrastructure and provide sustainable building solutions.

Keywords: compressed earth blocks, primary schools, sandcrete blocks, thermal comfort

INTRODUCTION

Creating comfortable learning environments is crucial for effective education. Factors such as temperature and ventilation significantly impact student concentration, engagement, and overall well-being (Wargocki et al., 2019). This issue is particularly relevant in regions with challenging climates, such as Nigeria, where schools often face constraints in resources for active cooling. The building materials used in school construction play a critical role in regulating indoor temperatures and creating thermally comfortable spaces.

In recent years, sustainable building materials like Interlocking Compressed Earth Blocks (ICEBs) have garnered attention as potential alternatives to conventional materials. ICEBs are composed of locally available soil and boast minimal energy requirements, rendering them a potentially cost-effective as well as environmentally friendly building solution (Morel et al., 2001). This paper examines the attributes of ICEBs and their potential to enhance classroom thermal comfort.

In Nigeria, thermal comfort within classrooms is essential for effective learning. Hot and stuffy classrooms contribute to decreased student concentration, increased fatigue, and reduced learning performance (Munonye et al. 2023). Conventional building materials, such as Sandcrete Blocks (SCB), often exacerbate this problem due to their poor thermal insulation properties, leading to increased heat gain and reliance on unavailable or unaffordable cooling solutions.

This study aims to assess classroom thermal comfort in selected schools in Anambra State, Nigeria, by comparing temperature data from SCB and ICEB classrooms. In order to determine which of the two building materials types demonstrate improved thermal comfort. The findings will contribute to the understanding of how sustainable building materials can improve learning conditions. This research addresses a gap in the existing literature by providing empirical evidence on the thermal performance of ICEB versus SCB in Nigerian schools.

LITERATURE REVIEW

Empirical studies

Previous studies have highlighted a strong correlation between thermal comfort and learning performance. Hot and stuffy classrooms decrease students' attention spans, increase irritability, and hinder cognitive functions (Wargocki et al., 2019). Furthermore, inadequate ventilation can lead to a build-up of indoor air pollutants, negatively impacting students' health and academic achievement (Smith et al., 2012).

The significance of schools is evidenced by the time children spend in them -approximately 30% of their time (Zomorodian et al., 2016). One of the primary reasons for the extensive research conducted on indoor comfort in schools is the considerable amount of time children spend indoors. The indoor environment experienced during this period has a substantial impact on their health and cognitive development (Munonye & Maduabum, 2024). Children aged 0-14 years constitute a substantial portion of the population in the study area, highlighting the need for targeted attention (World Bank, 2023). Given that schoolchildren dedicate a considerable portion of their day to educational activities, establishing a conducive and productive thermal environment is imperative (United Nations, 2015). Although ASHRAE 55 (2013) and ISO 7730 (2005) provide standards for thermal comfort, their relevance to children remains contentious, as studies suggest notable differences in thermal perception between children and adults (Teli et al., 2014; Munonye, 2020; Munonye, et al., 2021). Buildings play significant parts in providing thermal comfort to building occupants.

The building envelope is a critical element in regulating heat flow, serving as a physical barrier that manages indoor environmental conditions (Oginni, 2017). Often referred to as the "third skin," it comprises walls, roofs, windows, doors, and floors, which work together to limit unwanted heat ingress and promote thermal stability (Udawattha & Halwatura, 2018). The effectiveness of the building envelope in managing heat transfer directly influences energy requirements for cooling and heating (Jannat et al., 2020). It acts as the primary barrier controlling heat exchange with the external environment. Thermal mass, often integrated within this envelope, functions as a thermal battery, absorbing and releasing heat to mitigate temperature fluctuations within the interior space. The efficacy of thermal mass heavily depends on the performance of the building envelope, making both elements essential for achieving optimal thermal comfort and energy efficiency in passive building design.

