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Natural Ventilation as The Primary Passive Cooling Strategy for Large-Scale Mixed-Use Buildings in Bonny's Hot-Humid Coastal Climate.

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Abstract- Buildings use a lot of energy and produce a significant amount of carbon emissions, so there's a growing interest in designing them in a way that reduces the need for energy-intensive systems. In Nigeria, the rapid growth of cities, increasing demand for cooling, and ongoing issues with electricity supply have made it essential to find building solutions that are more environmentally friendly, especially in mixed-use developments that serve many different purposes and house large numbers of people. Using natural ventilation, orienting buildings to maximize natural light, providing solar shading, incorporating thermal mass, integrating landscapes, and planning courtyards are all techniques that can help improve building performance while reducing energy consumption. This study looks at how these passive design techniques can be used in mixed-use buildings in Nigeria, with a focus on natural ventilation as a key strategy for cooling buildings without relying on mechanical systems. The study involved a thorough review of existing research and a comparison of four example projects: the Eastgate Centre in Zimbabwe, Menara Mesiniaga in Malaysia, Khoo Teck Puat Hospital in Singapore, and Pearl Academy in India. The results show that successfully implementing passive design requires combining multiple environmental strategies rather than relying on just one approach. By doing so, buildings can be designed to be more sustainable, energy-efficient, and environmentally responsive.

Keywords: Natural Ventilation, Passive Cooling, Mixed-Use Buildings, Hot-Humid Climate, Bioclimatic Architecture.

I. INTRODUCTION

The building sector is still one of the biggest consumers of energy worldwide and is still responsible for significant greenhouse gas emissions. Buildings account for around 30 percent of global final energy consumption and the majority of energy-related carbon emissions (IEA, 2022). As concerns on climate change, resource depletion, and environmental sustainability continue to grow, the focus will be on buildings that offer sufficient comfort and functionality at less cost and with less environmental impact. Building energy use is mainly made up of heating, cooling, lighting, and ventilation systems for the indoor environment. In tropical climates, cooling is a big part of building energy demand due to high temperatures and humidity throughout the year. As a result, many current buildings have turned to mechanical air-conditioning systems for thermal comfort, which is generally more expensive and dependent on energy infrastructure (Givoni, 1998).

Mixed-use developments are increasingly popular as they allow for more than one type of operation in the same building. Such buildings are typically used to facilitate commercial, recreational, retail, entertainment, hospitality, and administrative functions, and provide a diverse environment and a diverse range of users on the same day. However, the use of multiple functions in a single building often results in high energy consumption owing to longer operating hours and high occupancy levels, while other functionalities are also required.

1.1 PROBLEM STATEMENT

The problem is particularly acute in Nigeria, where rapidly growing urbanization and the growing demand of commercial and recreation activities have led to a growing building energy consumption. This is compounded by inconsistent electricity supply, rising energy costs and the widespread use of diesel generators. As such, cooling large buildings has become an operational cost for developers, facility managers and occupants alike (Oyedepo, 2014). So, despite the benefits of passive design, most of the current mixed-use projects in Nigeria are still based on mechanical cooling systems, in many cases overlooking the opportunities presented by the local climate. Even though there is extensive literature on passive design and sustainable architecture, it is primarily focused on residential buildings and passive design as a general idea, with less awareness about the use of passive design in large and complex mixed-use buildings in this country. With the knowledge gap between theoretical knowledge and practical implementation in Nigeria, this is where the problem is most acute. To balance indoor comfort metrics with environmental/economic efficiency in architectural complexes, design techniques must be employed to seamlessly integrate natural daylighting and thermodynamic cooling in mixed-use spatial zoning.

1.2 AIM OF THE STUDY

The objective of this study is to explore passive design techniques in mixed-use buildings as a sustainable design practice in Nigeria, with an emphasis on the role of natural ventilation for thermal comfort, energy consumption reduction and environmental performance.

1.3 OBJECTIVES

There are 4 key objectives to guide the study. They are:

1. To study how passive design techniques can be applied to mixed-use buildings in Nigeria.
2. To assess the effectiveness of passive design techniques in increasing energy efficiency and thermal comfort in mixed-use developments.
3. To analyze selected case studies to see how passive design strategies contribute to sustainable building performance.
4. To provide suggestions on the integration of passive design techniques into mixed-use buildings in Nigeria.

