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TEMPERATURE VARIATION WITH ALTITUDE ACROSS SELECTED BUILDINGS AT FEDERAL UNIVERSITY OF LAFIA, NIGERIA

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ABSTRACT

This physics-based study quantitatively investigates the contravention of the atmospheric environmental lapse rate within multi-storey buildings in a tropical savanna climate (Lafia, Nigeria; 8.480°N, 8.520°E), where indoor thermal gradients invert due to solar gain and stack effect. The aim was to measure the magnitude of vertical temperature stratification across seasons in two three-storey buildings (academic, residential). Using a calibrated infrared thermometer (±1.0 °C), temperatures were measured at three heights per floor (0.3, 1.2, 2.1 m) at 09:00, 14:00, and 18:00 h over the dry (February), early rainy (June), and late rainy (September) seasons. Results show a consistent positive gradient, peaking at 1.1 °C (Social Science) and 0.9 °C (Hostel) in the dry season, with upper-floor temperatures reaching 38.8 °C. The mean vertical gradient attenuated seasonally from 0.70 °C (February) to 0.40 °C (June) and 0.25 °C (September), a 64 % reduction, while the academic building exhibited a steeper annual gradient (0.45 °C) than the hostel (0.39 °C). The findings demonstrate that buoyancy-driven heat accumulation imposes a quantifiable thermal penalty on upper floors. Consequently, we recommend integrating specific passive physics controls: high-albedo (>0.7) reflective roofing, enhanced roof insulation (R-value > 3.5 m²K/W), and optimized cross-ventilation (target ACH > 15–20) to disrupt stratification and reduce dry-season cooling loads.

Keywords: Thermal comfort, Altitude variation, Temperature stratification, Thermal gradient, Energy efficiency

INTRODUCTION

Global energy consumption presents a significant challenge, with residential and commercial sectors accounting for 30–40 % of total energy use worldwide (Abe *et al.*, 2023; Cengel & Boles, 2015). A considerable proportion of this energy is expended maintaining indoor thermal comfort, often through mechanical cooling and lighting systems (Dhaka *et al.*, 2012; Fanger, 1970). In tropical regions, widespread mechanical cooling is economically challenging, making passive strategies essential for occupant comfort (Adebayo, 2014; Adebayo *et al.*, 2021).

Buildings in tropical savanna climates experience seasonal variations, with dry and rainy periods influencing indoor thermal environments. Multi-storey structures often develop vertical temperature gradients, as warmer air rises and cooler air settles. This stratification can impact occupant comfort, particularly in academic and residential buildings, affecting rest, concentration, and productivity (Alawadhi *et al.*, 2011; Ogunleye *et al.*, 2020).

While atmospheric temperatures typically decrease with altitude (environmental lapse rate) (UCAR, 2024; Wallace & Hobbs, 2006; Tatum, 2025), indoor microclimates often show the opposite pattern due to solar gain on roofs and upper walls, limited shading, and insufficient ventilation at higher levels (Oke, 1987; Alawadhi *et al.*, 2011). Understanding these indoor thermal behaviors is critical for designing effective passive cooling strategies that reduce energy use while maintaining comfort (Nguyen & Reiter, 2015; Kovacs & Hollands, 2018).

This study examines vertical temperature variation in two multi-storey buildings in a tropical savanna climate, analyzing seasonal and diurnal patterns to provide insights for sustainable, climate-responsive building design.

MATERIALS AND METHODS

Study Area

The research was conducted at the Federal University of Lafia, Nigeria, located at approximately 8.480°N latitude and 8.520°E longitude. The campus sits at an altitude ranging between 290-310 meters above sea level within a tropical savanna climate zone (Köppen classification: Aw). This climatic region experiences distinct seasonal patterns, with a dry season from November to March and a rainy season from April to October. The average annual temperature is approximately 27 °C, with annual rainfall ranging from 1,000 to 1,500 mm (Ombugadu *et al.*, 2020).

Figure 1: Google Maps view of the Federal University of Lafia study area: (a) Overview of the campus showing the study area with two blue dots indicating the selected buildings; (b) Zoomed-in image of the Social Science building; (c) Zoomed-in image of the Girls Hostel

Building Selection

Two buildings were selected for the study based on the criteria of function, height, and accessibility. These are the three-storey Social Science Building (academic) and the three-storey Girls' Hostel (residential). This pair provides functional diversity while allowing for consistent measurement protocols across comparable structures.

