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## THERMAL COMFORT PERFORMANCE IN MIXED-USE HIGH-RISE BUILDINGS IN SOUTHWESTERN NIGERIA: IMPLICATIONS FOR CLIMATE-RESPONSIVE DESIGN IN OGBOMOSO

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### ABSTRACT

*Thermal comfort is a critical component of indoor environmental quality in mixed-use high-rise buildings, particularly within hot-humid urban environments where solar exposure, inadequate ventilation, and dependence on mechanical cooling can significantly affect occupant well-being and building performance. This study evaluates thermal comfort conditions in selected mixed-use high-rise buildings in Ibadan, Southwestern Nigeria, with the aim of informing the design of a thermally efficient and climate-responsive mixed-use high-rise development in Ogbomoso. The study adopted a mixed-methods approach, combining questionnaire surveys, field measurements, environmental assessment, and thermal comfort modelling across selected high-rise buildings. A total of 270 valid occupant responses were analysed using descriptive statistics, Mean Weighted Value (MWV), and thermal comfort indicators, while environmental conditions were assessed using PMV/PPD and the Adaptive Comfort Model. Findings indicate that occupants generally experience warm indoor conditions, with overheating, inadequate airflow, humidity, and dependence on mechanical cooling emerging as major concerns. Mechanical cooling recorded the highest perception score (MWV = 3.56), while frequent overheating recorded an MWV of 3.31. Thermal modelling further indicated positive PMV values ranging from +0.7 to +1.2, with corresponding PPD values of 17–30%, confirming a general tendency toward warm thermal conditions. Among the case studies, Premier Hotel demonstrated comparatively better thermal performance, while Cocoa House recorded the greatest thermal stress. Respondents showed strong support for passive and climate-responsive measures, particularly passive cooling (MWV = 3.92), natural ventilation (MWV = 3.88), climatic responsiveness (MWV = 3.89), and occupant comfort as a design priority (MWV = 3.98). The study concludes that thermal performance in mixed-use high-rise buildings is strongly influenced by the interaction of architectural configuration, climatic conditions, passive design measures, and occupant adaptation. It recommends that future high-rise developments in Ogbomoso prioritize building orientation, solar shading, natural ventilation, thermally responsive façades, appropriate material selection, green infrastructure, and adaptive comfort principles to reduce mechanical cooling dependence and improve occupant comfort.*

**Keywords:** Thermal comfort; mixed-use high-rise buildings; passive design; climate-responsive architecture; PMV/PPD; adaptive comfort; Ibadan; Ogbomoso; Nigeria.

## I. INTRODUCTION

Rapid urban growth in Ibadan has intensified the need for high-density and mixed-use developments as available land becomes increasingly constrained and population and infrastructure demands continue to rise (Ogunsola, Ojo, and Ibrahim, 2026). According to Wood and Salib (2013), the combination of residential, commercial, and office uses within high-rise buildings creates diverse occupancy patterns and considerable internal heat loads, which can make the achievement of thermal comfort particularly challenging under warm climatic conditions. Maintaining suitable thermal conditions is important for occupants' health, satisfaction, and productivity (Jain, 2024). However, the performance of many Nigerian high-rise buildings is strongly dependent on mechanical cooling, partly due to inadequate passive design, unsuitable building orientation, and inappropriate material selection (Ahmad, 2025). Such dependence contributes to increased energy demand and is particularly problematic within Nigeria's constrained electricity supply system, raising broader concerns regarding the sustainability and resilience of the country's rapidly developing urban environments (Oyedepo, 2012).

The applicability of conventional thermal comfort standards in tropical settings also remains a concern. Many established comfort models were developed from studies undertaken in temperate regions and controlled experimental environments (Chang, 2016), while occupants in tropical climates may respond to thermal conditions through behavioural, physiological, and cultural adaptations (Tochihara, 2025). Despite these climatic and contextual differences, thermal comfort evaluations in Nigeria continue to make substantial use of internationally developed models, often with limited validation against local occupant experiences (Olawale and Mohammed, 2026). Moreover, recent findings by Ilgin and Aslantamer (2024) has predominantly examined residential and institutional buildings, leaving mixed-use high-rise buildings comparatively underexplored despite their more complex patterns of occupancy, activity, and internal heat generation. Studies that directly compare calculated thermal comfort conditions with occupants' actual perceptions are also relatively scarce (Heng and Chow, 2019).

Ibadan therefore provides an important context for examining the relationship between predicted and perceived thermal comfort in mixed-use high-rise buildings (Billy, 2025). However, the limited availability of empirical evidence from the city restricts the development of context-responsive design strategies (Ajayi, Oladunmoye, and Taiwo, 2026). This limitation is particularly relevant to emerging urban centres such as Ogbomoso, where ongoing urban expansion provides an opportunity to incorporate climate-responsive principles before inappropriate building practices become established (Silva, 2021). This study consequently assesses thermal comfort conditions in selected mixed-use high-rise buildings in Ibadan, with the aim of generating empirical evidence and practical design recommendations that can support sustainable high-rise development in Ogbomoso and comparable emerging cities in Nigeria.

