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ASSESSMENT OF SUSTAINABLE DESIGN STRATEGIES IN ENERGY-EFFICIENT HIGH-RISE MIXED-USE TOWERS IN TROPICAL CLIMATES

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ABSTRACT

High-rise mixed-use towers in tropical climates, including Abuja's tropical savanna environment, face environmental conditions that can increase cooling demand, particularly high solar exposure, substantial diurnal temperature variation and the need for reliable environmental control. This study examines the extent to which sustainable design strategies are incorporated in selected mixed-use and high-rise precedents, with particular relevance to Abuja's Central Business District. A purposive case-study approach was employed to examine five precedents: World Trade Center Abuja, Pixel Building in Melbourne, The Edge in Amsterdam, PARKROYAL on Pickering in Singapore, and Oasia Hotel Downtown in Singapore. The cases were analysed thematically using architectural documentation, published project information, certification records and available performance literature. Recurring strategies included external solar shading, perforated and layered façades, controlled glazing, natural or mixed-mode ventilation, vertical functional zoning, atrium and void spaces, thermal buffering and integrated greenery. The analysis indicates that environmental performance in the selected precedents is generally approached through combinations of complementary architectural and building-system strategies rather than through a single intervention. The study contributes a precedent-based framework for translating climate-responsive strategies into high-rise mixed-use design within tropical savanna environments, with particular relevance to Abuja's Central Business District.

Keywords: Sustainable Design Strategies; High-Rise Mixed-Use; Energy Efficiency; Passive Design

1 INTRODUCTION

The increasing development of high-rise and mixed-use buildings has intensified the need for environmentally responsive approaches to building design. Vertical development allows multiple functions to be accommodated within increasingly dense urban areas, but it also introduces complex relationships between building form, façade exposure, solar radiation, ventilation, occupancy and building-services requirements in Tropical Climates. These relationships are particularly important in warm climates, where solar gains and elevated outdoor temperatures can increase the demand for mechanical cooling. Consequently, improving the environmental performance of high-rise buildings requires

consideration of both building-services systems and the architectural decisions that influence the environmental loads placed upon them.

The building envelope is particularly significant because it mediates the relationship between external climatic conditions and indoor environments. Orientation, glazing, shading, façade configuration and ventilation openings can influence solar exposure, daylight and opportunities for natural airflow. Strategies such as external shading, recessed façades, balconies, perforated screens, layered envelopes and vegetated façades have therefore become increasingly relevant to climate-responsive high-rise design. Similarly, vertical zoning, atria, voids and transitional spaces can influence how different building functions relate to daylight, ventilation, solar exposure and environmental control. Their application, however, is dependent on climatic context, building function, construction technology and operational requirements.

These considerations are particularly relevant to Abuja, Nigeria, where continuing urban development and the growth of commercial and mixed-use activities have increased the importance of energy-conscious building design. Abuja's tropical savanna climate is characterised by high solar exposure, elevated daytime temperatures and distinct wet and dry seasons. Research conducted in Abuja has documented significant thermal discomfort in residential buildings during the dry season and has investigated passive cooling interventions as a means of improving indoor environmental conditions (Adaji et al., 2019; Adaji et al., 2020).

A further challenge is that sustainable design strategies are often discussed as individual interventions rather than as interconnected components of building design. Solar shading, natural ventilation, thermal mass, reduced glazing, vertical greenery, atria and environmental technologies may each contribute to building performance, but their application and effectiveness depend on how they are combined with building form, spatial organisation and building-services systems. This makes precedent analysis particularly valuable for identifying how sustainable strategies have been incorporated into existing buildings and determining which underlying principles may be transferable to other contexts.

International high-rise and environmentally responsive buildings provide a substantial body of precedent knowledge. However, differences in climate, occupancy, construction practices, building regulations, energy infrastructure and operational conditions mean that strategies demonstrated in one location cannot automatically be transferred to another. A tropical building in Singapore, for example, operates under different climatic conditions from a building in Melbourne or Amsterdam. Consequently, the value of comparative case-study analysis lies less in treating these projects as direct models and more in identifying recurring environmental strategies, examining their architectural integration and considering their contextual relevance.