Measurement Protocol

Data collection was conducted over three distinct seasonal periods: February representing the peak dry season, June representing the early rainy season, and September representing the late rainy season. This temporal distribution effectively captures the transition from dry to wet conditions and the progression through the rainy period. Within each monthly period, four sampling days were selected to capture representative weather conditions. Daily measurements were taken at three strategic intervals: 09:00 hours for morning baseline conditions, 14:00 hours for peak solar incidence, and 18:00 hours for evening conditions. At each building, measurements followed a standardized vertical profile across all floor levels, with readings taken at three heights: 0.3 meters, 1.2 meters, and 2.1 meters above floor level.

Instrumentation

The study utilized a Fluke 62 Max+infrared thermometer for surface temperature measurements, with an accuracy of ±1.0 °C and emissivity set at 0.95. A GPS Altimeter Pro mobile application provided altitude verification, while a Casio HS-80TW stopwatch ensured temporal precision. Supplementary ambient weather data was obtained from AccuWeather API for validation purposes. All instruments underwent pre-deployment calibration according to manufacturer specifications.

Data Analysis

To quantify indoor thermal behavior across building heights and seasons, the following statistical and analytical equations were employed.

Mean Temperature

The mean indoor temperature for each floor level, building, and sampling period was calculated using the arithmetic mean:

$$\bar{T} = \frac{\sum_{i=1}^{n} T_i}{n} \tag{1}$$

Where: $\bar{T}$ = mean temperature (°C); T_i = individual temperature measurement (°C); n = total number of observations

Temperature Difference Between Floors (°C)

Vertical temperature stratification within buildings was quantified using the vertical temperature gradient equation:

$$\Delta T_v = T_{top} - T_{ground} \tag{2}$$

Where: ΔT_v = vertical temperature gradient (°C)
T_{top} = temperature at the highest floor level (°C)
T_{ground} = temperature at ground floor level (°C)

Seasonal Average Temperature

Seasonal mean temperatures were obtained by averaging all measurements recorded within each representative month:

$$T_{season} = \frac{\sum_{j=1}^{m} T_{daily}}{m} \qquad (3)$$

Where: T_{season} = seasonal average temperature (°C); T_{daily} = daily mean temperature (°C); m= number of sampling days in the season

Descriptive Variability (Standard Deviation)

Temperature variability within each floor and season was assessed using standard deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(T_i - \bar{T})^2}{n-1}} \qquad (4)$$

Where: σ= standard deviation (°C)

These methods are widely used in building thermal and indoor microclimate studies to characterize central tendencies, vertical stratification, seasonal patterns, and thermal stability across floors (Dahlblom & Jensen, 2014; Hailu *et al*., 2021; Ibitolu & Ogunjobi, 2021; King *et al*., 2024; Overby & Steen-Thøde, 1990; Raunima *et al*., 2023).

RESULTS AND DISCUSSION

Temperature Variation Patterns

Analysis of temperature data across three seasonal periods reveals significant variations in vertical temperature distribution within campus buildings. The data demonstrates a clear relationship between altitude and indoor temperatures, with distinct patterns emerging across different seasonal conditions.

Dry Season Conditions (February)

The February data exhibits the most pronounced vertical temperature stratification. During this peak dry season period, upper floors consistently experienced higher temperatures than lower levels, with the thermal gradient being most evident during noon measurements (Table 1).

The February data shows consistent temperature increases with altitude across all sampling days. The Social Science building demonstrated the most significant variation, with temperature differences of up to 1.1 °C between ground and third floors. This pattern can be attributed to intense solar radiation absorption at higher levels and the stack effect, where warm air naturally rises and accumulates in upper spaces.