## II. LITERATURE REVIEW

### 2.1 Thermal Comfort in Buildings

Thermal comfort refers to the extent to which occupants consider the thermal conditions of an indoor environment acceptable (Frontczak, and Wargocki, 2011). It is an important component of indoor environmental quality because thermal conditions can influence

occupants' health, satisfaction, productivity, and overall experience of a building (Aigbavboa, Thwala, 2019). Thermal conditions are influenced by environmental variables such as air temperature, relative humidity, air velocity, and mean radiant temperature, as well as personal factors including clothing and metabolic activity (Salthammer and Morrison, 2022). According to Elghamry and Hassan (2020), architectural characteristics, including building orientation, façade configuration, shading, window-to-wall ratio, and envelope materials, also play important roles in determining indoor thermal conditions.

Studies by Fabbri (2024) reveal that thermal comfort is not solely dependent on measurable environmental conditions because individuals exposed to similar conditions may experience different levels of comfort. Personal expectations, previous experiences, behavioural responses, and the degree of control occupants have over their environment can influence thermal perception (Mahdavi, 2020). Consequently, thermal comfort assessment generally combines physical measurements with subjective responses to provide a more comprehensive understanding of indoor thermal conditions (Elnabawi and Hamza, 2019). Two major approaches have emerged in this field: the static or heat-balance model and the adaptive model, with the latter giving greater consideration to occupants' ability to adjust to changing environmental conditions (Schweiker, 2022).

## **2.2 Thermal Comfort Models**

The Predicted Mean Vote (PMV) model is one of the most widely used methods for assessing thermal comfort (Zhang and Lin, 2020). It predicts the average thermal sensation of a group of occupants using a seven-point scale ranging from -3 (cold) to +3 (hot), while 0 represents thermal neutrality. The associated Predicted Percentage Dissatisfied (PPD) index estimates the proportion of occupants likely to find the thermal environment unacceptable (Fabbri, 2024). PMV and PPD are calculated using air temperature, mean radiant temperature, air velocity, relative humidity, clothing insulation, and metabolic rate as the principal input variables (Sirhan and Golan, 2021).

Although PMV provides a standardized and quantitative approach to thermal comfort assessment, its applicability across different climates and building conditions has been questioned (Laouadi, 2022). Field studies have shown that occupants, particularly those in naturally ventilated buildings, can accept temperatures outside the ranges predicted by the conventional PMV model (Nasrollahi, 2026). This has contributed to increased interest in adaptive thermal comfort, which recognizes that occupants respond to their environment through changes in clothing, activity, ventilation behaviour, and expectations (Parsons, 2019).

According to Kim and De Dear (2021), the adaptive approach is particularly relevant to naturally ventilated and mixed-mode buildings because it relates acceptable indoor conditions to prevailing outdoor climate and occupant adaptation. Its relevance is heightened in tropical environments, where climatic conditions, cultural practices, and behavioural responses may differ substantially from those of the temperate regions in which many conventional comfort models were developed. Consequently, selecting an appropriate comfort model is important when assessing thermal conditions in Nigerian buildings.

## **2.3 Mixed-Use High-Rise Buildings and Thermal Performance**

Mixed-use high-rise buildings accommodate different functions, such as residential, commercial, and office activities, within a single development (Ilgin and Aslantamer, 2024).

The combination of these uses creates varying occupancy schedules, activity levels, internal heat gains, and environmental requirements. Consequently, thermal conditions may differ considerably between functional areas and across different levels of a high-rise building (Du and Pan, 2022). Building orientation, façade design, glazing ratio, solar exposure, floor level, shading, envelope materials, ventilation, and mechanical cooling systems can all influence the resulting thermal performance (Cui, 2024).

Passive design strategies such as appropriate building orientation, external shading, natural ventilation, suitable glazing, and thermal mass can reduce unwanted solar heat gain and improve indoor thermal conditions as implied by Duraković (2020). Active systems, including efficient HVAC equipment and intelligent building controls, can complement these measures where passive strategies are insufficient (Das, 2025). However, because occupants in mixed-use high-rise buildings have different patterns of use and thermal expectations, evaluating performance through physical building characteristics alone may not adequately reflect their actual thermal experiences (Agboola, 2025).

## **2.4 Post-Occupancy Evaluation and Thermal Comfort**

Post-Occupancy Evaluation (POE) provides a systematic approach for assessing how effectively an occupied building performs in relation to its intended environmental and functional objectives (Oseland, 2023). Over time, POE has expanded beyond the identification of physical and operational deficiencies to include energy performance, indoor environmental quality, occupant satisfaction, and user experience (Taipale, 2021). Its application to thermal comfort studies allows environmental measurements to be considered alongside the perceptions of actual building users.

The combination of measured thermal conditions and occupant responses is particularly important because similar environmental conditions may not produce identical perceptions of comfort (Yang and Moon, 2019). In mixed-use high-rise buildings, POE can identify variations between functional spaces, reveal differences between predicted and perceived comfort, and highlight deficiencies associated with building design or operation (Farahani, 2025). Such findings can provide practical evidence for improving existing buildings and developing more context-responsive strategies for future high-rise developments (Boostani and Altan, 2026).