The roof is typically the most solar-exposed element of a school building. Using pitched roofs with ventilated attic spaces, ceiling-level insulation, and high albedo (surface reflectivity) roofs help reduce heat transfer into occupied areas. These strategies are particularly important in low-rise classrooms, where high internal loads and inadequate roof performance can significantly affect comfort levels (Zomorodian et al., 2016). Applying light colours—such as white or pale tones—to roofs and external walls enhances albedo, thereby reducing the solar radiation absorbed by the building envelope. This practice contributes to lower internal temperatures, particularly in low-mass, highly exposed school buildings (Umoh et al., 2024).

Thermal mass denotes the capacity of a material to absorb, store, and subsequently release heat. Thermal lag, on the other hand, is defined as the rate at which a material relinquishes its stored heat. Generally, a direct correlation exists for the majority of commonly used building materials, whereby an increase in thermal mass corresponds to an extended duration of thermal lag. Materials characterised by high thermal mass and prolonged lag times are frequently referred to simply as 'thermal mass.' (Baggs & Mortensen (2006). The thermal mass of building materials significantly impacts their capacity to regulate heat flow. High thermal mass materials, such as concrete and earth-based blocks, absorb, store, and gradually release heat, contributing to stable indoor temperatures. Heywood (2015) suggests that buildings with heavy walls exhibit a delayed response time, known as the "thermal flywheel effect." In warm climates, this characteristic mitigates daytime heat build-up and prevents rapid temperature fluctuations, thereby enhancing thermal comfort.

Passive design involves working with the environment to minimise unwanted heat or cold while utilising sunlight and breezes (Cairns Regional Council, 2011). In tropical climates, key principles include preventing heat gain through proper orientation, shading of walls and windows, insulation, the use of thermal mass, and reflective surfaces. Implementing passive design strategies—such as natural ventilation and high thermal mass materials—can improve indoor comfort while reducing energy dependence. Materials with moderate to high thermal mass, such as compressed earth blocks or concrete, can help stabilise indoor temperatures by absorbing heat during the day and releasing it at night. However, their effectiveness depends on the specific climatic context and must be supported by effective ventilation to prevent internal overheating (Latha et al., 2015; Pacheco-Torgal & Jalali, 2012; Adegun & Adegbile, 2018; Ogunsote & Prucnal-Ogunsote, 2002).

In warm, humid climates, the primary goals are to minimise solar heat gain and maximise natural ventilation to effectively remove internal heat and moisture, thus promoting evaporative cooling from the skin (Latha et al., 2015). Natural ventilation, achieved through both cross and stack strategies, is crucial in warm, humid environments. Cross ventilation requires operable openings on opposite or adjacent walls, while stack ventilation operates by placing vents at both low and high levels to promote vertical airflow. In classrooms, this strategy aids in removing heat and humidity, aligning with adaptive comfort requirements, especially when mechanical cooling systems are absent (Zomorodian et al., 2016).

Aligning the building's long axis east–west reduces the exposure of the longer walls to the intense low-angle morning and afternoon sun. Conversely, the north and south façades, which receive sunlight at a higher angle, are relatively easier to shade. This orientation decreases heat gain and is essential for climate-responsive school design, where limiting direct solar exposure is crucial for maintaining indoor comfort (Zomorodian et al., 2016). Shading is one of the most critical passive strategies. Implementing overhangs on the north and south façades, along with vertical fins or verandahs on the east and west, helps block solar radiation before it reaches the building envelope. The effectiveness of shading devices is significantly affected by their geometry, a finding validated in Southeast Nigeria (Munonye et al., 2021). Shading, is also considered important due to its high benefits in heat avoidance (Abbakyari &Taki, 2017). In classrooms, shading mitigates glare and internal heat gain, both essential for ensuring thermal comfort (Zomorodian et al., 2016).

Trees, shrubs, and vegetative ground cover provide passive cooling by shading building surfaces and outdoor areas while enhancing the microclimate through evapotranspiration. Replacing hard paving with vegetation around classrooms reduces surface heat and supports broader thermal comfort objectives (Umoh et al., 2024; Umeora, et al. 2023). The strategies discussed here are based on climate-responsive design principles (Umoh et al., 2024) and their proven benefits for thermal comfort in educational environments (Zomorodian et al., 2016).