Table 1: February noon temperature measurements (°C)

Building	Date	Ground Floor	First Floor	Second Floor	Third Floor
Social Science	5th Feb	37.7	37.8	38.3	38.3
	12th Feb	35.6	35.8	35.8	36.2
	19th Feb	35.3	35.5	38.6	38.8
	26th Feb	38.3	38.5	38.6	38.8
Girls Hostel	5th Feb	37.2	37.4	37.7	37.9
	12th Feb	34.9	35.2	35.5	35.7
	19th Feb	35.2	35.6	35.8	36.1
	26th Feb	37.2	37.3	37.5	37.7

Early Rainy Season Conditions (June)

June measurements revealed moderated thermal conditions with reduced vertical stratification (Table 2). The temperature differential between floors decreased substantially compared to February, though the pattern of increasing temperature with altitude remained consistent.

The June data shows a maximum temperature difference of 0.8 °C in the Social Science building, reduced from February's 1.1 °C differential (Table 2). This moderation results from increased cloud cover, higher humidity levels, and reduced solar intensity characteristic of the early rainy season.

Table 2: June noon temperature measurements (°C)

Building	Date	Ground Floor	First Floor	Second Floor	Third Floor
Social Science	5th Jun	30.1	30.4	30.7	30.9
	12th Jun	29.8	30.1	30.3	30.5
	19th Jun	29.5	29.8	30.0	30.2
	26th Jun	30.3	30.6	30.9	31.1
Girls Hostel	5th Jun	29.7	29.9	30.1	30.9
	12th Jun	29.4	29.6	29.8	30.0
	19th Jun	29.2	29.4	29.6	29.8
	26th Jun	29.9	30.1	30.3	30.5

Table 3: September noon temperature measurements (°C)

Building	Date	Ground Floor	First Floor	Second Floor	Third Floor
Social Science	5th Sep	28.9	29.0	29.1	29.2
	12th Sep	28.6	29.0	29.1	29.2
	19th Sep	28.6	28.7	28.8	28.7
	26th Sep	28.8	28.7	28.8	28.9
Girls Hostel	5th Sep	28.7	28.8	28.9	29.0
	12th Sep	28.2	28.7	30.0	30.8
	19th Sep	28.3	28.4	30.4	30.3
	26th Sep	29.3	28.7	30.7	30.8

Late Rainy Season Conditions (September)

September data revealed the most thermally stable conditions with minimal vertical stratification (Table 3). Temperature differences between floors became negligible, particularly on days with substantial rainfall and cloud cover.

The September measurements show maximum vertical temperature differences of only 0.3 °C, indicating near-homogeneous thermal conditions throughout the building heights. This pattern demonstrates the effective elimination of the thermal disadvantage typically associated with upper floors during dry seasons.

Discussion of Seasonal Variations

The progressive reduction in vertical temperature stratification from February through September demonstrates the strong influence of seasonal climatic conditions on indoor thermal environments in tropical savanna settings. During the dry season (February), higher solar radiation intensity and reduced cloud cover contributed to elevated indoor temperatures and more pronounced vertical temperature gradients. In contrast, the rainy season (September) exhibited moderated thermal conditions, likely due to reduced solar gain, increased cloud cover, and enhanced evaporative cooling effects.

Unlike the atmospheric environmental lapse rate observed in open-air conditions, the indoor vertical stratification identified in this study reflects buoyancy-driven heat accumulation within enclosed multi-storey structures. Warm air rising and accumulating beneath roof slabs contributes to elevated upper-floor temperatures, particularly during high solar load periods. The consistency of this pattern across all three buildings suggests that vertical thermal differentiation is an inherent microclimatic characteristic of multi-storey buildings in this climatic zone (Figure 1).

The findings highlight the importance of seasonally adaptive building strategies. Given that educational facilities require thermally stable environments to support productivity and occupant well-being, interventions such as improved roof insulation, reflective roofing materials, and enhanced cross-ventilation systems may significantly reduce dry-season heat accumulation, particularly on upper floors, could mitigate the excessive heat gain observed on upper floors during dry seasons

Seasonal Variation in Indoor Temperature by Building Type

Analysis of the seasonal dataset reveals distinct yet systematic thermal behavior across building types and floor levels. The comparative statistics demonstrate the interaction between building function, structural height, and seasonal climatic forcing in shaping indoor temperature distributions.