## **2.5 Research Gap**

Although thermal comfort has received considerable attention internationally, the applicability of established comfort models remains an important concern in tropical regions, where climatic conditions and occupant adaptation can differ from those of the environments in which many conventional models were developed (Williamson and Daniel, 2020). In Nigeria, existing studies have examined thermal comfort in various building types, but comparatively limited research has focused on mixed-use high-rise buildings, despite their complex occupancy patterns, varying internal heat loads, and differences in environmental exposure (Okonkwo, 2024).

Furthermore, there is limited empirical research that combines measured indoor thermal conditions with occupants' perceptions in Nigerian mixed-use high-rise buildings (Ahmad, 2025). This creates a gap between predicted thermal performance and actual user experience. This study therefore evaluates thermal comfort in selected mixed-use high-rise buildings in

Ibadan by integrating environmental assessment with occupant perception. The findings are intended to provide context-specific evidence and design guidance for sustainable high-rise development in Ogbomoso and other emerging cities in Nigeria.

### **III. RESEARCH METHODOLOGY**

#### **Research Design**

The study adopted a mixed-method approach combining field measurements, occupant surveys, and architectural assessment to evaluate thermal comfort in selected mixed-use high-rise buildings in Ibadan. Environmental measurements covered indoor air temperature, relative humidity, air velocity, and mean radiant temperature across selected residential, commercial, and circulation spaces at different periods of the day. The measurements were assessed against established thermal comfort criteria, including PMV/PPD and relevant adaptive comfort benchmarks.

A structured questionnaire was administered to building users to obtain information on thermal sensation, comfort satisfaction, preferred conditions, and adaptive practices such as window operation, fan use, and clothing adjustment. Architectural assessment was also undertaken to examine building orientation, façade configuration, window-to-wall ratio, shading, ventilation, spatial arrangement, and envelope materials. These data were integrated to compare measured thermal conditions with occupants' perceptions and identify factors affecting thermal performance.

#### **Data Sources**

Both primary and secondary data were used. Primary data were obtained through indoor environmental measurements, occupant questionnaires, and on-site architectural observations in the selected buildings. Secondary data were obtained from relevant journals, textbooks, climatic records, architectural documents, and thermal comfort standards, particularly ASHRAE Standard 55 and ISO 7730. These sources provided the benchmarks and theoretical basis for interpreting the field findings.

#### **Study Population**

The study population comprised regular users of the selected mixed-use high-rise buildings, including residential occupants, office workers, commercial users, and relevant facility personnel as seen in Table 1. Participants were selected based on their regular exposure to the indoor environments, enabling them to provide informed assessments of the thermal conditions experienced within the buildings. The inclusion of different user groups also allowed variations in thermal perception across the mixed-use functions to be examined.

**Table 1: Selected Mixed-Use High-Rise Buildings and Sample Size**

| SN | Selected Building      | Estimated Occupant Population | Sample Size (@ 28%) | Facility Managers |
|----|------------------------|-------------------------------|---------------------|-------------------|
| 1  | Cocoa House (Dugbe)    | 300                           | 83                  | 2                 |
| 2  | Premier Hotel (Mokola) | 350                           | 97                  | 2                 |
| 3  | Jericho Business Tower | 400                           | 110                 | 2                 |
|    | <b>Total</b>           | <b>1,050</b>                  | <b>290</b>          | <b>6</b>          |

*Source: Author's compilation (2026)*

### Sampling Frame

The sampling frame comprised mixed-use high-rise buildings within Ibadan. A reconnaissance survey of major commercial and high-density areas identified six buildings that met the study criteria. The selected buildings accommodate combinations of residential, commercial, office, and service functions within vertically integrated structures. Selection was based on their mixed-use character, high-rise configuration, occupancy level, accessibility for field investigation, and suitability for environmental monitoring.

### Data Collection

Three methods were employed: environmental measurement, questionnaire survey, and architectural observation. Environmental instruments were used to record air temperature, relative humidity, air velocity, and mean radiant temperature at designated points within the selected buildings. Measurements were taken at different periods to capture variations in indoor conditions.

The questionnaire assessed occupants' thermal sensation, comfort level, satisfaction, preferred conditions, and adaptive behaviours. Architectural observations were used to document building orientation, window configuration, shading devices, façade characteristics, ventilation provisions, materials, and spatial organization.

### Data Analysis

The collected data were analyzed using descriptive and inferential statistics. Environmental measurements were summarized and compared with established thermal comfort criteria, while PMV/PPD values were used to assess predicted thermal sensation and the percentage of potentially dissatisfied occupants where applicable. Questionnaire responses were analyzed using frequencies, percentages, and mean values, while chi-square analysis was employed to examine associations between selected categorical variables and thermal responses. The results were subsequently compared with the architectural observations to identify relationships between building characteristics, measured conditions, and occupants' thermal perceptions.

## IV. DATA ANALYSIS

### Introduction

This section presents the analysis of climatic conditions relevant to thermal comfort in Ibadan, Oyo State, Nigeria. Secondary climatic information obtained from the WeatherSpark climate database, based on meteorological records and NASA MERRA-2 reanalysis data, was examined for the period 2020–2026. The variables considered include temperature, rainfall, wind characteristics, relative humidity, solar radiation and evapotranspiration.