This study addresses this issue through the comparative analysis of five selected precedents: World Trade Center Abuja, Pixel Building in Melbourne, The Edge in Amsterdam, PARKROYAL on Pickering in Singapore, and Oasia Hotel Downtown in Singapore. The cases provide a combination of local and international examples through which sustainable approaches to façade design, solar control, ventilation, vertical organisation, greenery, daylighting and environmental technologies can be examined. World Trade Center Abuja provides a local reference, while the international cases broaden the analysis by demonstrating alternative approaches to environmental design in different climatic and urban contexts.

The study uses purposive case selection and thematic analysis to identify recurring sustainable design strategies and examine how these strategies are incorporated into building form, envelope and spatial organisation.

The research is guided by the following question:

What sustainable design strategies are demonstrated in selected high-rise and mixed-use precedents, and how can these strategies inform the design of energy-conscious high-rise mixed-use buildings in Abuja's tropical savanna climate?

Accordingly, the objective of the study is to identify and analyse sustainable design strategies demonstrated in selected high-rise and mixed-use precedents and establish their relevance to energy-conscious high-rise mixed-use development in Abuja's tropical savanna climate. The analysis focuses on recurring themes including bioclimatic façade systems, passive-first environmental design, vertical zoning, atria and void spaces, vertical greenery, environmental technologies and holistic integration of complementary strategies. The findings are subsequently interpreted in relation to the climatic and functional requirements of high-rise mixed-use development in Abuja.

2 LITERATURE REVIEW

2.1 Defining Key Concepts

Sustainable design strategies refer to architectural strategies that prioritise passive environmental strategies in response to local climatic conditions before resorting to mechanical systems. These Passive design strategies encompass building orientation, external shading, natural and stack ventilation, high thermal mass, reduced window-to-wall ratios (WWR), double skin facade and evaporative cooling. In this study the term specifically refers to strategies that enhance energy efficiency without affecting occupant comfort in high-rise mixed-use buildings (Givoni, 2019; Olgyay, 1963).

High-rise mixed-use describes a vertical building typology exceeding twelve storeys that accommodates at least three distinct functional programmes within a single structure, typically retail or commercial uses at the podium level, office spaces in the mid-zone, and residential or hospitality functions in the building crown. This typology maximises land-use efficiency in dense urban centres such as Abuja's Central Business District.

Energy efficiency in the context of this research refers to the reduction of operational energy demand—particularly cooling, ventilation, and lighting loads—through architectural and passive design measures, measured against conventional baseline models. The study targets potential reductions in the range of 25–40%.

Passive design encompasses architectural and material strategies that minimise energy demand without continuous mechanical input. These include optimal building orientation, external shading, natural and stack ventilation, high thermal mass, reduced window-to-wall ratios, and the strategic use of thermal buffering elements.

2.2 Existing Theories and Frameworks

Bioclimatic design theory, pioneered by Olgyay and further developed by Givoni and Yeang, positions the building envelope as the primary mediator between internal and external environments (Yeang, 2019). In tropical and subtropical climates, this theory emphasises solar control, natural ventilation, and thermal mass as foundational strategies. Empirical studies in Nigeria and comparable tropical savanna contexts consistently demonstrate the efficacy of these approaches. Field measurements in Abuja have recorded indoor operative temperatures of 32–34°C in free-running buildings without passive interventions, exceeding ASHRAE adaptive comfort limits by 3–5°C (Mustapha et al., 2023). Retrofitting with reflective roofing and overhangs has lowered diurnal peaks by 4–6°C and extended comfort hours substantially (Adaji et al., 2019).

In high-rise applications, atrium-driven stack ventilation and double-skin façades have achieved cooling reductions of 20–42% while maintaining acceptable thermal comfort (Kim & de Dear, 2021; Agbaje et al., 2024; Wang et al., 2021). Vertical zoning further enhances performance by aligning functional requirements with microclimatic opportunities: cross-ventilation at lower levels, daylight optimisation for offices, and buoyancy-driven airflow for upper residential floors. Green roofs and vertical greenery provide additional thermal buffering, evaporative cooling, and ecological benefits (Erebor et al., 2025).

These frameworks collectively support a passive-first hierarchy in which mechanical systems serve only as supplementary measures once passive potential has been maximised.