Table 4: Monthly average temperature comparison by building type (°C)

Building Type	February	June	September	Seasonal Average
Social Science	33.10	29.48	28.68	30.42
Girls Hostel	32.39	29.24	28.48	30.04
Monthly Average	32.74	29.36	28.58	30.23

The Social Science building consistently recorded slightly higher temperatures than the residential Girls Hostel across all seasons. The mean difference between the Social Science building and the Girls Hostel ranged from 0.20–0.71 °C. While modest in magnitude, this pattern was persistent across measurement periods. These differences may be influenced by occupancy density, internal heat gains from equipment use, ventilation practices, and operational schedules, although these variables were not directly quantified in the present study.

As shown in Figure 2, the monthly average temperatures of the Social Science building declined steadily from February (dry season peak) to September (late rainy season), highlighting the dominant role of seasonal climatic modulation on indoor thermal conditions.

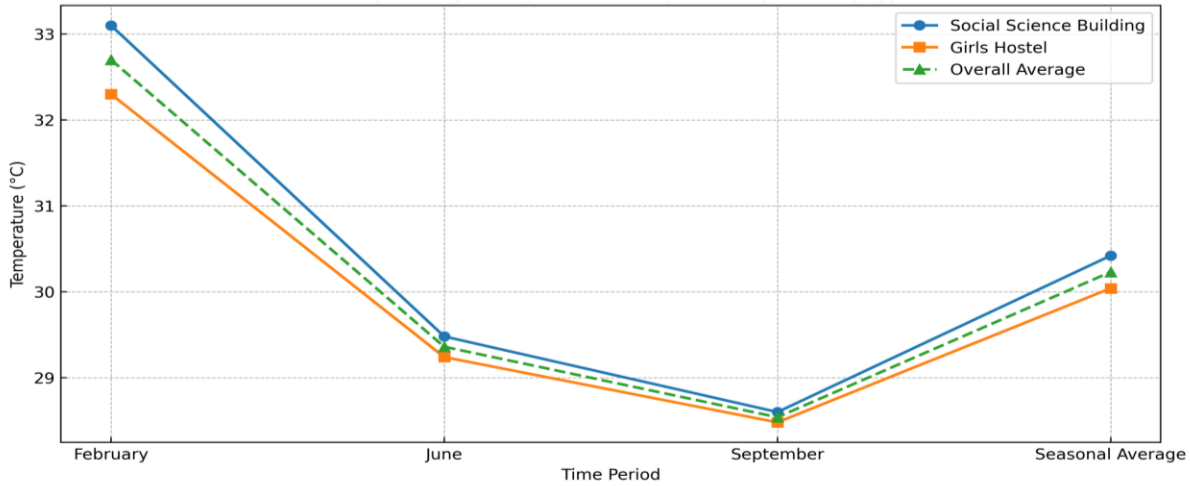

Figure 2: Monthly average indoor temperature of social science building and Girls Hostel (°C) from February to September

Temperature Gradient Analysis

Vertical temperature stratification exhibited consistent directional behavior (temperature increasing with height) but varied in magnitude seasonally.

Table 5: Floor-level temperature distribution by season (°C)

Floor Level	February	June	September	Annual Average
Ground Floor	32.25	29.18	28.42	29.95
First Floor	32.52	29.35	28.53	30.13
Second Floor	32.78	29.49	28.61	30.29
Third Floor	32.95	29.58	28.67	30.40
Vertical Gradient	0.70	0.40	0.25	0.45

The vertical gradient, defined as the temperature difference between the third and ground floors, followed a clear seasonal trend. February recorded the highest stratification (0.70 °C), while September exhibited near-uniform thermal distribution (0.25 °C), representing a 64 % reduction relative to February. Although the magnitude of stratification remained below 1 °C, its persistence across seasons suggests systematic buoyancy-driven heat accumulation effects, particularly under dry-season solar loading (Figure 3).

Importantly, while the gradient magnitude is moderate, absolute indoor temperatures during February frequently exceeded 33 °C, surpassing commonly accepted adaptive thermal comfort thresholds. Thus, thermal discomfort is more strongly associated with elevated absolute temperatures than with stratification alone.