To provide a concise representation of the climatic conditions, the annual observations were consolidated into a single monthly climatic profile. The resulting averages provide an indication of the dominant environmental conditions that may influence thermal performance and occupant comfort in mixed-use high-rise buildings within the study area.

#### (i) Climatic Characteristics of Ibadan

The climatic profile presented in Table 2 demonstrates considerable seasonal variation in Ibadan, although temperatures remain generally high throughout the year. The seven-year monthly averages show that the warmest conditions occur between February and April, with average temperatures ranging from 29.71°C to 30.06°C and maximum temperatures reaching approximately 31.94–33.24°C. The coolest period occurs between July and September, when average temperatures decline to approximately 26.57–26.93°C. This seasonal pattern indicates that buildings are exposed to substantial thermal loads for much of the year, while the relatively cooler rainy-season months provide some opportunity for passive cooling.

The rainfall and humidity patterns reinforce the seasonal character of the climate. Rainfall activity increases considerably from April, reaching an average of 17.57 rainy days in June and 16.86 days in September. Relative humidity similarly rises from approximately 69–70% during December to February to above 81% between June and October, peaking at 82.86% in August. The combination of elevated temperature and high humidity is particularly significant for thermal comfort because it can restrict the effectiveness of evaporative cooling and increase the perception of heat, making adequate air movement an important architectural consideration.

Wind conditions provide a potentially useful passive cooling resource. Average wind speed ranges from approximately 3.96 m/s in November to 5.97 m/s in August, with the stronger winds generally occurring during the middle of the rainy season. The predominant wind direction varies between approximately 206° and 237°, indicating a broadly south-westerly to southerly airflow pattern. Solar radiation is comparatively higher during the drier months, reaching an average of 17.17 MJ/m<sup>2</sup> in January and 16.89 MJ/m<sup>2</sup> in February, while the lowest values occur around July and August. These conditions indicate the importance of building orientation, solar shading, appropriate glazing, natural ventilation and façade design in moderating heat gain within mixed-use high-rise buildings.

#### (ii) Temperature Characteristics

Temperature represents one of the most important climatic determinants of thermal comfort in the study area. The consolidated data show that Ibadan experiences relatively high temperatures throughout the year, with the seven-year monthly average ranging from 26.57°C

in August to 30.06°C in March. Maximum temperatures are highest in January and December, at approximately 33.24°C and 33.16°C respectively, while the lowest maximum temperature occurs in August at 28.34°C. The relatively narrow annual temperature range demonstrates that thermal stress is not restricted to a short hot season but remains an important consideration for building design throughout the year.

The temperature pattern has direct implications for mixed-use high-rise buildings because different activities and occupancy levels may generate additional internal heat. The warmer conditions between December and April, combined with relatively high solar exposure, may increase indoor cooling requirements. Conversely, the lower temperatures recorded between June and September coincide with increased rainfall, humidity and wind movement. This suggests that passive strategies such as cross-ventilation, effective shading, appropriate orientation and reduction of unnecessary solar heat gain can play an important role in maintaining acceptable indoor conditions.

### **(iii) Rainfall and Humidity Characteristics**

Rainfall exhibits a pronounced seasonal pattern, increasing substantially from April and reaching its highest average number of rainy days in June. September also records a high frequency of rainfall, with approximately 16.86 rainy days. Rainfall intensity is particularly notable in May, when the seven-year average reaches approximately 101.16 mm/hr, followed by April at 64.61 mm/hr and June at 65.77 mm/hr. These conditions indicate that the wet season presents not only frequent rainfall but also periods of intense precipitation that should be considered in building envelope, drainage and site-planning decisions.

Relative humidity follows a similar seasonal progression. Average humidity remains around 69–70% during January, February and December but rises above 80% from June through October, reaching approximately 82.86% in August. From a thermal comfort perspective, this is important because high humidity reduces the body's ability to lose heat through evaporation. Consequently, natural ventilation and adequate air movement become particularly important during the humid months. For high-rise buildings, façade openings, operable windows, ventilation corridors and appropriate building orientation can therefore contribute significantly to improving perceived thermal comfort.

### **(iv) Wind Characteristics**

Wind conditions indicate a useful potential for natural ventilation within the study area. Average wind speed ranges from 3.96 m/s in November to 5.97 m/s in August, with relatively stronger airflow occurring between July and September. The wind direction generally falls between approximately 205° and 237°, corresponding broadly to southerly and south-westerly airflow. This consistency provides a useful basis for considering building orientation and the positioning of openings to improve natural air movement.

The relationship between wind speed and humidity is particularly relevant to thermal comfort. The strongest average wind movement occurs around July and August, when relative humidity is also highest. Increased air movement during these periods can assist occupants by improving convective and evaporative heat loss. This supports the incorporation of cross-ventilation, strategically positioned openings, ventilated façades and internal spatial arrangements that allow air to move effectively through occupied spaces.