1.4 RESEARCH QUESTIONS

1. What are the benefits of using passive design techniques in mixed-use buildings in Nigeria?
2. How does passive design improve energy efficiency and thermal comfort in mixed-use development?
3. What lessons can be learnt from selected case studies about the adoption of passive design strategies?
4. How can passive design techniques be incorporated into future mixed-use building development in Nigeria?

II. LITERATURE REVIEW

2.1 Passive Design Principles in Architecture

The concept of passive design is built on the basis of a strategic concept in orientations, form, materials, landscape and environmental conditions to offer thermal comfort without reliance on mechanically powered equipment. When it comes to active environmental control systems, passive design is based on natural adaptation to climatic forces that affect indoor environment and the performance of buildings (Lechner, 2014). Courtyards, shaded verandas, thick walls, high ceilings and well-placed openings have been used in the past to enhance airflow and reduce heat gain (Fathy, 1986). Correct orientation can reduce cooling loads by minimizing direct solar radiation on exposed surfaces and enhance natural ventilation and daylight access by building well (Olgyay, 2015).

2.2 Benefits of Passive Design in Mixed-Use Buildings

The most significant benefit of passive design in mixed-use buildings is the reduction of energy consumption. Natural ventilation is key to better thermal comfort in mixed-use buildings. Studies have demonstrated that increased air movement enhances occupants' perception of comfort by making heat dissipated away from the human body (Nicol & Humphreys, 2002). In addition to energy and environmental benefits, passive design can also enhance occupant wellbeing, safety and operational resilience in the case of grid dropouts (Oyedepo, 2014).

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2.3 Barriers to Passive Design Adoption in Nigeria

Over the last several decades, globalization and technological advancement have contributed to the increasing popularity of international architectural styles that place a high priority on fully glazed façades and sealed building envelopes over climatic response. Some passive strategies may require additional investment in both design and construction processes and long-term benefits are not always considered in project decision-making (Lechner, 2014). Moreover, environmental simulation software, building performance assessment tools and sustainability training are not accessible to local professionals due to financial and technological constraints (RIBA, 2020).

2.4 Passive Design and Natural Ventilation in Hot-Humid Climates

The hot-humid climate is characterized by high temperatures, high relative humidity levels, high annual rainfall and limited seasonal variation. In Bonny, the relative humidity level is often above 70 percent for most of the year (NIMET, 2023). Natural ventilation is highly affected by multiple environmental and architectural factors. Wind availability is one of the most important aspects of ventilation performance. Studies have found that cross ventilation is most effective when openings are placed on the opposite and adjacent sides of the building, allowing continuous airflow through spaces (Awbi, 2003).

III. METHODOLOGY

This study takes a qualitative comparative case study approach to examine the use of passive design practices. It uses secondary data (e.g., academic papers, technical architectural reports, drawings, et cetera) and environmental data sets. The analysis assesses wind and airflow dynamics along with envelope orientations from a wide range of global and regional examples to provide some useful ideas and guidelines for the design of modern projects in hot-humid climate.

3.1 CASE STUDY SELECTION CRITERIA

The following criteria were used to select the case studies:

i. Scale and Typological Complexity:
The selected systems should have a very complex planning metric and large spatial programs that are equivalent to mixed use applications.

ii. Climatic Adaptive Merit:
The projects should have been based on the best passive or bioclimatic solutions that are tailored to a local wind and solar situation.

iii. Availability of Empirical Performance Data:
Complete formal publications, spatial plans or secondary environmental evaluations are required.

iv. Geographic and Tropical Context Relevance:
Such projects must be in tropical or equatorial climate zones (SE Asia and sub-Saharan Africa) so that the wind-driven and humidity mitigation strategies can be adapted to the hot-humid environment in coastal Nigeria (Koenigsberger et al., 1974; Olgyay, 2015).

v. Presence of Complex Circulation Networks:
The buildings must be well-designed with multiple levels and circulation systems in place (e.g., multi-tier atriums, linear transition corridors, open circulation spines) so that passive circulation flows can be reviewed and linked to the movement of the main occupant.

vi. Architectural Recognition and Empirical Validity:
The institutional preference is for landmarks published in academic and professional structural archives to be recognized as well, so that secondary data for comparison can be robust and valid.