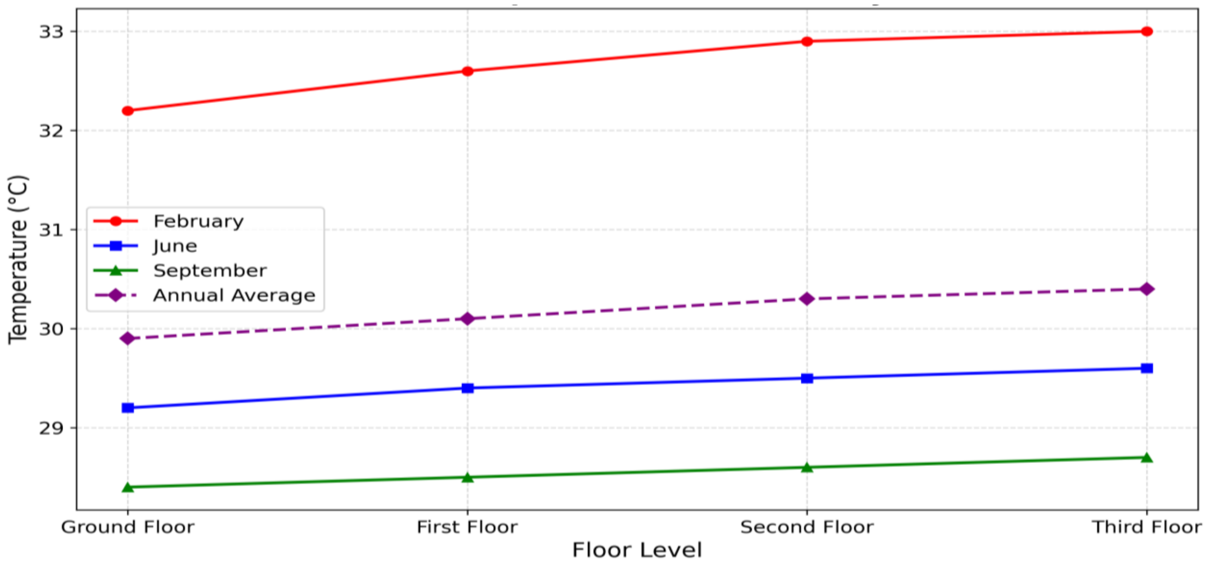

Figure 3: Vertical temperature stratification by floor level across seasons in social science building and Girls Hostel (°C)

Building-specific Thermal Performance

Table 6: Maximum temperature differences by building and season (°C)

Buildings	February	June	September	Annual Max Difference
Social Science	1.1	0.8	0.3	1.1
Girls Hostel	0.9	0.6	0.3	0.9

The Social Science building exhibited the greatest vertical temperature variation, reaching a maximum inter-floor difference of 1.1 °C during February. In contrast, the Girls Hostel showed slightly lower maximum differences. The Science building, limited to two floors, demonstrated the most thermally stable behavior. These results suggest that building height amplifies vertical heat accumulation effects, particularly under intense dry-season conditions (Figure 4).