2.3 Knowledge Gaps and Research Opportunities

Despite the abundance of evidence supporting passive strategies, several critical gaps persist. First, high-rise-specific, performance-validated climate-responsive precedents remain scarce in West Africa (Bassey et al., 2023). Second, existing Nigerian building energy codes are largely voluntary and lack rigorous differentiation by climate zone (Nigerian Energy Commission, 2021). Third, while simulation studies and low-rise field research are relatively common, the translation of proven strategies into mixed-use high-rise typologies under Abuja's specific urban island and grid-constraint conditions is underexplored. Fourth, the interplay between bioclimatic façades and vertical zoning; two interdependent strategies received limited empirical attention in the Nigerian context.

These gaps justify the present study's focus on assessing the actual extent of implementation across selected international and local mixed-use developments, thereby generating transferable knowledge for Abuja's rapidly verticalizing CBD

2.4 Proposed Conceptual Model

The conceptual model guiding this research integrates bioclimatic façade systems, vertical functional zoning, atrium-driven ventilation, projected shading, horizontal ventilation and thermal mass into a wholistic passive-first framework. The model posits that when these strategies are combined from the earliest design stages, cooling energy demand can

be reduced by 38% while adaptive thermal comfort is not deterred. This framework informed both the selection of case studies and the subsequent thematic analysis

3 METHODOLOGY

A purposive case-study approach was adopted. The qualitative phase, which forms the core of this paper, centred on case-study investigation and thematic analysis. Five mixed-use high-rise or high-rise-adaptable precedents were purposively selected using criteria synthesised from the literature (Yeang, 2019; Wood & Salib, 2021; Alade et al., 2025): climate similarity (tropical savanna, hot-humid, or hot-dry with transferable lessons); functional mix (retail, office, and residential/hospitality); height (greater than 12 storeys or buildings with principles scalable to high-rise and recency (2010–2025 constructions or studies).

The selected cases comprise:

- World Trade Center Abuja, Nigeria (2014–ongoing) — the primary local contextual benchmark;
- Pixel Building, Melbourne, Australia (2010) — examined through a tropical retrofit simulation lens;
- The Edge, Amsterdam, Netherlands (2015) — analysed with available tropical adaptation studies;
- Parkroyal on Pickering, Singapore (2013) — a mature tropical bioclimatic exemplar;
- Oasia Hotel Downtown, Singapore (2016) — a high-rise mixed-use tower employing a perforated veil façade.

Data sources included google photographs, architectural drawings, site plans, sections, elevations, published performance reports, certification documents (Green Mark, Green Star, BREEAM), photographic documentation, and peer-reviewed evaluations. Qualitative data were subjected to thematic analysis. Architectural and performance information was coded according to recurring strategies, depth of implementation, performance outcomes, and limitations. Themes were refined iteratively until saturation was reached. Limitations of the methodology include reliance on secondary performance data rather than primary post-occupancy measurements for all cases.

4 RESULTS- KEY FINDINGS

4.1 Case Study 1: World Trade Center Abuja, Nigeria

The World Trade Center Abuja is a multi-tower mixed-use development (office, residential, hospitality, and retail) located along Constitution Avenue in the CBD. Phase 1 comprises 24-storey towers with further towers under construction. The architectural language is characterised by predominantly double-glazed curtain-wall façades and elongated balconies (as seen in figure 1).



Figure 1: WTO Glazed Façade system and Cantilevered balconies for shading

Source: Independent.ng (2023)

Merits include a slender high-rise form that increases façade exposure for daylight, the presence of balconies that provide limited solar buffering (particularly on east and west elevations), and a modern aesthetic (see figure 1). However, demerits are significant from a climatic perspective: the towers are arranged primarily to optimise land value rather than climatic orientation; as seen in figure 2. East–west façade exposure is high; glazing ratios remain typical of international glass towers as seen in plate 1; and there is an absence of deep external shading devices, light shelves, or systematic passive solar control at the master-plan level. Sustainable strategies are present only in superficial form. The project therefore illustrates the limited extent of climate-responsive implementation currently characteristic of many Nigerian high-rise developments.