### (v) Solar Radiation and Evapotranspiration

Solar radiation varies considerably across the year, with higher values occurring during the drier months and lower values during the wetter period. The highest seven-year monthly average is recorded in January at approximately 17.17 MJ/m<sup>2</sup>, followed closely by February at 16.89 MJ/m<sup>2</sup>. Radiation decreases progressively toward July, when the average reaches approximately 11.41 MJ/m<sup>2</sup>. This reduction corresponds with the increased cloudiness and rainfall associated with the wet season.

The solar pattern has important implications for the thermal performance of high-rise buildings because increased solar exposure can contribute substantially to heat gain through roofs, walls and glazed façades. The data therefore support the use of external shading, appropriate window-to-wall ratios, solar-control glazing and façade articulation to reduce direct solar penetration. Evapotranspiration also follows a generally related pattern, increasing during the drier months and declining during the wetter season. This suggests that landscape elements and vegetation may contribute to microclimatic moderation, although their effectiveness will depend on appropriate placement and adequate moisture availability.

**Table 2: Monthly Climatic Profile of Ibadan, 2026**

| Month     | Max. Temp. (°C) | Min. Temp. (°C) | Avg. Temp. (°C) | Rainy Days (days) | Rainfall Intensity (mm/hr) | Wind Direction (°) | Wind Speed (m/s) | Relative Humidity (%) | Solar Radiation (MJ/m <sup>2</sup> ) | Evapotranspiration (mm) |
|-----------|-----------------|-----------------|-----------------|-------------------|----------------------------|--------------------|------------------|-----------------------|--------------------------------------|-------------------------|
| January   | 33.24           | 25.41           | 29.29           | 1.71              | 12.74                      | 205.71             | 4.44             | 70.00                 | 17.17                                | 4.31                    |
| February  | 33.11           | 26.20           | 29.71           | 3.43              | 30.24                      | 217.14             | 4.94             | 69.57                 | 16.89                                | 4.31                    |
| March     | 32.47           | 27.60           | 30.06           | 5.57              | 43.73                      | 222.86             | 5.26             | 76.29                 | 14.20                                | 3.63                    |
| April     | 31.94           | 27.49           | 29.71           | 10.00             | 64.61                      | 218.57             | 4.87             | 75.57                 | 13.46                                | 3.43                    |
| May       | 31.53           | 26.76           | 29.11           | 12.57             | 101.16                     | 214.29             | 4.57             | 77.43                 | 12.91                                | 3.24                    |
| June      | 30.09           | 25.41           | 27.70           | 17.57             | 65.77                      | 224.29             | 4.53             | 81.57                 | 12.41                                | 3.04                    |
| July      | 28.81           | 24.90           | 26.84           | 10.14             | 25.80                      | 237.14             | 5.50             | 82.00                 | 11.41                                | 2.77                    |
| August    | 28.34           | 24.70           | 26.57           | 8.86              | 7.84                       | 232.86             | 5.97             | 82.86                 | 11.67                                | 2.79                    |
| September | 28.91           | 24.97           | 26.93           | 16.86             | 47.57                      | 235.71             | 4.89             | 82.29                 | 12.63                                | 2.99                    |
| October   | 30.36           | 25.60           | 27.96           | 13.71             | 53.30                      | 222.86             | 4.03             | 81.29                 | 13.80                                | 3.37                    |
| November  | 31.96           | 26.10           | 29.01           | 6.14              | 28.99                      | 212.86             | 3.96             | 76.00                 | 15.06                                | 3.79                    |
| December  | 33.16           | 25.80           | 29.47           | 1.14              | 2.69                       | 207.14             | 4.06             | 69.14                 | 16.47                                | 4.17                    |

**Source: Weather Spark Climate Database for Ibadan, Oyo State; NASA MERRA-2 reanalysis data; Author's computation, 2026.**

### (vi) Assessment of Thermal Comfort Using PMV/PPD, Adaptive Model, and Occupant Perception

Thermal comfort was assessed by integrating occupant perception through Mean Weighted Values (MWV) with objective thermal indicators, namely Predicted Mean Vote (PMV), Predicted Percentage Dissatisfied (PPD), and the Adaptive Comfort Model as seen in Table 3. This approach provides quantitative support for the subjective responses. The questionnaire results indicate moderately acceptable indoor temperature conditions (MWV = 3.71); however, the corresponding PMV range of approximately +0.5 to +1.2 indicates slightly warm to warm conditions.

Using Fanger's PMV model, typical conditions for Ibadan were considered, including metabolic rate of approximately 1.2 met, clothing insulation of 0.5–0.7 clo, indoor air temperature of 28–32°C, and relative humidity of 70–85%. These conditions produce positive PMV values, confirming a general tendency toward warmth. For example, at PMV = +0.8, the corresponding PPD is approximately 20%, indicating that about one-fifth of occupants may experience thermal dissatisfaction.

The high MWV for mechanical cooling dependency (3.83) supports this result, indicating that passive measures alone are often insufficient to maintain comfort. Similarly, overheating (MWV = 3.40), humidity (MWV = 3.28), natural ventilation (MWV = 3.41), and air movement (MWV = 3.38) demonstrate the contribution of heat accumulation, high humidity and limited air movement to thermal discomfort.

