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Enhancing Thermal Comfort in High-Rise Condominiums Through Passive Design Strategies in Lagos, Nigeria

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ABSTRACT

Thermal comfort in buildings is a challenging environmental issue confronting occupants, especially in tropical climates like Nigeria. Thermal comfort is essential in urban centres like Lagos due to high population density, limited urban land, and congestion. The impacts manifest more in compact high-rise buildings not adopting passive design strategies. The study investigates the passive design strategies adopted in high-rise condominiums designed to enhance occupants' thermal comfort in Lagos, Nigeria. The study relied on qualitative data collected through case studies, observation checklists, and in-depth interview guides from seven purposely selected high-rise condominiums. Data were analysed using simple statistical tools and content analysis techniques. The data analysis showed that only 28.6% (2 out of 7 case studies) of the buildings adopted passive design strategies. 71.4% (5 out of 7 case studies) depended on active ventilation for thermal comfort. Findings show that passive design strategies in high-rise condominium buildings consider a location's climate and site conditions to maximise the health and comfort of building occupants while minimising energy use. It is relevant and is in tandem with SDGs 3, 11and 13. The results implied that occupants are experiencing discomfort with thermal indoor qualities in their homes. The study concludes that thermal discomfort affects occupants' well-being.

1. INTRODUCTION

Thermal comfort for building occupants is a vital factor and a concern to the occupants, developers, architects, and built environment professionals [1]. It is because thermal comfort ensures comfort for occupants of dwelling units. Thermal comfort is related to sustainable energy, which the United Nations adopted as a pillar of the Sustainable Development Goals (SDGs). SDG 7 will guarantee universal access to cheap, dependable, sustainable, and contemporary energy by 2030 [2]. This measure will improve energy efficiency, increase renewable share, and diversify the energy mix while ensuring energy affordability for member citizens. The expected benefits of this global adoption are unfelt in most developing countries (Sub-Saharan Africa), especially in Nigeria, where energy development is still at the lowest ebb. The energy crisis in Nigeria has continued over recent years despite power sector reforms by successive governments. The issues associated with energy crises and thermal comfort in buildings are still prevalent. Thermal comfort is the air temperature experienced in an area or state of mind that articulates satisfaction with the thermal setting to measure subjective evaluation [3, 4]. Thermal comfort is vital for residents' well-being, efficiency, and competence with efficient building designs. Aghimien et al. [5] and Rivera et al. [6] opined that providing passive rather than active design strategies in high-rise buildings is necessary to save energy.

Passive design features such as climate, trade winds, sun path, and temperature sustain a green inward temperature in the design process [7]. It is a design that exploits the outside factors in a location to uphold a calm temperature in a structure and improve the well-being and comfort of residents residing in houses inclined to severe climates [8, 9]. Passive designs in high-quality buildings are due to the current realism of climate change, economic recession, and global warming [10]. According to reference [11], residential high-rise buildings worldwide require thermal comfort and air quality through passive means to minimise energy consumption. A contributing factor to the urban housing problem in Nigeria. Particularly Lagos, which has a high rate of urbanisation, high population density, and scarcity of land. It is in line with Goal 11: Sustainable cities and communities by 2030, ensure access for all to adequate, safe and affordable housing and essential services and plans towards inclusion, sustainable urbanisation, resource efficiency, mitigation, and adaptation to climate change and reduce the adverse per capita environmental impact of cities. These have consequences for housing, hence the rise in high-rise buildings and condominium construction.

Condominiums are necessary because they can accommodate more occupants than low-cost flats [12]. High-rise buildings are a trend today due to a lack of land in rapidly developing countries [13]. van Hoof et al. [14] posited that a condominium makes a more compact town with savings in services, agricultural land, and integration between indoor thermal comfort, landscape, energy and the building. Nimlyat et al. [15] identified the challenges facing high-rise condominiums in Nigeria, such as thermal discomfort, fire outbreaks, problems with heights, and long vertical distance travel in exits and access to the building. Oginni [16] submitted that other high-rise building challenges are air movement, air temperature, relative humidity, mean radiant temperature, clothing, and activity level. Adeogun [17] identified poor design, orientation, and inappropriate use of building materials and components as causes of thermal discomfort in high-rise residential buildings in Lagos. High-rise residential buildings are contemporary, efficient and functional towers [18]. It is the realisation of this challenge that the Nigerian government has recently concentrated on high-rise building design and construction to mitigate the discomfort experienced by some urban residents. Furthermore, the Nigerian government established National Building Codes (NBC) and Fire Safety Codes across the country to help regulate the design and construction of high-rise buildings [19].

Another problem is the inconsistent nature of the power supply, the high cost of cooling and ventilating equipment, and the greenhouse gas emissions from such equipment. The rapid geometric increase and influx of people into Lagos have also prompted the need to enhance energy efficiency and achieve thermal comfort indoors for residents in Lagos. The rationale for this study is the realisation that the indoor environment in residential buildings tends to affect occupants either definitely or adversely because of the physical reactions and mental responses to the environment [20]. Thermal comfort is vital in social performance and impacts occupants' health, welfare, and productivity irrespective of socio-economic status, colour, or creed [8]. The parameter that affects the occupants' well-being is thermal comfort derived from the indoor spaces [21]. Therefore, this research aims to assess thermal comfort in high-rise condominiums by adopting passive design strategies in selected condominiums in Lagos, Nigeria, used as case studies. The study research questions include: What relevant checklists are needed to conduct case studies of existing high-rise condominiums? What are the passive design strategies that enhance thermal comfort in high-rise condominiums? What is the effect of passive design strategies on maximising thermal comfort in high-rise condominiums?