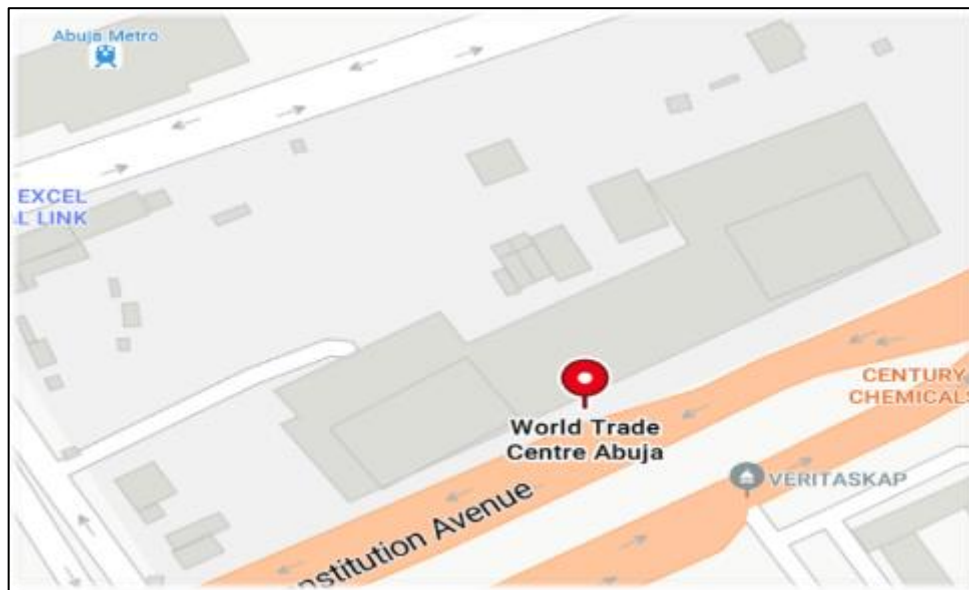


Figure 2: WTO orientation with much of Elevation along East to West Sun Orbit

Source: Google Aerial Photograph (Nov 2025 Imagery).

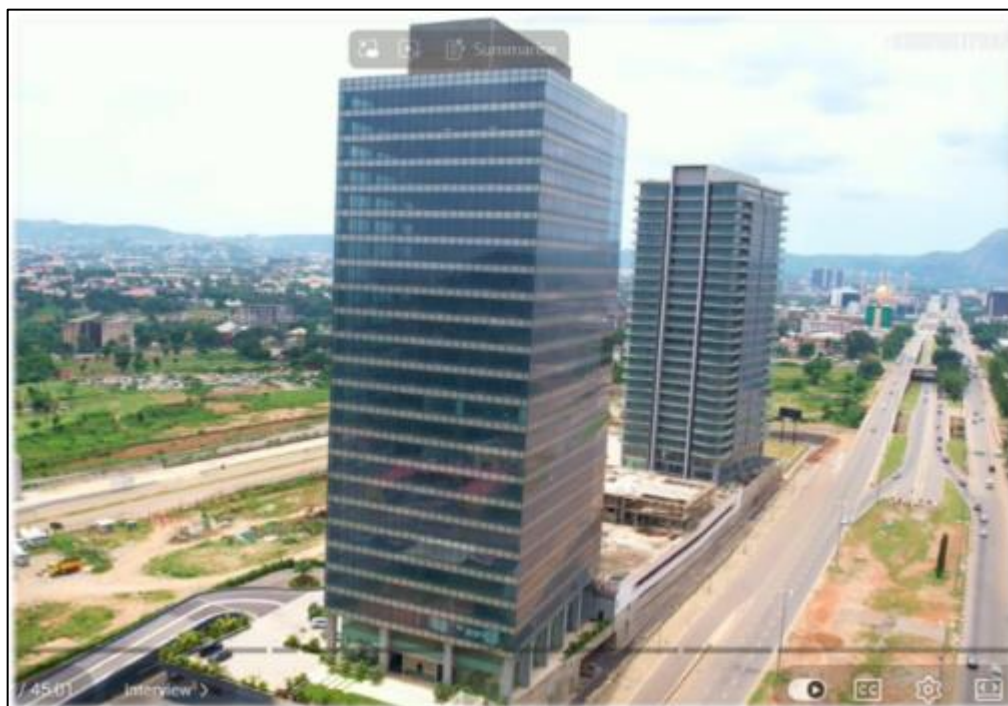


Figure 3: WTO Tower 2 Glazed façade system

Source: Comfort Properties walkthrough (2023)