3.2 CASE STUDY 1: Eastgate Centre, Harare, Zimbabwe (Pearce, 1997)

Location: Harare, Zimbabwe
Architect: Mick Pearce
Year and Area: 1996; 5,600 m² (office/retail zones)

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The Eastgate Centre in Harare is a beautiful example of what architects get when they look to nature for solutions to engineering problems without spending energy-intensive machines. Mick Pearce designed this mid-rise office and retail building at such an innovative biomimetic level that it is celebrated for its innovations in design. Rather than relying on conventional electric chillers, Pearce looked at the sophisticated climate control systems built into regional termite mounds and replicated that same physics in the building itself to cope with high commercial heat loads.

i. Ventilation and Airflow Dynamics Analysis

The structure is a unique biomimetic system built upon the temperature regulation properties of African termite mounds. Natural stack ventilation is the main cooling method. Outside air is pushed into the lower floor rooms through the vertical concrete structure shafts and is naturally exhausted through high chimneys at roof level (Pearce, 1997).

ii. Relationship with Surrounding Microclimate

The performance cycle is optimized by Harare's unique diurnal temperature drop. High-mass masonry components absorb radiant heat throughout the day and release it back into moving air tracks at night, ensuring cool internal environments during business hours (Pearce, 1997).

iii. Case Study Evaluation Summary

The Eastgate Centre illustrates how big-scale commercial developments can change their approach to intensive mechanical refrigeration and adopt smart nature-based airflow loops instead. By treating the central atrium as a huge public circulation spine that functions along with its thermal chimneys, the building creates an incredibly intuitive, highly visible movement track for users while at the same time providing long-term energy savings. Yet its reliance on large daily-to-night temperature swings to flush out heat is a serious warning for coastal settings like Bonny, where the design must be modified rather than simply copied (Pearce, 1997).

Figure 1: Diagram of a termite tower and a termite tower.
Source: Greenfieldmegan 69766 4440791 Biomimicry-presentation Reduced-1-1qf73rd.

Figure 2: Section showing stack ventilation effect of Eastgate Center’s chimney
Source: hiddenarchitecture.net

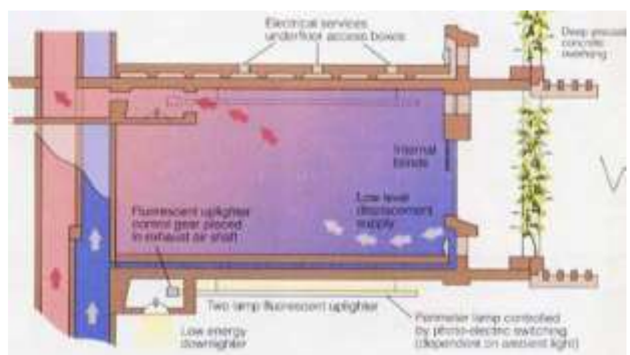

Figure 3: Ventilation diagram
Source: hiddenarchitecture.net

3.3 CASE STUDY 2: Menara Mesiniaga, Subang Jaya, Malaysia (Yeang, 1996)

Location: Subang Jaya, Malaysia
Architect: Ken Yeang
Year and Area: 1992; 15 stories

Menara Mesiniaga stands out as a bold reimagining of what a corporate high-rise can look like when it respects its environmental context. Ken Yeang designed this 15-story tower as a direct critique of the typical fully glazed, sealed glass box that dominates modern cities. The skyscraper is structured as a living "bioclimatic" ecosystem, with a handsome circular tower covered with sun-shading louvers and broken by spiraling outdoor terraces, proving how high-density office buildings can breathe on their own in hot and sticky climates.

i. Bioclimatic Form and Facade Planning Analysis

The pocketed sky-courts spiral outwards from the circle-shaped tower edge, allowing natural cross-ventilation deep into high-density office areas while integrating protective solar shading fins (Yeang, 1996).