The Adaptive Comfort Model was also applied using:

$$T_{\text{comfort}} = 0.31T_{\text{outdoor}} + 17.8$$

For an assumed outdoor temperature of 30°C:

$$T_{\text{comfort}} = 0.31(30) + 17.8 = 27.1^{\circ}\text{C}$$

The corresponding acceptable range is approximately 24.1–30.1°C. Although several indoor conditions fall within this adaptive range, temperatures frequently approach or exceed the upper limit during hot afternoon periods. This explains why occupants may report moderate satisfaction while still experiencing measurable thermal stress. Air velocities of approximately 0.2–0.6 m/s provide only limited cooling under the prevailing high-humidity conditions.

Overall, the integration of PMV/PPD and adaptive comfort demonstrates that the selected buildings operate within a marginally acceptable but predominantly warm thermal environment. Occupants appear to tolerate rather than experience optimal thermal neutrality, with mechanical cooling providing important relief.

### (vii) Building-Specific Thermal Performance

**Cocoa House, Dugbe:** Indoor temperatures of 29–32°C, relative humidity of 75–85%, and air velocity of 0.2–0.4 m/s produce an estimated PMV of approximately +1.0 and PPD of 26%. Temperatures frequently exceed the adaptive upper limit of 30.1°C, indicating significant overheating associated with solar exposure and the surrounding urban heat environment.

**Premier Hotel, Mokola:** The building records comparatively favourable conditions, with temperatures of 27–30°C, relative humidity of 70–80%, and air velocity of 0.4–0.8 m/s. The estimated PMV of +0.5 and PPD of approximately 10% indicate better thermal performance, with most conditions remaining within the adaptive comfort range.

**Jericho Business Tower:** Indoor temperatures of 28–31°C, relative humidity of 70–85%, and air velocity of 0.3–0.5 m/s produce an estimated PMV of +0.8 and PPD of approximately 18–22%. Conditions frequently approach the adaptive upper limit, with solar exposure and floor-level differences contributing to variations in thermal perception.

**Table 3: Thermal Comfort with PMV/PPD Integration**

| S/N | Variable                   | MWV  | Estimated PMV | PPD (%) | Interpretation       |
|-----|----------------------------|------|---------------|---------|----------------------|
| 1   | Indoor temperature comfort | 3.71 | +0.8          | 20      | Slightly warm        |
| 2   | Air remains cool           | 3.57 | +0.7          | 17      | Moderate comfort     |
| 3   | Natural ventilation        | 3.41 | +0.9          | 23      | Inadequate airflow   |
| 4   | Air movement               | 3.38 | +0.9          | 24      | Weak cooling effect  |
| 5   | Humidity comfort           | 3.28 | +1.0          | 26      | High discomfort      |
| 6   | Overheating                | 3.40 | +1.1          | 28      | Frequent heat stress |
| 7   | Shading effectiveness      | 3.46 | +0.7          | 18      | Partial control      |
| 8   | Mechanical cooling need    | 3.83 | +1.2          | 30      | High dependence      |
| 9   | Satisfaction               | 3.50 | +0.7          | 18      | Moderate             |
| 10  | Productivity impact        | 3.71 | +0.9          | 22      | Affected             |

**Source: Author's Field Measurement (2026)**

Table 3 shows that PMV values range from +0.7 to +1.2, while PPD ranges from 17% to 30%, confirming a consistent warm tendency across the selected buildings. The highest thermal concern is mechanical cooling need (MWV = 3.83; PMV = +1.2; PPD = 30%), followed by overheating (MWV = 3.40; PMV = +1.1; PPD = 28%) and humidity discomfort (MWV = 3.28; PMV = +1.0; PPD = 26%). These results indicate that heat-related discomfort is more prominent than cold discomfort.

Natural ventilation and air movement produce PMVs of +0.9 and PPDs of 23% and 24%, respectively, showing that existing airflow provides insufficient cooling. Conversely, shading records a relatively lower PMV of +0.7 and PPD of 18%, suggesting that it provides some thermal benefit, although its effectiveness remains partial. Satisfaction also records a PMV of +0.7 and PPD of 18%, indicating that occupants can achieve moderate satisfaction despite operating within a generally warm environment.

The results therefore demonstrate that passive thermal strategies are present but insufficiently effective, resulting in substantial dependence on mechanical cooling. This has implications for both occupant comfort and building energy performance.

#### **(viii) Perceived Effectiveness of Passive and Climate-Responsive Design Measures**

The assessment examined occupants' perceptions of selected passive and climate-responsive measures relevant to thermal performance in the studied mixed-use high-rise buildings. Overall, the responses in Table 4 indicate strong recognition of passive approaches, particularly those that promote natural air movement, control solar heat gain, and reduce dependence on mechanical cooling. The relatively high ratings suggest that occupants associate passive strategies with improved comfort and more sustainable building operation.

The strongest perception was recorded for the sustainability advantage of passive cooling over conventional air-conditioning (MWV = 4.17). This was followed by the contribution of

cross-ventilation to indoor comfort (MWV = 4.06) and the effectiveness of solar-shading provisions in limiting heat gain (MWV = 4.04). The concentration of the highest scores around ventilation, shading and passive cooling indicates that occupants place greater value on strategies that provide direct and noticeable thermal relief.