4.2 Case Study 2: Pixel Building, Melbourne (Tropical Retrofit Perspective)

The Pixel Building is a compact, six-storey commercial/office prototype that achieved carbon neutrality and a perfect 6-Star Green Star rating. Its defining features are orientation-specific colourful external shading panels (as seen in plate 2), mixed-mode ventilation combining night cooling with operable windows as observed in figure 3.

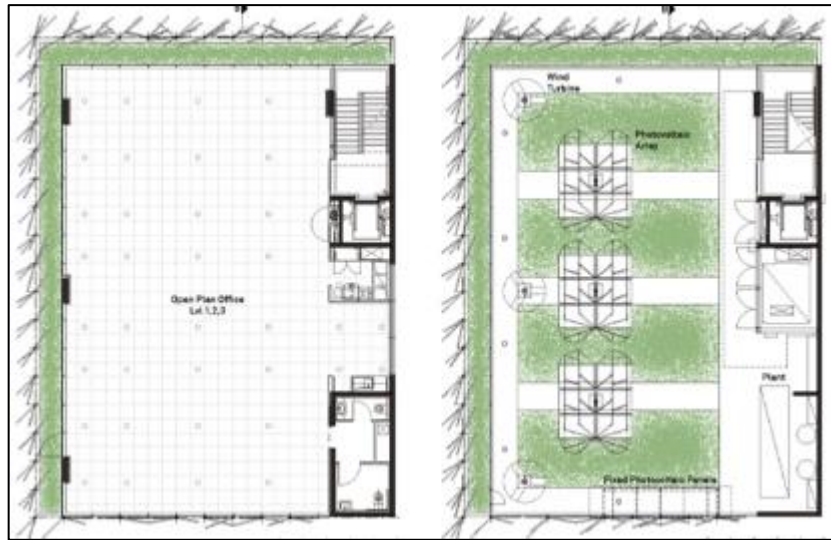


Figure 4: Double skin façade and foldable louvres on floor plan view

source: Archdaily (2011)

The building demonstrates that climate-data-driven façades and mixed-mode operation are highly transferable principles, although its low-rise scale requires vertical scaling and structural adaptation for a high-rise application. Its primary limitation for direct replication is height; its strength lies in the clarity of its passive and renewable integration.



Figure 4: Pixel building foldable façade plates for optimal shading and ventilation

Source: Archdaily (2011)

4.3 Case Study 3: The Edge, Amsterdam (Tropical Adaptation)

The Edge is a 15-storey mixed-use office and retail building widely recognised for its BREEAM Outstanding rating. Its central atrium functions simultaneously as a thermal chimney for stack-effect ventilation and as a daylight distributor. Intelligent sensor-controlled systems manage lighting, HVAC, and blinds. A 2023 tropical simulation incorporating phase-change materials demonstrated the concept's viability under high diurnal temperature swings (Zhiri et al., 2023). The U-shaped plan (as seen in figure 4) and vertical organisation of functions provide a clear precedent for mixed-use zoning and atrium-driven ventilation transferable to Abuja (see figure 5).

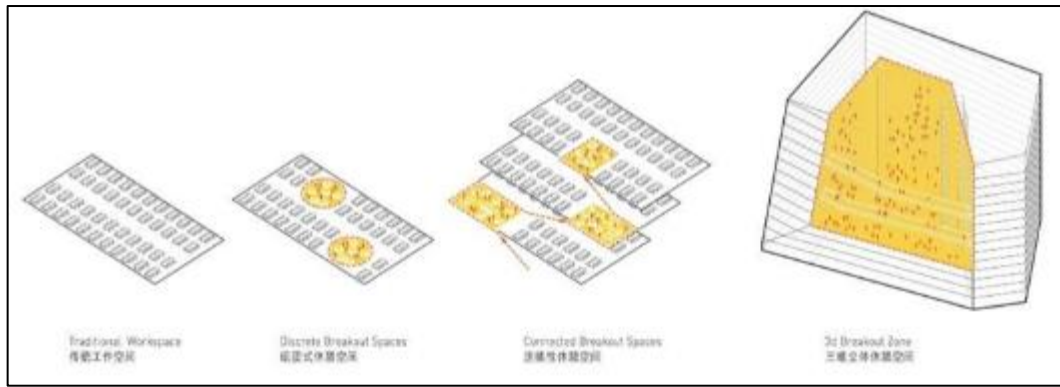


Figure 5: Edge U shaped building Atria

Source: Archdaily (2016)