2. LITERATURE REVIEW

Thermal comfort is a vital requirement in any building and shapes the accessibility and affordability of sustainable energy as encapsulated in SDGs 7 and 11. For users and occupants to have optimal thermal comfort, there is a need to reduce thermal discomfort. This review examines the literature on thermal comfort and high-rise condominiums and the theoretical framework from studies with keywords such as condominium, thermal comfort, and passive design strategies.

2.1 Condominium building

Condominiums are structures with multiple floors and entail parcels of land jointly owned and used by several households [22]. Madsen and Paasch [23] asserted that a condominium is a multilevel construction separated parallel or perpendicularly into units. Each unit is maintained and used by diverse occupants. Treffers and Lippert [24] stated that condominiums have several apartments owned by individuals. In many countries, condominiums are for residential and commercial purposes. In Nigeria, condominiums are frequently confused with apartment buildings. The ownership form differentiates apartment buildings from condominiums [25]. According to reference [26], Apartment buildings are corporately owned by an individual but leased to single tenants, and the landlord might be involved directly or indirectly in the management of the building. There are two basic types of condominiums.

2.2 Thermal comfort

Thermal comfort is a state of mind that expresses happiness with the thermal environment [27]. Studies show thermal comfort interacts with environmental adaptation and human body parameters [28]. Temperature variations permit natural ventilation use and passive cooling systems to decrease the thermal load of structures in tropical regions [29]. Accordingly, Wang et al. [30] posited that the inside thermal condition in construction is suitable when 80% of the occupants are satisfied and happy within it. A study by Orman et al. [31] revealed that people spend up to 90% of their time indoors, so the quality of the indoor environment impacts their quality of life. Martins et al. [32] revealed that thermal environments and personal and other contributing factors determine thermal comfort. The fundamental principle for comfort is thermal. Without optimising thermal balance, comfort is impossible. Major factors which affect human comfort are air temperature, radiation, air movement, and humidity, as illustrated on the bioclimatic chart proposed to aid architectural design [33, 34].

2.3 Passive design strategies in high-rise condominiums

Several factors are responsible for thermal comfort in buildings, especially high-rise buildings. Kurniawan et al. [35] asserted that people consider thermal comfort strategies first when measuring occupants' comfort in buildings. Generally, two design strategies (passive and active) can achieve thermal comfort. However, Inusa and Alibaba [36] and Shi et al. [37] recommended a blend of active and passive design strategies to attain sustainability in homes and other architectural designs. Passive design strategy uses outdoor variables like temperature, sun path, climate, and trade winds to sustain a sustainable indoor temperature in the design process [38]. It is a strategy that uses the exterior factors in a setting to maintain a relaxed temperature in a structure, refining the well-being and comfort of persons living in homes prone to harsh weather [9]. Residential buildings help to protect occupants against adverse weather conditions and solar radiation [39].

Bevilacqua [40] found that passive design decreases or removes supplementary heating or cooling. Vandenbogaerde et al. [41] suggested that passive design is not a link/supplement to architectural design but a design procedure incorporating structure. Munonye and Ji [42] believe thermal comfort concerns should be controlled at the architectural design stage, specifically in Nigeria, because of its warm-moist atmosphere. Nawayai et al. [43] recommended that architects have principal roles in ensuring the design of visual and thermal comfort in structures for occupants' comfort and well-being. Yang et al. [44] investigated passive design strategies for urban areas in dry and hot climates. Passive design strategies such as the right choice of building materials, adequate natural ventilation, and proper building orientation can reduce the energy consumption in buildings. Ibem et al. [45] explain that architects in Lagos have good data on passive design strategies. Elaouzy and El Fadar [46] and Olojede and Owolabi [47] identified passive design strategies like window hoods, exterior overhangs, and double-glazed windows as structure features that enhance low energy usage in housing units and help moderate thermal comfort.

Mushtaha et al. [48] identified passive design strategies like building orientation, building layout, window design, adequate ventilation, insulation, building materials' thermal mass, and shading devices to enhance thermal comfort. Zhong et al. [49] and Moghaddam et al. [50] study emphasised that building orientation is vital to reflect while designing passive constructions to exploit climate conditions, like cooling wind and sunlight. Wijesooriya and Brambilla [51] advocated for bioclimatic design principles, such as designing structures based on the setting of the local climate to offer the optimum thermal comfort of the home. Galiano-Garrigós et al. [52] alluded that the advantages of passive design are energy efficiency, enhanced thermal comfort, environmental friendliness, aesthetically pleasing, and cost savings in buildings. The deductions and inferences demonstrate the importance and the need to address thermal comfort in buildings for users' comfort. Few researchers assessed the impact of passive design strategies in enhancing thermal comfort in high-rise condominiums. This research attempts to fill the gap.

3. MATERIALS AND METHODS

3.1 The study area

Lagos is located in the Southwestern part of Nigeria and lies amid longitudes 20 42" E and 30 22 "E and latitudes 60 22" N and 60 42" N [53]. It is bounded in the North and East by Ogun, Nigeria, in the West by the Republic of Benin, and in the South by the Atlantic Ocean, as shown in Figure 1. Lagos was formed on May 27, 1967, by Decree No. 14 [54]. The state was an administrative entity and the federal capital. The capital of Lagos moved to Ikeja in 1976. However, Lagos remains the economic and commercial capital with two of the largest seaports in the megacity and another planned for the Lekki Free Zone [55] - a new private refinery by the Dangote Group in Lagos, Nigeria. The Lagos Megacity is the most economically viable in the country. Lagos has the smallest landmass and the highest urban population (27.4%) in Nigeria [56]. Akinyoade et al. [57] estimated Lagos to have about 24.6 million inhabitants in 2015. The population of Lagos grows ten times faster than New York and Los Angeles, and it has a combined population of more than 32 African nations. The population was 40 million in 2020 [58]. All these factors affect housing in Lagos and the need to address thermal comfort in such houses. Lagos has a tropical wet and dry climate. It experiences two rainy seasons, with the heaviest rains falling from April to July and a weaker rainy season from September to November [59, 60]. Lagos has abundant water resources, such as surface water (rivers, lagoons, lakes, and creeks) and groundwater. It impacts available land for building development and has led to the reclamation of swamps for development. Lagos Megacity has as many as 200 slums, with two out of every three living in slums [61].