ii. Microclimate Modification

The perimeter vegetation buffers and sky courts lower wind velocities and local relative humidity levels before the air from the surrounding environment flows through the interior louvers (Yeang, 1996).

iii. Case Study Evaluation Summary

Menara Mesiniaga is a very encouraging template for high-density tropical design that is about how passive elements are very much what drives the overall form and layout of a high-density commercial building. The way its outdoor pocket terraces spiral up the facade is a great double purpose, serving as a climate-smart breeze catcher at the same time as a clear, memorable architectural landmark that makes it very easy for occupants to orient themselves. Its complex facade geometry does pose some maintenance challenges, but it is a wonderful example of the way that a dense, multi-story mixed-use development can work out a hybrid environmental approach to create a balance between modern workday expectations and climate response in a world of climate change (Yeang, 1996).

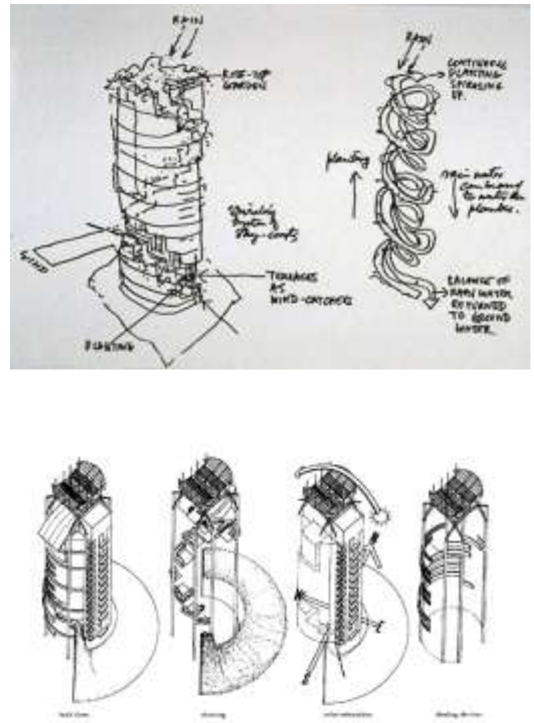

Figure 4: Conceptual sketches and axonometric view of Menara Mesiniaga
Source: www.archnet.org

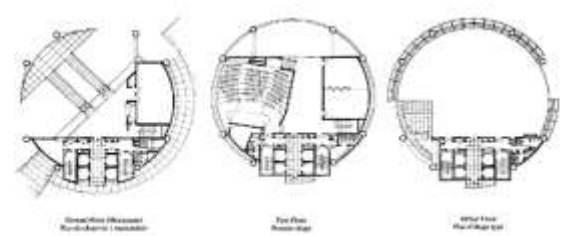

Figure 5: Floor Plans of Menara Mesiniaga
Source: www.archnet.org

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Figure 6: Façade detail showing terraced garden and aluminium screens
Source: www.archnet.org

3.4 CASE STUDY 3: Khoo Teck Puat Hospital, Yishun, Singapore (Tan, 2012)

Location: Yishun, Singapore
Architect: RMJM / CPG Consultants
Year and Area: 2010; 105,000 m²

Khoo Teck Puat Hospital is an extraordinary project because hospitals are often hard to run without intensive, full-time air conditioning. The design team broke with traditional hospital design and incorporated nature and biophilic thinking into the design. By wrapping the hospital wings around a large, robust central courtyard and using aerodynamic paneling to create a space that is alive, clean sea breezes sweep through the wards to keep patients comfortable and connected to the outdoors.

i. Natural Airflow and Biophilic Integration Analysis

The architecture uses a large central courtyard to pull regional sea breezes in. Wing walls and open corridors can guide natural air vectors into patient wards, reaching almost 70% natural ventilation in institutional zones (Tan, 2012).

ii. Microclimatic Modification

Green roofs, interior water features, and multiple-tier plants can help cool the structure via evapotranspiration, which reduces the impact of the heat island on the town (Tan, 2012).

iii. Case Study Evaluation Summary

Khoo Teck Puat Hospital demonstrates that even the most environmentally demanding and sensitive building types can achieve high energy targets with a very special biophilic philosophy. The layout of high traffic circulation routes and open corridors around a large green courtyard ensures that fresh and evaporatively cooled sea breezes are flowing over occupants and that lesson is even more applicable for coastal areas such as Bonny. In the end, it shows that when we make the landscape a functional, climate-responsive infrastructure and not just an aesthetic afterthought, we have a really good, human-friendly layout where an outdoor environment guides the inhabitants and also a comfort zone in the indoor environment (Tan, 2012).