Figure 6: Edge building section showing vertical zoning and atrium-driven ventilation

Source: Archdaily (2016)

4.4 Case Study 4: Parkroyal on Pickering, Singapore



Plate 1: Parkroyal tropical green façade and central void as sky garden

Source: Archdaily (2013)

Designed by WOHA Architects, this 16-storey hotel and office mixed-use building multiplies green area beyond the site landscape to extensive hanging gardens, sky terraces, and layered perforated façades as seen in plate 3.

Vertical zoning places active commercial and public functions at lower levels, residential/hospitality and offices in the mid-to-upper zones, and green recreational spaces as transition areas. Central voids as seen in plate 3 support stack and cross ventilation. The project achieved Green Mark Platinum certification and demonstrates that vertical greenery can function as genuine thermal and ecological infrastructure rather than mere decoration. High initial and maintenance costs constitute the principal limitation for direct transfer to the Nigerian context, yet the performance outcomes remain highly instructive.

4.5 Case Study 5: Oasia Hotel Downtown, Singapore

Also designed by WOHA, this 27-storey mixed-use tower (retail, office, and hotel) is distinguished by a red perforated aluminium mesh “veil” façade (as seen in plate 4) that effectively shades the building while permitting natural ventilation and diffused daylight. Four large open sky gardens inserted at regular intervals function as “vertical lungs,” enhancing stack effect, providing thermal buffering, and supporting biodiversity. Al-Kodmany (2023) stated that “landscaping is used extensively supporting biodiversity in the urban environment with a green plot ratio of 1100%” meaning that the total vegetated surface area is approximately 11.1 times the project's site area.



Plate 2: Oasia building Section and elevations showing perforated double skin façade and mid void

Source: Archdaily (2016)

The building achieved Green Mark Platinum certification. Its perforated veil concept and sky-garden strategy are particularly close to the climate-responsive façade approaches suitable for Abuja’s tropical savanna conditions.

4.6 Thematic Analysis of Implementation Extent

Cross-case thematic analysis identified seven dominant themes that illuminate both the extent and the depth of sustainable strategy implementation:

4.6.1 Bioclimatic Façade Systems as Primary Energy Moderators

High-performing cases treat the envelope as an active environmental regulator. Pixel, Parkroyal, and Oasia employ external shading, perforated screens, or vegetated layers. The Edge utilises intelligent glazing integrated with an atrium. World Trade Center Abuja relies mainly on double glazing and balconies—an incomplete response. Collective evidence establishes double-skin, perforated, and vegetated façades as among the most effective passive cooling tools for tropical high-rises (Agbaje et al., 2024; Wang et al., 2021).

Key Findings

4.6.1.1 World Trade Center Abuja

- Uses a predominantly double-glazed curtain wall system.
- Projected Balconies function as solar buffers.

However, excessive glazing increases east–west heat gain.

4.6.1.2 Pixel Building

- Employs colourful external shading panels.
- Façade is orientation-sensitive and climate-driven.
- Demonstrates how shading devices significantly reduce cooling loads.

4.6.1.3 The Edge

- Uses intelligent façade systems with smart controls.
- Atrium-integrated glazing balances daylight with heat reduction.

4.6.1.4 Parkroyal on Pickering

- Integrates layered greenery and deep overhangs.
- Façade acts as both thermal filter and ecological skin.

4.6.1.5 Oasia Hotel Downtown

- Introduces a perforated aluminium veil façade.
- Reduces solar gain while maintaining airflow and daylight.

4.6.2 Thematic Interpretation

The studies collectively establish that double-skin façades, perforated screens, balconies, and vegetated envelopes are among the most effective passive cooling tools for tropical high-rises.