Compressed Earth Blocks and Sandcrete block

Technical limitations, perceptual biases, and standardisation challenges hinder the widespread use of earth as a building material, despite its application in various structures such as airports, embassies, hospitals, museums, etc. (Rael, 2008). The variability in earth composition complicates standardisation. To address these issues, Compressed Earth Blocks (CEBs) were developed as a more durable alternative. However, CEBs possess limitations, including weight, the requirement for costly mortar, and reliance on skilled masons, which can lead to extended construction times. Interlocking Compressed Earth Blocks (ICEBs) were developed to enhance CEBs by incorporating a shear key and locking mechanism, allowing for interlocking without mortar (Saari, et al., 2017). This innovation reduces cement usage, accelerates construction, and lessens the need for skilled labour.

Research on sustainable building materials has demonstrated the potential of ICEBs to improve thermal comfort and reduce energy consumption. ICEBs offer a more sustainable alternative due to their local availability, low embodied energy, and enhanced thermal properties (Morel et al., 2001). The thermal mass of ICEBs enables them to absorb and store heat during the day, gradually releasing it at night, thus reducing temperature fluctuations and maintaining a more stable indoor climate. However, their effectiveness is contingent upon climate and construction quality.

Sandcrete blocks (SCB) remain the most common walling material in Nigerian construction. According to the Standards Organisation of Nigeria (SON), the minimum compressive strength requirement is 2.0 N/mm² for average blocks, with no single block falling below 1.75 N/mm². However, studies such as Olanipekun (2013) and Adeyemi et al. (2020) show that field samples frequently fall below expected strength, often ranging between 1.2 and 1.8 N/mm². Their manufacture is energy-intensive and reliant on imported cement, contributing significantly to the carbon footprint of building projects. However SCBs are known for their poor insulation properties and high thermal conductivity, leading to rapid heat transfer from the external environment into building interiors (Adedeji, 2011; NBRRI, 2020).

There has been limited research on the application of ICEBs in Nigerian schools and the impact of their thermal performance on student learning outcomes. This study aims to address this gap by providing empirical data on the thermal performance of ICEB classrooms compared to SCB classrooms in Anambra State, Nigeria, and discussing the implications for improving educational quality.

METHODOLOGY

The Study area

Anambra state is one of the six states in South East Geographical zones of Nigeria. It has a total land mass of 4,416 of km and situates on the Eastern side of River Niger. The state has 177 towns in 21 Local Government Areas (Ugonabo & Emoh, (2013)). According to National Bureau of statistics (2006), Anambra State is the 2nd most urbanized state in the country having 62% of its total population living in urban areas. Though most Anambra population is rural, the state is experiencing rapid urbanization and because of its relatively small land mass, the state is virtually becoming one huge urban area. Consequently, it has one of the highest population densities in Africa at 947 persons living within every square kilometre (UN- Habitat, 2009).

Awkuzu, Akwaeze and Aguluezechukwu are towns in Anambra State (Figure 1). Awkuzu is situated at Latitude 6.24°N, Longitude 6.95°E (elevation 110m), Awkuzu is in the Anambra North Education Zone. Akwaeze is positioned at Latitude 6.06°N, Longitude 7.02°E (elevation 287m), and is in the Anambra Central Education Zone. Aguluezechukwu is located at Latitude 6.01°N, Longitude 7.11°E (elevation 237m), and is in the Anambra South Education Zone