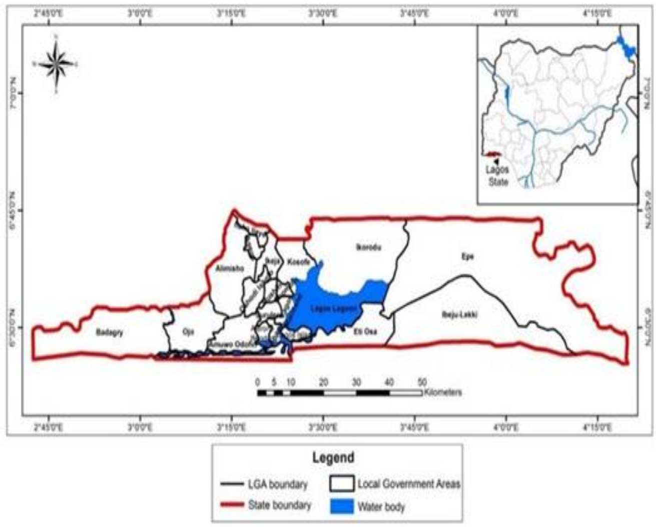


Figure 1. Map of Lagos
Source: refer to reference [62]

3.2 Research design

The research employed is a case study design. According to reference [63], the approach gives an in-depth insight into a given problem. Case studies involve studying and analysing similar buildings to gain in-depth knowledge and help with the design method. Hence, the investigators adopted that approach. Furthermore, the researchers also employed observation checklists for data collection. The observation checklist is a tool that helps researchers collect data through direct and indirect observation. The observational approach further helped the researchers, due to security concerns in Lagos, Nigeria, to attain the set objectives.

3.3 Recruitment procedure

The investigators asked everyone who attended our orientation workshop to participate in the study. Participation entailed sitting through an IDI for 45 to 60 minutes. Among all attendees, only fifteen agreed to participate in the IDI (see Appendix 1). Fifteen signed consent forms were administered to study participants who expressed interest in the IDI exercise. However, thirty-five residents agreed to participate in the training, following the recommendation in qualitative research to ensure a suitable representation of Lagos residents' lived experiences and diversity. A purposive sampling method was used with six criteria: age, Gender, marital status, education, occupation and years in Lagos, as shown in Table 1.

3.4 Data collection

Data collection was from the case studies of seven (7) purposively selected high-rise condominiums. The buildings are Infinity Tower, Blue Waters, Azuri Tower, Eko Court Tower, Eko Pearl Tower, 1004 Estates, and Royal Residence (Eden Heights) Tower. The three vital criteria for selecting seven (7) high-rise condominiums for the case studies include: 1. a high-rise condominium, 2. display elements of passive or active strategies, and 3. have passive design mechanisms in the design and construction of such buildings. The operationalisation of variables includes the data, type and source, as shown in Table 2.

Table 1. Demographic information of the participants

Name	Age	Sex	Marital Status	Education	Occupation	Years in Lagos
AP	48	M	Married	M.Sc.	Household Head	22
KSA	46	M	Married	B.Sc.	Household Head	24
HE	52	M	Married	M.Sc.	Landscape Architect	26
AC	44	M	Married	M.Engr.	Service Engineer	18
KD	55	M	Married	PhD	Architects	23
GA	47	F	Married	B.Sc.	Household Head	14
LP	42	F	Married	M.Sc.	Household Head	19
BA	40	M	Married	B.Engr.	Electrician Engineer	16
MO	33	M	Single	M.Sc.	Therapeutic Architect	13
SH	43	M	Married	B.Engr.	Household Head	21
JM	49	M	Married	PhD	Sustainability experts	17
GB	51	M	Married	M.Engr.	Mechanical Engineer	24
SM	38	F	Married	B.Sc.	Household Head	15
MSI	45	F	Married	M.Engr.	Civil Engineer	20
WU	41	F	Single	PhD	Building Engineer	18

Mean Age: 42.3, Mean Years in Lagos: 25.4

PhD-Doctor of Philosophy, M.Engr.-Master of Engineering, M.Sc.-Masters of Science, B.Engr.- Bachelors of Engineering, B.Sc.-Bachelor of Science, M-Male, F-Female

Table 2. Primary data, type, and sources

S/N	Data	Type	Source
1	Infinity Tower	Qualitative	Observation
2	Blue Waters Tower	Qualitative	Observation
3	Azuri Tower	Qualitative	Observation
4	1004 Estate Tower	Qualitative	Observation
5	Eko Court Complex	Qualitative	Observation
6	Eko Pearl Tower	Qualitative	Observation
7	Royal Residence Tower	Qualitative	Observation

The photographs of floor plans and elevations of the selected condominium assist participants in telling a story through images. Images provide an enduring scene record and perception to conduct relevant case studies of existing high-rise condominium buildings in Lagos to identify the passive design features. A photograph allows intricate passive design strategies to be captured and shared. This study highlights the essential passive and active design features of a high-rise condominium visible in the photos. This study used the snapping features approach of the selected condominium case study, whilst considering thermal comfort based on the location climate and site condition contribution framework toward SDGs 11. The passive design features checklist was used to assess the thermal comfort of a high-rise condominium. Assessments of these features rely on standard global classification. Photos were made in June and July 2023 by two (2) research assistants and the co-author, who received instructions from the principal investigators to cover each case study via the Internet and correspondents from Lagos, Nigeria. The guideline was for research assistants to take photographs based on a high-rise condominium's essential passive and active features checklist, see Appendix 2.