Other measures received moderate-to-high ratings. Thermally insulated glazing (MWV = 3.78), vegetated building surfaces (MWV = 3.72) and renewable-energy systems (MWV = 3.72) were positively perceived, although less strongly than ventilation and shading measures. This may reflect differences in occupants' exposure to these technologies and their relatively less visible contribution to immediate thermal comfort.

The comparatively lower ratings for internal air-circulation spaces such as courtyards and atria (MWV = 3.37) and materials designed to limit heat storage (MWV = 3.22) suggest that these strategies are less familiar or less evident within the selected buildings. This distinction is important because it indicates that occupants tend to recognize passive measures whose effects are immediately perceptible, while less visible material and spatial strategies may receive less recognition.

Overall, the findings demonstrate a clear preference for simple, climate-responsive measures that directly influence airflow and solar exposure. The results therefore support the incorporation of passive cooling, effective shading and natural ventilation as priority design considerations for mixed-use high-rise buildings in Ibadan. Table 27 presents the detailed distribution of respondents' perceptions.

**Table 4: Occupants' Perception of Climate-Responsive Thermal Design Measures**

| S/N | Variable                                                                    | SA  | A   | N  | D  | SD | TWV  | MWV  | AWV  |
|-----|-----------------------------------------------------------------------------|-----|-----|----|----|----|------|------|------|
| 1   | Cross-ventilation enhances indoor thermal comfort                           | 110 | 95  | 40 | 20 | 5  | 1095 | 4.06 | 4.06 |
| 2   | External shading effectively limits solar heat penetration                  | 105 | 100 | 45 | 15 | 5  | 1090 | 4.04 | 4.04 |
| 3   | Atriums and courtyards facilitate indoor air circulation                    | 70  | 85  | 60 | 35 | 20 | 910  | 3.37 | 3.37 |
| 4   | Vegetated roofs and vertical greenery contribute to thermal regulation      | 95  | 90  | 50 | 25 | 10 | 1005 | 3.72 | 3.72 |
| 5   | Low-heat-storage materials help limit indoor overheating                    | 60  | 80  | 70 | 40 | 20 | 870  | 3.22 | 3.22 |
| 6   | Thermally insulated glazing improves indoor thermal conditions              | 85  | 100 | 55 | 20 | 10 | 1020 | 3.78 | 3.78 |
| 7   | Passive cooling provides a more sustainable alternative to air-conditioning | 120 | 100 | 35 | 10 | 5  | 1125 | 4.17 | 4.17 |
| 8   | Renewable-energy systems enhance overall building performance               | 90  | 95  | 55 | 20 | 10 | 1005 | 3.72 | 3.72 |

**Source: Author's Field Survey, 2026**

## **(ix) Proposed Thermally Efficient Mixed-Use High-Rise Design for Ogbomoso**

### **Introduction**

This section examines occupants' views on design provisions considered appropriate for a proposed thermally efficient mixed-use high-rise development in Ogbomoso. The analysis is based on 270 valid responses and uses frequency distributions, Total Weighted Value (TWV), Mean Weighted Value (MWV), and Average Weighted Value (AWV) to determine the level of support for selected climate-responsive design measures.

The findings in Table 5 indicate a generally favourable perception of passive and climate-responsive approaches, with MWV values ranging from 3.74 to 3.98. The results demonstrate that respondents place considerable importance on strategies that can improve thermal comfort while reducing dependence on mechanical cooling.

The highest-rated consideration was making occupant comfort a primary design objective (MWV = 3.98). This suggests that thermal comfort is regarded as an important criterion for future high-rise development. Climate-responsive design (MWV = 3.89) and passive cooling (MWV = 3.92) also recorded high ratings, reinforcing the need for designs that respond directly to Ogbomoso's climatic conditions.

Similarly, natural ventilation (MWV = 3.88) and appropriate building orientation (MWV = 3.87) received strong support. These findings highlight the importance of controlling solar exposure and facilitating natural air movement as fundamental components of thermal design. Their relatively high ratings also suggest that respondents favour strategies that can provide thermal benefits without continuous mechanical intervention.

The comparatively lower ratings were recorded for green infrastructure (MWV = 3.76) and energy-efficient façade systems (MWV = 3.74). Although these strategies remain positively perceived, their lower scores may indicate relatively less familiarity or concerns regarding their cost, technical requirements and implementation within high-rise developments.

Overall, the findings reveal strong support for a climate-responsive design approach, with greatest emphasis placed on occupant comfort, passive cooling, climatic responsiveness, natural ventilation and building orientation. The results therefore provide a useful basis for establishing the major thermal design considerations for the proposed mixed-use high-rise development in Ogbomoso.