4.7 Passive-First Design Outperforms Mechanical Dependence

External shading, natural and stack ventilation, thermal buffering, and reduced solar gain appear consistently in the international cases. These buildings demonstrate measurable cooling reductions and greater resilience during power interruptions which are outcomes of direct relevance to Nigeria’s unreliable grid (Mustapha et al., 2023; Xi et al., 2025). Sustainable Strategies identified are illustrated in table 4.1 below.

Table 1: Key Passive Strategies Identified

Strategy	Evidence across case studies
External shading	Pixel, Oasia, Parkroyal
Natural ventilation	Edge, Oasia
Stack ventilation	Edge, Parkroyal
Thermal buffering	Parkroyal, Oasia
Reduced solar gain	All case studies
Daylighting optimization	Edge, Pixel

Source. Thematic Observation

4.8 Thematic Interpretation

The case studies consistently demonstrate that Passive strategies reduce cooling loads significantly, Buildings become more resilient during power outages and Thermal comfort improves without excessive energy demand.

4.8.1 Vertical Zoning Enhances Microclimatic Performance

Successful precedents deliberately organise functions by height: retail/public (lower), offices (mid), residential/hospitality (upper), with green or void transition floors. This climatic zoning optimises cross-ventilation at podium level, daylight for offices, and stack effect for upper residences. The Vertical Zoning Patterns identified are laid out in table 4.2 below

The Observed Zoning Patterns are as follows:

Table 2: Vertical Zoning Patterns Identified

Lower floors	Middle floors	Upper floors
Retail/public	Offices	Residential/hotel
High activity	Controlled occupancy	Privacy & ventilation
Public interaction	Daylight optimization	Stack ventilation benefits

Source. Thematic Observation

4.8.2 Case Evidence

4.8.2.1 Parkroyal on Pickering

Commercial podium below, Hospitality above and Green transition zones between functions.

4.8.2.2 Oasia Hotel Downtown

Sky gardens separate activity zones.

Open-air transition levels improve ventilation.

4.8.2.3 The Edge

Atrium-centered office organization enhances daylight penetration and airflow distribution.

4.9 Thematic Interpretation

Vertical zoning is not merely functional it is climatic, environmental, and energy-responsive

4.9.1 Atria and void spaces improve natural ventilation

Central atria or open sky voids function as thermal chimneys, daylight distributors, and air-circulation spines (The Edge, Parkroyal, Oasia). Functions of Atria Identified are as follows:

Table 3: Identified Functions of an Atria

Environmental role	Impact
Thermal chimney	Enhances stack ventilation
Daylight distributor	Reduces artificial lighting
Air circulation spine	Improves indoor airflow
Social interaction space	Enhances user experience

Source. Thematic Observation

4.9.2 Case Evidence

4.9.2.1 The Edge

Central atrium acts as thermal and daylight core.

4.9.3 Parkroyal on Pickering

Central voids facilitate passive airflow.

4.9.4 Oasia Hotel Downtown

Open sky voids function as “vertical lungs.”

4.9.4.1 Thematic Interpretation

Void spaces are critical environmental infrastructure in tropical high-rises.

Vertical Greenery as Thermal and Ecological Infrastructure

Parkroyal and Oasia demonstrate that sky gardens and vegetated façades deliver solar shading, evaporative cooling, air filtration, biodiversity, and psychological benefits, transforming greenery into performative infrastructure.

Notable Functions Identified includes:

Table 4: Functions of Vertical Greenery as Thermal and Ecological Infrastructure

Function	Benefit
Solar shading	Reduced heat gain
Evaporative cooling	Lower ambient temperatures
Air filtration	Improved air quality
Biodiversity restoration	Urban ecological integration
Psychological comfort	Enhanced wellbeing

Source. Thematic Observation

4.9.5 Case Evidence

4.9.5.1 Parkroyal on Pickering

Extensive sky gardens.

Green terraces exceed site footprint.

4.9.5.2 Oasia Hotel Downtown

Vegetation integrated into façade and sky courts.

4.9.5.3 Thematic Interpretation

Green infrastructure becomes thermal infrastructure, ecological infrastructure, social infrastructure.