The researchers used an in-depth interview guide to elucidate information from experts/professionals and condominium occupants. It was used as the case study to answer objective 2, identifying the passive design strategies that enhance thermal comfort in high-rise condominium buildings. Aliu [64] opined that the observation schedule is a document prepared to improve the examination of variables in the sampled population. However, the passive design strategies in the study improve the thermal comfort of high-rise condominiums based on the review of related literature. The design strategies include building form, building orientation, spatial organisation, landscape, building material, natural ventilation, and daylighting. The investigators analysed data collected from the fieldwork using descriptive statistics such as tables, figures, plates, charts, and descriptive analysis.

3.5 Data analyses

The researchers employed the condominium essential passive and active features checklist for the primary data analyses (a priori thematic analysis). The study explores enhancing thermal comfort in high-rise condominiums by adopting passive design strategies. The authors analysed each case study based on functionality, structural stability, and aesthetic appeal, focusing on thermal comfort. Photographs were from Infinity Tower, Blue Waters, Azuri Tower, Eko Court Tower, Eko Pearl Tower, 1004 Estates, and Royal Residence (Eden Heights) Tower, all in Lagos, Nigeria. The authors achieved data saturation for every case study. Photographs were clustered based on the domains of the checklist, and the stories relating to these photos were used to describe the passive and active design features and their thermal comforts in high-rise condominiums. After collecting the photograph data, the authors presented the pictures to the interviewed experts/professionals for checking and validation. Also, passive design strategies of the condominium were analysed using photos to see if design features enhance thermal comfort and occupants' well-being. We developed observational notes and transcribed and analysed them using thematic analysis. The authors deductively coded the transcripts under a pre-existing theme; 'Enhancing Thermal Comfort in High-Rise Condominiums Through Passive Design Strategies in Lagos, Nigeria'. The authors presented the participants' experiences in the subject matter through direct quotes and ethnographic synopses.

4. RESULTS AND DISCUSSIONS

The result section analysed the data gathered using case studies, descriptive statistics, and records from direct observations. The study investigates thermal comfort in high-rise condominiums in Lagos, Nigeria, by adopting passive design strategies. All seven high-rise condominiums were used as case studies to explore the application of passive design mechanisms in the design and construction of such condominiums. And examine how thermal comfort enhanced the adoption of passive design strategies in high-rise condominiums. The results were presented sequentially according to the following objectives: Conduct relevant case studies of existing high-rise condominium buildings in Lagos to identify the passive design features. Identify the architectural features for passive design strategies that enhance thermal comfort in high-rise condominium buildings. Analyse the effect of passive design strategies on maximising thermal comfort in high-rise condominium buildings.

4.1 Case study results on design features in Lagos high-rise condos

The first objective was to conduct relevant case studies of existing high-rise condominiums in Lagos, Nigeria. Table 3 shows the summary of results obtained on the passive and active design features utilised in the selected building in Lagos used as case studies. The findings revealed that many buildings depend on active rather than passive cooling systems. Figure 2 shows that 71.4% (5 out of 7) of the selected buildings adopted the active design strategies, while 28.6% (2 out of 7) adopted the passive design strategies. Analysis of the fieldwork indicated that Infinity Tower scored high in passive design strategies and low in active strategies. It is due to the adoption of building forms that natural ventilation use is encouraged. For instance, observations show that Infinity Tower adopted (i) The L-shaped floor plan, which facilitated sufficient daylight and cross ventilation in the apartment; (ii) Proper use of large windows to aid ventilation; (iii) Proper segregation of spaces as the ground floor houses the commercial and recreational spaces.

Blue Water Towers were moderate in both the use of passive and high in the use of active design strategies. Condominiums that used moderate-passive and active design strategies include the Eko Court Complex, Eko Pearl Tower, and Royal Residence Tower. Blue Waters used moderate-passive strategies design but was high in active strategies design. Blue Waters has modern, active strategies for thermal comfort on every floor. The lowest in the ranking were Azuri Tower and 1004 Estate Tower, which scored low in passive principles use but relied more on active means. The result of thermal comfort design features of selected case studies, as shown in Table 3, implies that occupants use mechanical types more than passive types to ensure thermal comfort in their dwelling units. Figure 2 further confirms that passive design strategies lack adequate consideration in the design of five out of seven high-rise buildings.

It is significantly low, indicating a lack of awareness/attention to the importance of passive design strategies in high-rise condominium design. As a result, most of the building's orientation is to optimise natural daylight and ventilation use. Therefore, these findings are in tandem with the recommendations that suggest that passive design strategies should be adopted in buildings for efficient thermal comfort [65]. It further gives credence to the assumption that some housing developers prioritise more apartments for users' thermal comfort, as shown in Table 4.