Figure 7: Site plan of Khoo Teck Puat Hospital showing its 'hospital in a garden, garden in a hospital' concept.
Source: cooper.edu & www.academia.edu

Figure 8: Photos showing verdant greenery from the rooftop to the basement, giving Khoo Teck Puat Hospital its hospital-in-a-garden therapeutic experience.
Source: archinect.gumlet.io

Figure 9: Photos showing the central garden courtyard with water features and façade detail showing louvers.
Source: archinect.gumlet.io

3.5 CASE STUDY 4: Pearl Academy, Jaipur, India (Bennetts et al., 2011)

Location: Jaipur, India
Architect: Morphogenesis
Year and Area: 2008; 11,000 m²

The Pearl Academy in Jaipur provides an excellent example of how modern architecture can draw on old traditions to respond to harsh environmental conditions. Jaipur's heat can quickly overwhelm a building, but Morphogenesis brought two of the most popular local vernacular designs through: the baoli (stepped water reservoir) and the jaali (perforated stone screen). This makes for a lively and self-shading academic campus that feels like a sheltered oasis, where air pressure changes and evaporation are used to keep indoor temperatures down naturally.

i. Vernacular Courtyard Physics Analysis
The layout has an inner open-air stepped courtyard with a traditional water reservoir (baoli) and an outer perforated screen wall (jaali)

ii. Thermal Comfort Performance
The jaali screen creates a pressure difference that increases wind velocities but shields the central building facade from solar gain and lowers the temperature of air flowing into the interior rooms.

iii. Case Study Evaluation Summary
The Pearl Academy serves as a wonderful lesson in environmental passive cooling, demonstrating how relatively simple architectural elements with local materials can be used to compete with sophisticated mechanical systems. Its double-skin screen wall offers protection to the delicate interior from extreme heat gain and makes a beautiful, sheltered undercroft area to shelter students and to move them easily. Even if its evaporative cooling loop was originally designed to handle a hot-dry desert climate, the way that structural screens change air velocities and create framed and visually striking transition zones makes it an effective method of keeping public walkways comfortable in humid Nigerian conditions.

Figure 10: Photos showing open courtyard, stepped well or baoli, and perforated stone screens or jaalis.
Source: www.archdaily.com

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Figure 11: Section of Pearl Academy showing the direction of airflow through the scooped-out underbelly and open courtyards.
Source:www.archdaily.com

3.6 Comparative Analysis Matrix of Case Studies

Precedent	Location & Climate	Primary Strategy	Structural Feature	Environmental Performance Outcome
Eastgate Centre	Harare, Zimbabwe (Semi-Arid)	Stack ventilation via biomimetic chimneys.	Heavy concrete thermal mass.	90% reduction in active mechanical chiller operational energy demand.
Menara Mesiniaga	Subang Jaya, Malaysia (Hot-Humid)	Wind-driven cross-ventilation.	Spiraling sky-courts & sun-shading fins.	Effective deep-plan air circulation with targeted solar shielding microclimates.
Khoo Teck Puat	Yishun, Singapore (Hot-Humid)	Courtyard breeze collection.	Aerodynamic louvers & open single-loaded corridors.	70% natural ventilation rate achieved across highly demanding institutional layouts.
Pearl Academy	Jaipur, India (Hot-Dry)	Evaporative courtyard cooling.	Perforated double-skin *jaali* screens.	Substantial reduction in core thermal envelope radiant heat load.