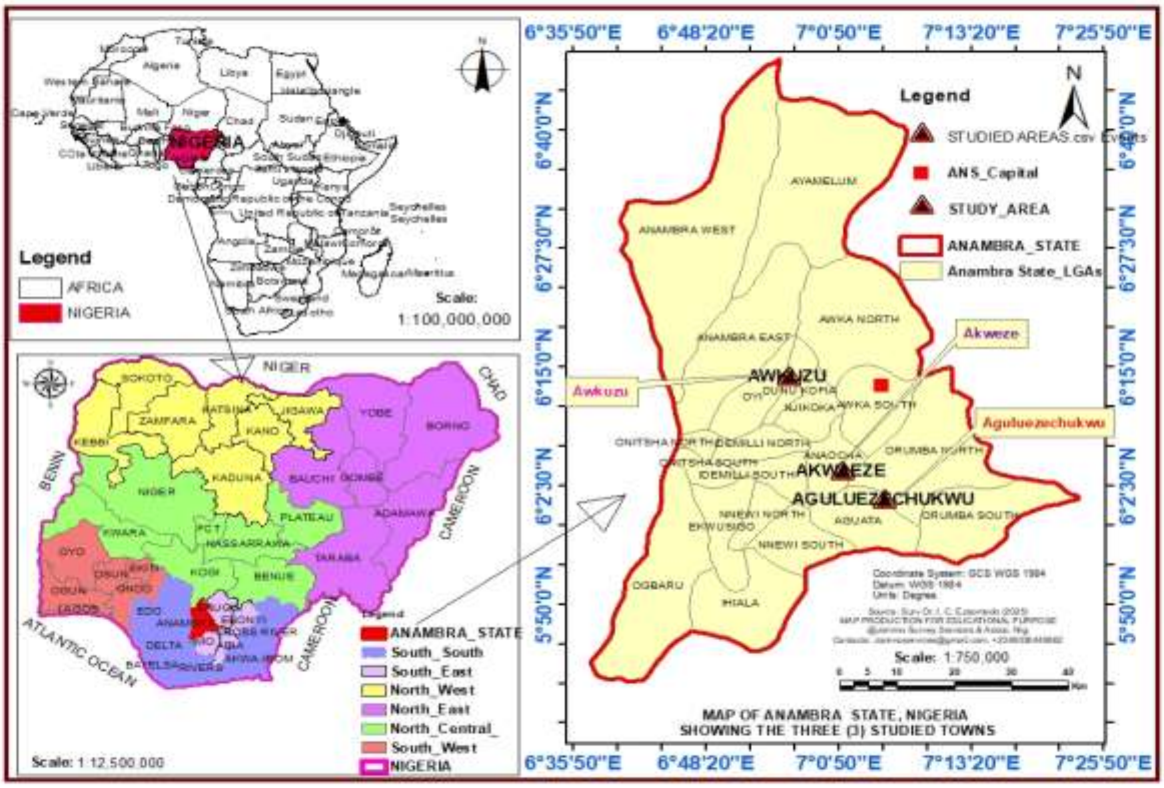

Figure 1: Location of the Study Areas

Study buildings and data collection

Two school buildings were selected from each of the three educational zones that make up Anambra state, using a purposive sampling technique and a comparative case study design. The schools are: St Peter's Catholic Community School Awkuzu (Anambra North), Akwaeze Community Primary School (Anambra Central) and Aguluezechukwu Central School (Anambra South). The basic criteria for the selection are that the schools must be located in the same compound and built with ICEB and SCB. The selected schools are shown in Figures 2-4 SCB blocks are hollow, 450 mm long x 225 mm wide x 225 mm high. The block's contents are sand and cement mixed typically in the ratio of 1:6. ICEB typically consists of laterite, cement, lime and water. It comes in various sizes: 220mm x 110mm x 65mm and in 295 mm x 140 mm x 100 mm. It has interlocking features that enables the blocks to fit together without mortar, providing structural stability.