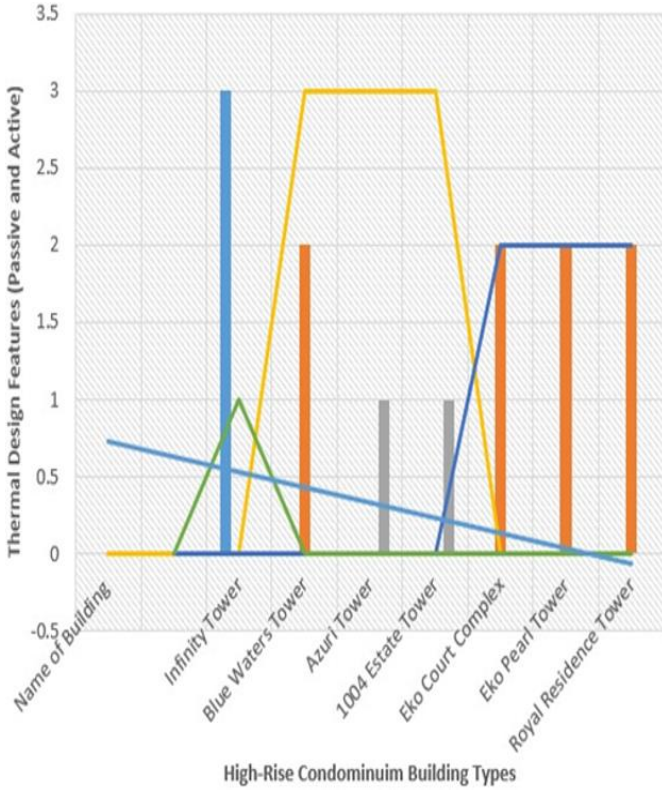


Figure 2. Thermal comfort design features of case study
Source: Authors (2022)

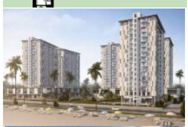
Azuri Tower shows adequacy in variables such as building orientation, landscape, and building material but reveals inadequacy in other variables such as building form, spatial organisations, natural ventilation, and daylighting. 1004 Housing ranked adequate in building form, orientation and landscape but indicated inadequacy in other parameters. Eko Court Complex was slightly adequate in building form, orientation and landscape but inadequate in others. Eureka Towers and Eko Pearl Tower presented adequacy in building forms, orientation and landscape but showed inadequacy in other parameters. The Royal Towers were inadequate in building form, orientation, landscape, and building materials but insufficient in others. Again, the result is significantly average, showing the inadequacy of the environmental factors. Attention was only to building forms and building orientation based on site accessibility. Hence, these were adequate and not based on site sustainable factors, which is inadequate. Masia et al. [66] had long advocated that building designs should consider the location's bioclimatic conditions and environmental factors to improve occupants' living standards. According to an engineer during IDI:

"The idea of passive building design for the tropics includes avoiding heat gain and orienting the building to reduce exposure to the midday sun. – Use materials with low thermal mass– Shade walls and windows, particularly walls with high thermal mass". **(Service Engineer, IDI: 2024)**

Table 3. Result of passive and active design features of selected case studies

Name of Building	Passive Design			Active Design		
	High 3	Moderate 2	Low 1	High 3	Moderate 2	Low 1
Infinity Tower	3	-	-	-	-	1
Blue Waters Tower	-	2	-	3	-	-
Azuri Tower	-	-	1	3	-	-
1004 Estate Tower	-	-	1	3	-	-
Eko Court Complex	-	2	-	-	2	-
Eko Pearl Tower	-	2	-	-	2	-
Royal Residence Tower	-	2	-	-	2	-

Table 4. Results obtained on the thermal comfort design features utilised in the selected building in Lagos are used as case studies

SN.	Case Study	Passive Design Features	Description	Diagram
	Address: The condominium building, situated at No. 4 Bourdilion Road, Ikoyi, Lagos, was established in 2014 and is set to be ready for occupancy in 2019. **Developer:** Elanlan Group and Kaizen Properties			
1	Infinity Tower	Features lush green garden, water bodies, swimming pools, a tennis court, a gym, a clubhouse for relaxation, ample parking, Spacious interiors, spacious design, L-shaped layout for optimal lighting for large windows, and Natural daylight: Cross ventilation, and a healthier environment.	Infinity Tower is a contemporary twin-tower development with 41 units of 3 and 4-bedroom flats, 5-bedroom duplex flats, and duplex penthouses. Divided into two wings, Wing A has 3-bedroom units, while Wing B has 4-bedroom units. The construction materials include glass, concrete, hollow blocks, and steel, with modern active and passive strategies for thermal comfort and fire safety measures on each floor.	 
	Address: The condominium building, situated at 102105 off Remi Oluwode Street, Lekki Phase 1, Lagos, known as Blue Water Lagos, was established in December 2018 and completed in 2019. **Developer:** Elanlan Group & African Capital Alliance, and master planned & designed by Nwonyama Okpanum & Associates			
2	Blue Water Tower	Facilities in Blue Water Lagos include a garden, gymnasium, panoramic lifts, clubhouse, outdoor children's area, and external visitors' parking space. Sun-filled spaces with efficient cooling, large windows for proper ventilation and amazing views, kitchens with service balconies	Blue Water Lagos is a modern condominium development comprising five 17-20-storey residential buildings with 1, 2, and 3-bedroom apartments. The tower sits on 37,000 sqm of sea-view land, showcasing quality and comfort in its design. Building materials used include glass, concrete, hollow blocks, and steel, with modern active and passive strategies for thermal comfort, such as cross-ventilation and proper orientation, on every floor.	  
	Address: The 1004 Estate, located off Ozumba Mdadiwe Road in Victoria Island, boasts proximity to critical areas like Ikoyi, Lekki Phase 1, Lagos Island, Yaba, and Surlier, completed in May 2010. **Developer:** UACN Property Development Company (UPDC) and Union Homes Savings and Loans Plc			
3	1004 Estate Tower	The provision of a refuse chute, towers equipped with emergency escape staircases, cross-ventilation in some rooms, spacious interior spaces, a spacious building design, a well-landscaped environment with green lawns	1004 Estates is a condominium development comprising five 17-20 storey residential buildings of 1, 2, 3, and 4-bedroom apartments. 1004-estates sit on an expanse of 37000 sqm of sea view land, with quality and comfort embedded in their design. Assessment Materials used for erection include glass, reinforced concrete, hollow blocks, and steel. The tower used active and passive fire safety measures using cement products and frame structures. Each floor has a sprinkler system, fire hose system, and fire extinguishers.	
4	**Address:** The Azuri Tower, located in Eko Atlantic City, Lagos, is a unique mixed-use commencing in early 2015, **Developer:** ITB Nigeria Limited			