4.9.5.4 Smart Technology as Support, Not Substitute

Sensor-controlled systems (The Edge) enhance passive performance but do not replace it.

4.9.5.5 Wholistic Environmental Integration

The highest performers succeed because façade, zoning, ventilation, greenery, and renewables operate synergistically. Isolated strategies yield limited gains (Alade et al., 2025; Ijahenda et al., 2025). Evidence Across Case Studies includes:

Table 5: Evidence of Sustainable and passive strategies employed in case studies

Building	Integrated strategies
WTC Abuja	Glazing + balconies
Pixel Australia	Shading + renewables + ventilation
The Edge Netherlands	Atrium + smart systems + daylight
Parkroyal Singapore	Greenery + zoning + passive cooling
Oasia Singapore	Veil façade + sky gardens + ventilation

Source. Thematic Observation

4.9.6 Thematic Interpretation

No single strategy alone achieves energy efficiency. The highest-performing buildings use hybrid Sustainable strategies integration.

4.10 Summary of Implementation Extent

International tropical precedents, particularly the Singapore cases, exhibit mature, high-extent implementation of passive-first bioclimatic strategies supported by certification and performance data. Adaptable temperate cases demonstrate transferable principles validated by tropical simulations. The local Nigerian case shows only limited implementation: modern aesthetics and partial glazing/balcony measures exist, but climatic orientation, deep shading, reduced WWR, and systematic passive ventilation remain underdeveloped.

5 DISCUSSION

The findings confirm that sustainable design strategies capable of delivering 30–42% cooling-energy reductions are already proven in tropical mixed-use high-rises (Agbaje et al., 2024). The critical gap in the Nigerian context is not technological feasibility but consistent, early-stage application. Preference for international glass-box aesthetics, perceived complexity, and concerns over capital cost continue to constrain adoption, even though long-term operational savings and grid-resilience benefits are substantial (Erebor et al., 2025).

Vertical zoning, bioclimatic façades (especially perforated or double-skin systems with ventilated cavities), atrium-driven ventilation, and strategic greenery emerge as the highest-impact and most transferable packages for Abuja's CBD. These strategies directly address the dominant climatic drivers—high solar gain, large diurnal swings, and urban canyon effects that reduce natural ventilation efficacy (Musa et al., 2022; Nimlyat et al., 2023).

The study also highlights the interdependence of strategies: a well-designed bioclimatic façade enhances the effectiveness of vertical zoning by enabling controlled airflow and solar gain across different functional zones. Holistic integration, rather than the isolated application of individual measures, is the decisive factor separating high-performing from under-performing buildings.

Limitations of the present analysis include reliance on secondary performance data and the absence of primary post-occupancy evaluation for the Nigerian case. These limitations do not invalidate the comparative findings but indicate the need for future empirical monitoring of newly designed passive towers in Abuja.

6 CONCLUSIONS

This assessment demonstrates that sustainable design strategies have been implemented to a high degree in selected international mixed-use high-rises operating in or adaptable to tropical climates. These buildings achieve significant energy-performance gains through passive-first, holistically integrated systems. In contrast, local Nigerian precedents, exemplified by World Trade Center Abuja, lag substantially in climatic responsiveness.

For Abuja and similar tropical savanna contexts, the evidence supports the following recommendations:

- Incorporation of mandatory passive-first design requirements into high-rise development approvals;
- Adoption of reduced window-to-wall ratios (30–40%) combined with external shading and ventilated façade systems;
- Systematic application of vertical climatic zoning and atrium or void systems;
- Integration of sky gardens and vertical greenery as genuine thermal infrastructure rather than decorative elements;
- Routine use of performance simulation employing local Typical Meteorological Year data as a standard design tool.

Broader adoption of these strategies can reduce pressure on Nigeria's fragile national grid, lower operational costs and carbon emissions, and produce high-rise mixed-use buildings that are simultaneously environmentally effective and architecturally expressive. Future research should prioritise post-occupancy evaluation of new climate-responsive towers in Abuja in order to close the simulation-to-reality gap and refine design guidelines for the region.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The author declares no conflict of interest

Data Availability Statement

The data supporting the findings of this study, including case-study documentation and thematic coding matrices, are available from the corresponding author upon reasonable request.

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