Figure 2: St Peters Catholic Community School Awkuzu (ICEB left side & SCB right side)
Source: Fieldwork (2023)

Figure 3: ICEB classroom block at Akwaeze Community Primary School
Source: Fieldwork (2023)

Figure 4: ICEB classroom block at Aguluezechukwu
Source: Fieldwork (2023)

Data Collection

Data were collected using TINYTAG calibrated digital data loggers (Figure 5) positioned on the teacher's table in the representative classrooms constructed with SCB and ICEB. Table 4 shows the technical details of the data loggers. The data loggers were positioned at a height of 1.5 metres. Temperature data were recorded at 15-minute intervals from 10:45 AM due to logistics reasons, and the fact that the pupils were already fully settled for the day's classes, and 2:00 PM the time for dismissal of classes, on the following dates:

1. Awkuzu - October 13, 2023
2. Akwaeze - October 18, 2023
3. Aguluezechukwu - October 24, 2023

Figure 5: Tinytag Ultra 2 (TGU-4500) and Tinytag Plus 2 (TGP-4017)
Source: Fieldwork (2023)

Table 1: Technical details of the data loggers

Instrument and Make	Measured parameter	Range	Resolution	Accuracy
Tinytag ultra 2 (TGU-4500) loggers	Indoor air temperature	-25 to +85ºC	±0.01ºC	±0.3%
Tinytag Plus 2 (TGP-4017) loggers	Outdoor Temperature	25 to +85 ºC	±0.01ºC	-

Source: Fieldwork (2023)

The collected temperature data were analysed employing descriptive statistics (mean, maximum, minimum, standard deviation) to compare temperature profiles between SCB and ICEB classrooms, as well as outdoor temperatures. Paired t-tests were utilised to ascertain the statistical significance of temperature differences (alpha = 0.05). Cohen's d was applied to measure effect size. Line graphs and histograms were used to visualise temperature fluctuations and distributions.

RESULTS AND DISCUSSION

Temperature comparison across schools

The temperature records revealed variability between locations. Table 2 summarises the temperature analysis. In Aguluezechukwu, a paired t-test showed no significant difference between SCB and ICEB classroom temperatures (t(15) = 1.92, p = 0.07, d = 0.47). In Akwaeze and Awkuzu, SCB temperatures were noticeably and significantly higher than ICEB temperatures. Outdoor temperatures fluctuated significantly, generally remaining lower than or as high as indoor temperatures.

Table 2: Summary of Mean Classroom Temperatures (°C) and Statistical Comparison

Parameter	Aguluezechukwu (24 Oct 2023)	Akwaeze (18 Oct 2023)	Awkuzu (13 Oct 2023)
Time Period	10:45-14:00	10:45-14:00	10:45-14:00
SCB Mean Temperature (°C)	30.34	31.58	32.16
ICEB Mean Temperature (°C)	29.45	30.65	30.26
Temperature Difference (°C)	0.89	0.93	1.9
t(15)	1.92	3.12	4.46
p-value	0.07	0.007	0.0004
Cohen's d	0.47	0.85	1.15
Observations	No significant difference; both materials exhibited temperatures between 30°C and 30.5°C; outdoor temperatures reached 31°C.	Significant difference; ICEB demonstrated better thermal efficiency with consistently lower temperatures than SCB.	Significant difference; SCB classrooms experienced higher temperatures than ICEB, with differences diminishing after 13:00.

Source: Fieldwork (2023)

Awkuzu (October 13, 2023): From 10:45 to 14:00, SCB classrooms generally experienced higher temperatures than ICEB classrooms, though the difference diminished after 13:00. The average SCB temperature was 32.16°C, and the average ICEB temperature was 30.26°C. The difference was statistically significant (t (15) = 4.46, p = 0.0004, d = 1.15). Temperature distributions are shown in Figure 6.

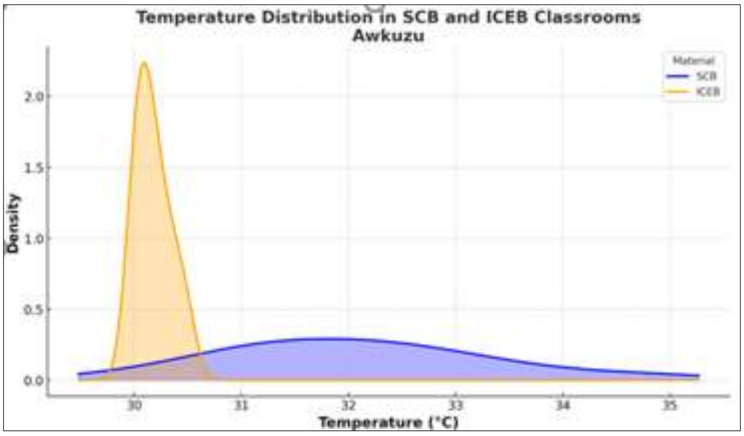

Figure 6: Awkuzu Temperature Distribution
Source: Fieldwork (2023)