	Azuri Tower	Features include recreation complexes with gyms, swimming pools, tennis courts, green areas, granite tiles, and designated parking bays. Passive fire prevention strategies, including cement products/frame structures, large windows, proper space organisation, spacious interiors, emergency escape staircase, optimal natural daylight and ventilation	Azuri Tower, located in Eko Atlantic's marina district, comprises three 32-floor towers, townhouses, and ground-floor retail elements: the towers house 7-bedroom villas, 6-bedroom penthouses, 2 and 4-bedroom apartments, and prime office space. The project features three sets of over 30-storey towers, offering a distinctive collection of luxury apartments, marina townhouses, and penthouses. The steel and concrete structures provide standard structures. Concrete encasement safeguards the steel from buckling, corrosion, and fire. Construction materials are glass, reinforced concrete, hollow blocks, and steel.	
Address: The Eko Court Complex is at 175-178 Kofo Abayomi Street, Victoria Island, Lagos, and It stands as a landmark in Victoria Island, reaching a height of 289ft				
5	Eko Court Complex	External parking lots and two visitors' staircases, A well-paved, ample relaxation and recreation, security lobby, lift lobby, a well-landscaped environment, a gym, a swimming pool, a tennis court, active and passive fire safety measures - a sprinkler system, fire hose system, and fire extinguishers on each floor	The complex comprises three high-rise and one low-rise building, totalling 155 apartments. Blocks A, B, and C, each with 24 floors, include two and three-bedroom apartments with a penthouse—ground-floor parking, totalling 42 car parks. Offices are on the terrace floor, with apartments on the upper floors featuring 2- and 3-bedroom flats. The construction materials are precast concrete, glass, reinforced concrete, hollow blocks, and steel. There are no service lifts, narrow stairs and a lift lobby, inadequate fire-fighting amenities, and limited parking facilities.	
Address: The Eko Pearl Tower project in Eko Atlantic, Black Pearl and Champagne Pearl Towers was in 2017. **Developer:** T.A.A. (Tabet Atelier d Architecture) and ESLA International Limited, a subsidiary of Chagoury Group				
6	Eko Pearl Tower	Feature - swimming pools, tennis courts, a squash court, a children's playground, landscaped paths, an open-air bar, a well-equipped gym, leisure features, security, intrusion alert, home automation system, ducting provision, fire detector system, parking, large windows, proper space segregation.	The Eko Pearl Tower comprises five towers, each with a unique identity and colour. Each building houses four apartments per floor: two penthouse apartments, a technical floor, a terrace floor, a ground floor, and a basement floor. The towers collectively cover a plot area of 22,738 m2, offering over 560 apartment units with views of the Atlantic Ocean, Victoria Island, and Lagos Island. Construction materials include glass, reinforced concrete, hollow blocks, and steel, employing active and passive fire safety measures. Absence of parking for visitors in the basement	
Address: Royal Residence is a residential development in Victoria Island, Lagos, comprising 50 units across 15 floors **Developer:** Design Union, ITB Nigeria, and West Hills Ridge Company Limited				
7	Royal Residence (Eden Height) Tower	Features are spa, club lounge, swimming pool, gym, security, sports complex, outdoor space, parking, fitness centre, child safety terrace, active fire safety measures - sprinkler, fire hose, fire hydrants, detectors and extinguishers Passive strategies - fire doors, cement product, intumescent coating and frame structures.	Royal Residence (Eden Heights) Tower provides one to four-bedroom apartments and penthouses with grade 'A' finishing and customisation options. The building features 27 apartment units, including one to four-bedroom flats and penthouses. Construction materials include glass, concrete, hollow blocks, and steel. Note the Absence of service lifts, inadequate size of stair and lift lobbies, insufficient fire-fighting amenities, and parking facilities.	

4.2 Passive design strategies for thermal comfort in high-rise condos

The findings of qualitative analysis of the seven case studies revealed little consideration for passive design strategies. Building orientations paid more attention to roads than other environmental considerations. The findings in the literature recommend that passive design strategies and design features that maximise thermal comfort are as follows: Building form, building orientation, landscape, sustainable building material, Natural ventilation, and daylighting. Corroborating these strategies with some experts interviewed, an architect said:

"Passive design strategies refer to design approaches that focus on utilising the natural environment to provide heating, cooling, ventilation, and lighting to a building. The main idea of passive building design is to reduce the energy consumption for lighting, heating, and air conditioning through architectural design rather than mechanical equipment. Critical passive design strategies for tropical climates include building form, building orientation, natural ventilation, shading devices, daylight, sustainable building materials, humidity control, insulated and ventilated roofs and landscape features". **(Therapeutic Architect, IDI: 2024)**

From Table 5, the building orientation is the passive design strategy adopted in these selected buildings. Accordingly, the building form and building materials are the main design strategies used by the selected buildings. These buildings also have landscape design features. The least adopted design strategies are spatial organisation, natural ventilation and day lightning. Natural ventilation and lighting contribute to the comfort of the occupants of a space. The clustered column chart in Figure 3 shows the rate of spaces in the selected building that are naturally ventilated and lightened. The results in Table 5 and Figure 3 revealed that only 40% of the buildings are ventilated and lit up through natural means, and 60% of the selected buildings are through mechanical means. The result showed that Infinity Towers utilised all the passive design parameters under consideration. The Blue Towers also used the parameters adequately but were inadequate in the landscape variable.