The comparative analysis matrix demonstrates that while each project has its own unique architectural form to suit its particular environment (Eastgate Centre's biomimetic stack chimneys, Menara Mesiniaga's spiraling sky courts, Khoo Teck Puat's biophilic courtyard catchments and Pearl Academy's traditional evaporative baoli systems for example), the successful passive design approach relies on a holistic set of environmental strategies rather than a single one. While the thermal mass and night-purging loops used in semi-arid and hot-dry climates need to be adapted to the local environment (as the diurnal temperature drops at coastal Nigeria are too narrow for them to be copied) hot-humid tropical models offer a very relevant model for hot-humid climates. These tropical examples demonstrate that aerodynamic wing walls, single-loaded open corridors and deep, plant-filled courtyards can increase wind-driven cross-ventilation and lower ambient air temperature through evapotranspiration. Taken together, these case studies demonstrate that passive cooling strategies have a significant effect on mechanical energy reduction and a practical basis for a hybrid layout of mixed-mode systems that uses HVAC only in high-load spaces, such as multiplex cinema auditoria.

IV. KEY FINDINGS AND DISCUSSION

The comparative analysis of literature and global precedents yields the following key findings:

i. Natural ventilation is effective across varied typologies.

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Natural ventilation is a successful cooling mechanism for a range of building sizes and applications and has to be incorporated at the start of the design process.

ii. Passive Strategies Function Best as an Integrated Ecosystem

An integrated system of features will be needed to achieve thermal comfort. Natural ventilation must be paired with specific solar shading, appropriate orientation and biophilic microclimatic cooling (Givoni, 1998; Lechner, 2014).

iii. Contextual adaptation is critical.

Reversing architectural form without taking into account local climate conditions can lead to system failure. Designs should be designed to respond to specific regional conditions, like the persistent high humidity in coastal areas such as Bonny (Givoni, 1998; Koenigsberger et al., 1974).

iv. Mixed-Use Contexts Enable Thermal Zoning

Large-scale properties can be divided into climate zones. The public areas, such as atriums, lobbies and food halls can be comfortably circulated through natural passive ventilation channels, with mechanical HVAC systems only targeting those in the most crowded spaces.

v. Mixed-Mode Systems Balance Comfort and Efficiency

For large-scale commercial development in a highly complex environment, mixed-mode systems can be quite successful. They function through passive air pathways in good weather and use active mechanical cooling during extreme weather peak periods (Heiselberg, 2002; Santamouris & Asimakopoulos, 1996).

V. RECOMMENDATION

The following recommendations are made to help Nigerian mixed-use developments adopt passive design and natural ventilation strategies for sustainable development:

i. Design Aerodynamic Envelopes to Capture Prevailing Winds

In coastal locations like Bonny, orient long building facades north-south and introduce wind scoops or wing walls to capture prevailing southwesterly sea breezes.

ii. Integrate Double-Skin Screens and Deep Shading

Incorporate external shading devices, deep roof overhangs, and perforated screen systems to reduce direct solar heat gains while allowing passive cross-ventilation.

iii. Utilize Central Courtyards and Atriums as Thermal Chimneys

Incorporate vertical atriums, light wells, and central open courtyards to facilitate buoyancy-driven stack ventilation, drawing warm air upward and out of the building.

iv. Deploy Evapotranspirative Landscape Systems

Place open water basins, water features and multi-tier vegetation around the main fresh air inlets to cool incoming air streams before they enter occupied spaces.

v. Standardize Mixed-Mode Operational Logic

Develop smart automated sensors to manage the transition from passive openings to active mechanical systems in order to save energy.

vi. Update Building Performance Codes and Professional Training

In addition, local architecture training should incorporate energy efficiency into regional planning codes and enhance microclimatic simulation.

VI. CONCLUSION

This study shows that in hot, humid coastal areas, natural ventilation can be a useful primary cooling technique for large-scale mixed-use complexes. Financial and operational dangers result from relying exclusively on sealed, completely glazed structures, particularly in light of Nigeria's present energy infrastructure issues. Modern constructions can lower energy consumption, enhance interior air quality, and boost structural resilience during power outages by including passive methods (such as appropriate orientation, solar shading, courtyard design, and biophilic landscaping). In order to create a more sustainable model for Nigeria's built environment, future broad adoption of these climate-responsive solutions will require coordinated efforts across professional practice, academic training, and green building code enforcement.

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