Akwaeze (October 18, 2023): SCB temperatures ranged from 30.4°C to 32.4°C, while ICEB temperatures ranged from 30.2°C to 31.1°C. SCB temperatures were consistently higher. The average SCB temperature was 31.58°C, and the average ICEB temperature was 30.65°C. A paired t-test showed a significant difference ($t(15) = 3.12$, $p = 0.007$, $d = 0.85$), with ICEB demonstrating better thermal efficiency (lower temperatures). Temperature distributions are shown in Figure 7.

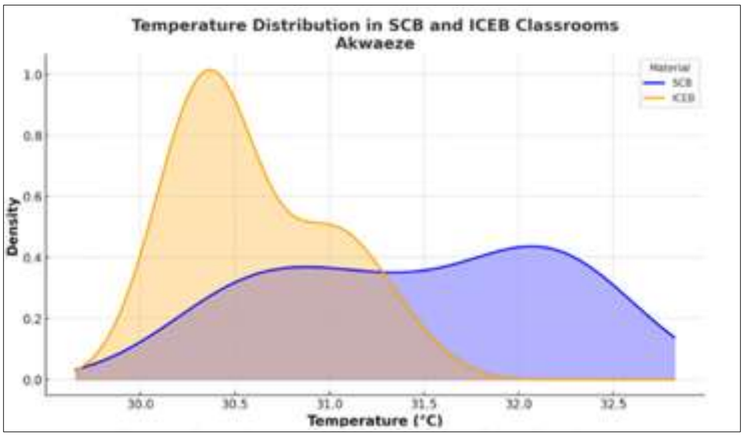

Figure 7: Akwaeze Temperature Distribution
Source: Fieldwork (2023)

Aguluezechukwu (October 24, 2023): From 10:45 to 14:00, the average SCB temperature was 30.34°C, and the average ICEB temperature was 29.45°C. A paired t-test showed no statistically significant difference ($t(15) = 1.92$, $p = 0.07$, $d = 0.47$). Both materials displayed temperatures generally between 30°C and 30.5°C. Outdoor temperatures reached 31°C. Temperature distributions are shown in Figure 8.

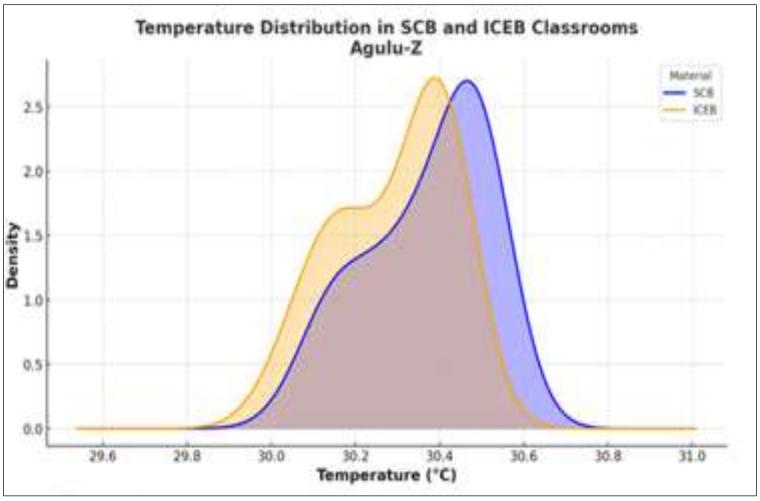

Figure 8: Aguluezechukwu Temperature Distribution
Source: Fieldwork (2023)

Classroom Comfort

In Akwaeze and Awkuzu, elevated temperatures recorded in SCB classrooms highlight the challenges of inadequate thermal performance. Students in these environments likely experienced uncomfortable thermal conditions, potentially leading to diminished concentration, increased fatigue, and lowered academic performance as also recorded in the work of (Lan et al., 2022). In contrast, classrooms built with ICEB materials in these locations provided a more stable and comfortable indoor climate relative to SCB, suggesting better mitigation of heat stress.