Table 5. Adequacy of passive design features on case study

Passive Design Strategies	Infinity Tower	Blue Waters Tower	Azuri Tower	1004 Estate Tower	Eko Court Complex	Eko Pearl Tower	Royal EdenTower
Building Form	6	5	2	5	6	5	6
Building Orientation	7	6	5	6	5	6	5
Spatial Organisation	6	6	2	2	3	2	3
Landscape	7	2	6	5	6	5	5
Building Material	5	5	5	2	2	6	5
Natural Ventilation	7	6	3	3	3	3	3
Day Lighting	6	5	3	3	2	2	3

1 – Absolutely Inadequate, 2 – Inadequate, 3 – Slightly Inadequate, 4 – Neutral, 5 – Slightly Adequate, 6 – Adequate, 7 – Absolutely Adequate

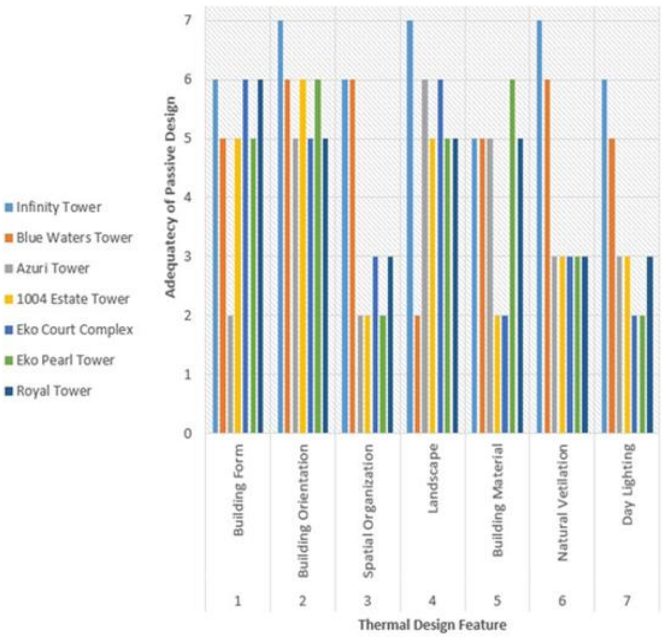


Figure 3. Natural ventilation and lightning of spaces in selected buildings
Source: Authors (2022)

4.3 Impact of passive design on thermal comfort in high-rise condos

Maximising thermal comfort inside a high-rise condominium is essential. Using passive design strategies is appropriate. The architects must design for human and thermal comfort through Passive design strategies.

"From an architectural point of view, thermal comfort is associated with soft materials and smooth surfaces such as textiles, porous surfaces or even wood. Flat and hard surfaces - metal or stone are less convenient for thermal comfort. Thus, passive design strategies include orientation, shading, insulation, ventilation, thermal mass, and natural lighting. By applying these strategies, buildings can reduce the need for heating and cooling and improve the thermal comfort of the occupants". **(Architect, IDI: 2024)**

These strategies are scientific, simple and easy to understand. Therefore, the following are passive design strategies incorporated into the high-rise condominium during design to maximise thermal comfort: building form, building orientation, spatial organisation, landscape, building material, natural ventilation and daylighting.

4.3.1 Building form

As an architect, it is vital to conceptualise sustainable building forms that give thermal comfort. Several strategies can be integrated, such as cooling towers, hot climate courtyard planning, skylights, louvres, etc. By combining these passive design strategies, active strategies are less. There are different climatic zones, and building forms can be according to various climatic zones to maximise thermal comfort, as shown in Figure 4. Building form parameters for dissimilar climatic zones are also diverse. According to an architect:

"Passive design strategies are approaches to building design that consider a location's climate and site conditions to maximise the health and comfort of building users while minimising energy use. Its goal is to increase indoor comfort. Therefore, several factors are required to achieve thermal comfort, including ambient temperature, humidity, air circulation, personal factors like clothing and metabolic rate, and building form and type". **(Landscape Architect, IDI: 2024)**

Figure 4. Bluewater Tower, Lagos, Nigeria
Source: silver oak properties

4.3.2 Building orientation

Building orientation offers passive thermal comfort. The location depends on the four directions: East, West, North and South. The high-rise condominium orientation uses solar gain to decrease heat load or guard excess solar gain to sustain comfort in the structure, as shown in Figure 5. Building orientation can vary according to the climate. For example, the orientation of high-rise condominiums in the tropics, like Nigeria, should be such that it reduces the solar gain and protects the excess solar gain in buildings. The extended facade should face north and south to benefit from indirect light devoid of glare and control direct solar heat gain from the South through shadings.

Figure 5. 1004 Estate Tower, Lagos, Nigeria
Source: hotel.ng places

4.3.3 Spatial organization

Figure 6. Floor plan of Royal (Eden height) Tower, Lagos, Nigeria

Passive design strategies utilise spatial design organisation mechanisms to naturally moderate temperature in high-rise condominium architecture. It is to attain harmony between the natural and the built environment with consideration of the accuracy of each project, such as its local micro-climate and available natural resources. Passive design strategies should follow a few principles besides the project location. Sunken courtyards are a design strategy that promotes passive cooling of buildings in tropical climates such as Lagos, Nigeria, which is more effective when combined with greenery, as in Figure 6. The internal space has self-shading throughout most of the day, allowing warm air from the building to rise to the courtyard to cool the indoor spaces.

4.3.4 Landscape

Landscaping in and out of the structure can sustain thermal comfort. There are many ways to design landscapes from within and outside. Perhaps in tropical climates, evergreen trees are planted in the South or West to block the direct harsh sunlight entering the building, as shown in Figure 7. Landscapes can be in the courtyard or other spaces for indoor spaces. Designing a water body in and out of condominiums can help create a micro-climate. This micro-climate can help maximise thermal comfort in high-rise condominium buildings. In tropical climates, it can have a cooling effect by absorbing heat and helping lower the temperature of the space. Water is one of the most efficient methods of maximising the passive design strategy in buildings, especially in dry climates. The impact of plants, both inside and outside, as they reduce solar radiation and achieve a microclimate that offers enhanced thermal comfort. In addition, plant selection can create limitless variations in landscaping design to maximise thermal comfort in the environment.