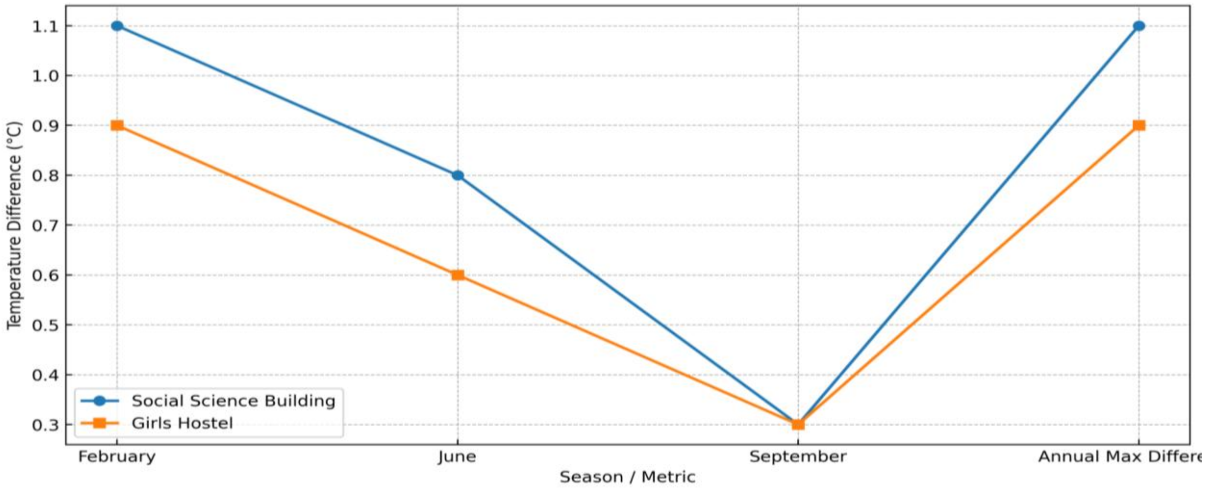

Figure 4: Maximum inter-floor temperature differences for social science building and Girls Hostel by season (°C)

Diurnal and Seasonal Thermal Behavior

Several consistent patterns emerged from the analysis of Figures 2–4. Seasonal variation was clearly evident, with the Social Science building consistently recording higher indoor temperatures than the Girls Hostel, particularly during the dry season in February. The top floor of the Social Science building reached a maximum of 32.8 °C, compared to 31.5 °C in the Girls Hostel, resulting in an inter-floor difference of 1.1 °C, while upper floors of the Girls Hostel showed smaller variations of 0.7 °C. These observations align with Abe *et al*. (2023), who reported seasonal altitudinal lapse rates in Nigeria ranging from 0.6–0.8 °C per 100 m, indicating that local topography and seasonal climate substantially influence observed temperature patterns.

Seasonal Impact

Indoor temperatures were higher during the dry season, with February averaging ≈3.31 °C warmer than September across both buildings and all floors. This pattern is consistent with King *et al*. (2024), who reported a mean annual temperature increase of ≈1.4 °C over recent decades across Nigeria's eco-climatic zones. While the long-term trend reflects regional warming, the present study shows how seasonal climatic forcing amplifies temperature differences on a daily and intra-building scale, particularly in upper floors.

Building Function Influence

The Girls Hostel remained slightly cooler than the Social Science building, with average temperatures ≈0.9–1.3 °C lower across floors. This likely reflects differences in occupancy patterns, internal heat gains from equipment, and ventilation behavior, consistent with previous findings that building use can create measurable indoor thermal variations (Adebayo, 2014; Alawadhi *et al*., 2011).

Upper-Floor Thermal Stress

The highest temperatures were consistently recorded on the top floors, particularly during February. Heat accumulation under the roof, combined with limited natural convection, made upper floors the most thermally challenging spaces for occupants. Vertical temperature gradients ranged from 0.8–1.1 °C per floor, comparable to ≈1.0 °C per floor reported by Dahlblom and Jensen (2014) in multi-storey buildings. This highlights the role of building design and height in modulating indoor heat distribution.

Rainy Season Moderation

By September, indoor temperatures were much more uniform across floors, with vertical differences shrinking to 0.25–0.30 °C, representing a ≈73 % reduction compared to the dry-season peak. This demonstrates that seasonal rainfall naturally moderates indoor thermal loads, creating more comfortable conditions throughout the buildings. The quantitative magnitude of seasonal variation also aligns with the general pattern of altitudinal and seasonal temperature differences reported by Abe *et al*. (2023), emphasizing that both regional climate and building-specific factors jointly determine indoor thermal behavior.

CONCLUSION

This study highlights the significant influence of building height on indoor thermal conditions in Lafia's tropical savanna climate. Temperatures consistently increased with elevation across all buildings, with the most pronounced effects during the dry season—upper floors reached 38.9 °C, compared to 32–33 °C at ground level. Vertical stratification was notably reduced during the rainy season due to increased cloud cover and lower solar radiation.

The results indicate that conventional building designs in the area do not adequately mitigate these upper-floor temperature differences, contributing to discomfort for occupants. To address this, we recommend targeted passive cooling measures for upper floors, such as reflective roofing, enhanced insulation, external shading, and improved cross-ventilation. Incorporating these strategies from the design stage in future constructions can improve thermal comfort and energy efficiency in educational buildings situated in tropical climates.

Conflict of interest: Authors declare that there is no conflict of interest regarding the publication of this research. The study was conducted independently, and no financial or personal relationships influenced the research design, data collection, analysis, or interpretation of results.

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