The findings in Aguluezechukwu suggest that building design specifics or other contextual factors (e.g., orientation, shading, ventilation specifics, surrounding microclimate) may have influenced the thermal performance, potentially reducing the relative advantage of ICEB in that particular case. Comparable temperature levels might be influenced by factors such as building orientation, window and roofing design, and shading efficiency. A comprehensive investigation into these aspects is needed in future works. Additionally, the higher p-value observed could relate to the specific conditions on the measurement day or sample size limitations, although the effect size (d=0.47) indicates a medium practical difference, albeit not statistically significant at the chosen alpha level.

Visual Data Representation

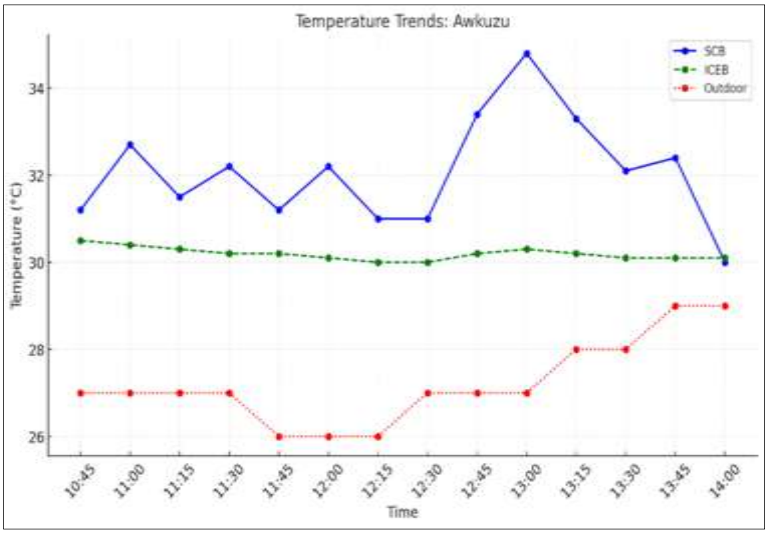

Figure 9. Temperature Profiles in Awkuzu School on October 13, 2023
Source: Fieldwork (2023)

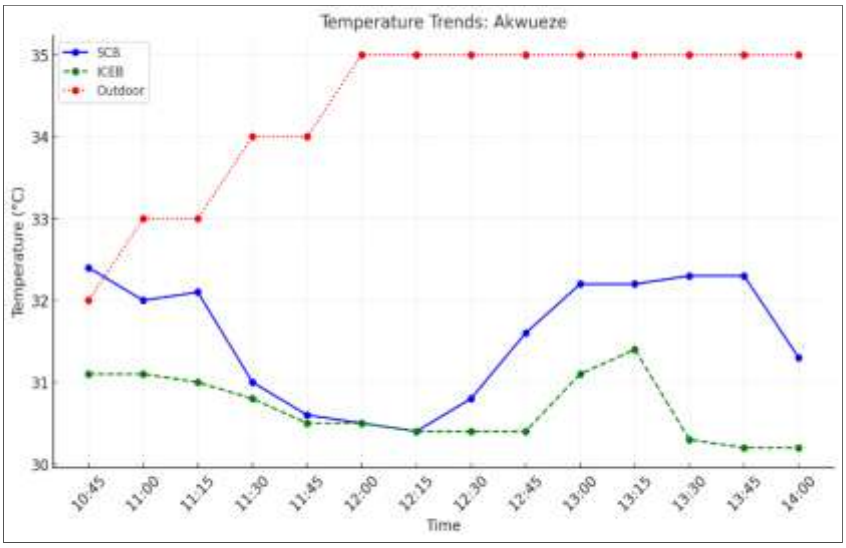

Figure 10. Temperature Profiles in Akwaeze School on October 18, 2023
Source: Fieldwork (2023)