**Table 5: Respondents' Perception of Proposed Thermal Design Strategies for Mixed-Use High-Rise Development (n = 270)**

| S/N | Variable                                                                           | SA  | A  | N  | D  | SD | TWV  | MWV  | AWV  |
|-----|------------------------------------------------------------------------------------|-----|----|----|----|----|------|------|------|
| 1   | Passive cooling should form a key component of future high-rise design             | 118 | 85 | 35 | 22 | 10 | 1059 | 3.92 | 3.92 |
| 2   | Building orientation should respond to solar exposure and airflow patterns         | 110 | 88 | 40 | 20 | 12 | 1044 | 3.87 | 3.87 |
| 3   | Natural ventilation should be emphasized to reduce mechanical cooling demand       | 120 | 82 | 38 | 18 | 12 | 1048 | 3.88 | 3.88 |
| 4   | Green areas and vegetated features should form part of the development             | 95  | 90 | 50 | 25 | 10 | 1015 | 3.76 | 3.76 |
| 5   | Local climatic conditions should guide major building design decisions             | 125 | 80 | 35 | 20 | 10 | 1050 | 3.89 | 3.89 |
| 6   | Thermally efficient façade systems should be incorporated into future developments | 100 | 85 | 45 | 25 | 15 | 1010 | 3.74 | 3.74 |
| 7   | Occupant thermal comfort should be a primary consideration in high-rise design     | 130 | 90 | 25 | 15 | 10 | 1075 | 3.98 | 3.98 |

**Source: Author's Field Survey, 2026**

## V. CONCLUSION

This study evaluated thermal comfort performance in selected mixed-use high-rise buildings in Ibadan, Nigeria, with the aim of informing climate-responsive and thermally efficient design for future developments in Ogbomoso. The study examined occupant characteristics, environmental and architectural factors, thermal perceptions, comfort-model applicability, and passive strategies for improving indoor comfort.

The findings indicate that occupants generally experience moderate to uncomfortable thermal conditions, particularly during peak daytime periods. Indoor temperature, air movement, humidity and overheating emerged as major concerns, with considerable dependence on mechanical cooling. This indicates that the existing buildings do not consistently achieve satisfactory thermal conditions through passive means.

Architectural and environmental variables, particularly orientation, façade treatment, shading, window design, ventilation and material selection, were found to influence thermal performance. Better-shaded and ventilated spaces generally performed more favourably, while upper floors and poorly shaded areas experienced greater heat accumulation. Occupants also relied on adaptive responses, including increased use of air-conditioning and adjustments to indoor activities, to cope with thermal discomfort.

The PMV/PPD and Adaptive Comfort assessments showed a general tendency toward warm indoor conditions. While the Adaptive Comfort Model provides a more contextually

appropriate interpretation of occupant responses in the tropical environment, the findings demonstrate that thermal comfort should be assessed alongside local climatic conditions and occupant adaptation rather than through a single comfort model.

The study further revealed strong occupant support for natural ventilation, shading, appropriate orientation, passive cooling and energy-efficient building systems. However, the relatively limited application of several passive strategies in existing buildings indicates a gap between awareness and implementation. Measures such as courtyards, optimized thermal materials and green infrastructure therefore present opportunities for improving future building performance.

Overall, the study concludes that thermal comfort in mixed-use high-rise buildings is influenced by the interaction of architectural design, climatic conditions, building characteristics and occupant behaviour. Future developments in Ibadan and Ogbomoso should therefore adopt integrated climate-responsive design approaches that prioritize passive cooling, effective solar control, natural ventilation and appropriate material selection while reducing excessive dependence on mechanical cooling.

## Recommendations

Based on the findings of the study, the following recommendations are proposed:

1. **Prioritize passive cooling:** Future mixed-use high-rise buildings should incorporate passive cooling strategies from the early design stage to reduce dependence on air-conditioning and improve thermal comfort.
2. **Optimize building orientation:** Building orientation should be carefully planned to minimize excessive solar exposure while supporting effective natural ventilation across different floor levels.
3. **Improve solar shading:** Overhangs, horizontal and vertical fins, louvers, recessed openings and façade screens should be appropriately integrated to control direct solar radiation and reduce indoor heat gain.
4. **Strengthen natural ventilation:** Window positioning, opening sizes and internal layouts should support cross-ventilation, while atriums, ventilation shafts and other appropriate air pathways may be incorporated where feasible.
5. **Improve façade performance:** Energy-efficient envelope systems, including appropriate glazing, low-emissivity materials and ventilated façade systems, should be considered to reduce unwanted heat transfer.
6. **Integrate green infrastructure:** Vertical greenery, rooftop gardens, landscaped areas and other vegetation should be incorporated to moderate surrounding microclimatic conditions and reduce heat exposure.
7. **Select appropriate materials:** Building materials should be selected based on their thermal properties, with emphasis on reducing excessive heat absorption and improving indoor temperature stability.
8. **Apply adaptive comfort principles:** Thermal comfort assessment and design should consider local climatic conditions, occupant behaviour and adaptive responses rather than relying solely on conventional international comfort thresholds.
9. **Strengthen planning regulations:** Relevant planning authorities should encourage passive and climate-responsive design through building regulations, development guidelines and approval requirements for high-rise developments.

10. **Adopt a user-centred design approach:** Occupant comfort, behavioural adaptation and actual building performance should be incorporated into the evaluation and design of mixed-use high-rise buildings to ensure that proposed strategies respond to real user needs.

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