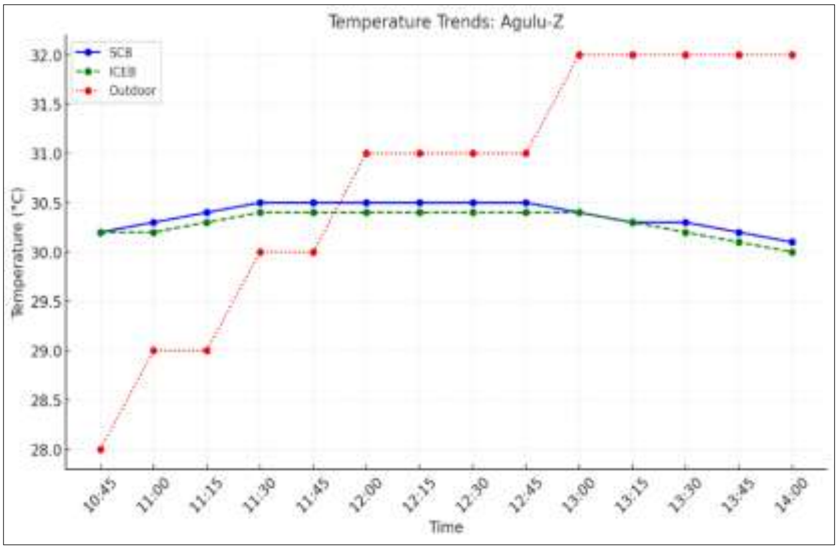

Figure 11. Temperature Profiles in Aguluezechukwu School on October 24, 2023
Source: Fieldwork (2023)

Figures 9-11 illustrate the temperature fluctuations over the measurement period in SCB and ICEB classrooms, alongside outdoor temperatures, for each respective school. The graphs visually represent the generally higher temperatures observed in SCB classrooms compared to the more stable and lower temperatures in ICEB classrooms in Awkuzu and Akwaeze, and the closer performance in Aguluezechukwu.

CONCLUSION AND RECOMMENDATIONS

This study provides nuanced evidence regarding classroom thermal comfort and the influence of walling materials in selected primary schools in Anambra State. In two of the three schools (Akwaeze and Awkuzu), ICEB classrooms demonstrated significantly better thermal performance compared to SCB classrooms, suggesting ICEB offers a viable alternative for reducing heat stress in educational buildings in this warm-humid climate. By adopting ICEB, schools could potentially create more thermally comfortable and productive learning spaces.

However, the results from Aguluezechukwu, where no significant difference was found, underscore that material choice alone does not guarantee optimal performance. Site-specific factors, overall building design, construction quality, and operational aspects like ventilation play crucial roles.

Given the potential benefits observed and the limitations of this case study (e.g., short-term measurements, uncontrolled occupancy), further research is recommended to validate these findings across different seasons and locations, and to explore the interplay of materials with other design factors.

To improve classroom thermal comfort in Anambra State schools, the following are recommended:

i. Consider the use of ICEB in the construction of new primary school classrooms in the warm-humid region of South East Nigeria, paying attention to appropriate design integration.
ii. Implement holistic passive cooling strategies alongside material selection, including optimizing building orientation, ensuring effective natural ventilation, providing adequate solar shading (especially for windows and walls), and using light-coloured, reflective roofing materials.
iii. Conduct further research investigating the long-term thermal performance of ICEB classrooms, student learning outcomes, and incorporating subjective feedback through student/teacher perception surveys, while controlling for or analysing environmental variables and design specifics.

Improving thermal comfort through sustainable and locally appropriate building materials and design strategies can significantly enhance learning environments and contribute to educational equity. Addressing this issue requires concerted efforts from government agencies, educational institutions, and relevant stakeholders to improve infrastructure and provide sustainable building solutions.

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