Figure 7. Infinity Tower, Lagos, Nigeria
Source: Author, 2023

4.3.5 Building material

Building materials play a vital role in thermal comfort inside the building. An architect should know the significance of material usage. Local/vernacular obtainable materials used can maximise thermal comfort and reduce building costs. Perhaps for tropical climates, minimum glass use is endorsed to minimise heat gain and to maximise thermal comfort inside the space, as shown in Figure 8.

Figure 8. Eko Pearl Tower, Lagos, Nigeria
Source: www.ekopearltower.com

4.3.6 Natural ventilation

Natural ventilation is the strategy that utilises air to make a structure energy efficient. It is vital to consider air movement throughout the space using natural ventilation as a passive design strategy. A household head interviewed said:

"Passive design works with the local climate to maintain a comfortable temperature in the home. Good passive design should reduce or eliminate the need for additional heating or cooling depending on your location, and it often relies on an active occupant to work correctly". **(Household Head, IDI: 2024)**

The opening orientation, such as doors and windows, can maximise thermal comfort through natural ventilation. Cross ventilation and induced natural ventilation (thermal induction systems) are recommended for high-rise condominiums in the tropics (place windows opposite each other), so the air circulation can help maximise thermal comfort by considerably reducing its internal temperature, as shown in Figure 9.

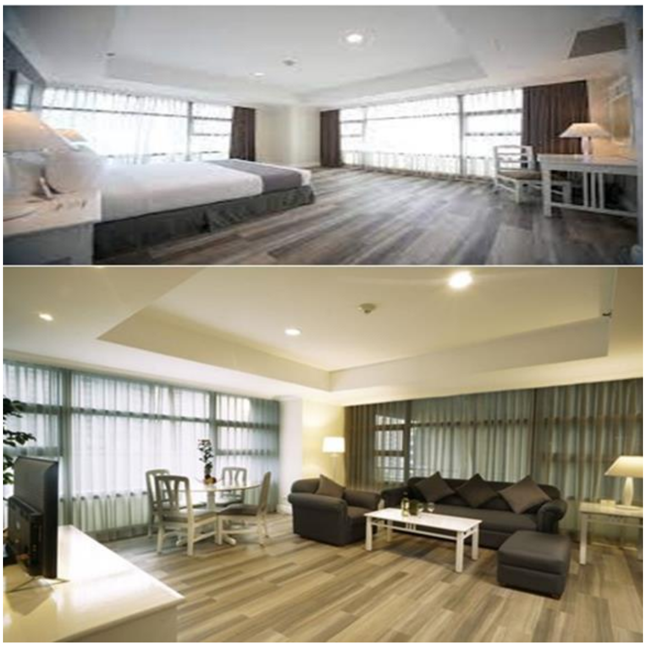


Figure 9. A typical naturally ventilated apartment in infinity residential tower, Lagos
Source: Authors, 2024

4.3.7 Daylighting

The Sun is the source of natural/daylighting and saves energy. Using daylighting as a passive design strategy can maximise thermal comfort inside the space, as shown in Figure 10. Natural/daylighting is beneficial because it reduces negative spaces, creates a positive setting among the users, and helps kill germs. However, as architects, we should take care of glare as it can create discomfort for occupants.

Figure 10. A typical naturally lit apartment in infinity residential tower, Lagos
Source: Author, 2024

5. CONCLUSION AND POLICY RECOMMENDATION

The research goal was to measure thermal comfort in high-rise condominiums by reviewing the adoption of passive design strategies in the design of selected condominiums in Lagos, Nigeria, used as case studies. Overall, the study concludes that most case studies lacked adequate attention to thermal comfort through passive design strategies. Most of the buildings relied on active means for thermal comfort. Thermal comforts in the buildings are significantly low or average. The findings revealed that the overall effects of applying passive design strategies are inadequate. The findings from qualitative analysis further revealed that thermal comfort is a significant factor influencing the occupants' satisfaction. Therefore, reliance on mechanical/active means of ventilation may have a negative correlation in a country where electricity is unreliable and significantly leads to thermal discomfort. Based on this conclusion, the paper recommends the following: First, architects and other built environment professionals should embrace an interpretation of location and climate parameters to enable them to design climate-responsive buildings that satisfy the thermal comfort of the indoor environment. Second, planning regulations should require all designs to show a better synthesis between building elements and local climate conditions. Therefore, passive design strategies should encouraged to enhance thermal comfort in high-rise condominium buildings. Third, stakeholders must assess the impact of buildings on the environment and the minimum acceptable requirements for a high-rise condominium must be met. Fourth, is there a need for strict enforcement of planning regulations, as they concern gross floor area to control the total site coverage and building footprint? Fifth, there is more attention to the services and functionality of the entire building than just the architectural spaces.

6. LIMITATIONS AND CONTRIBUTIONS

The study provides rich insights into the pathways of enhancing thermal comfort in high-rise condominiums through passive design strategies. It can explore many new perspectives on thermal comfort in high-rise condominiums. However, the study has some limitations. Firstly, the findings derived from IDIs and observation schedules may not represent all the thermal comfort in high-rise condominiums in the tropics. Purposive sampling was used in the study, which could introduce selection bias and limit the generalizability of the results. Second, lived experiences due to the number of years of residents and the expertise of the professionals could affect the research findings. It can lead to underreporting of some factors enhancing thermal comfort in high-rise condominiums through passive design strategies or a skewed representation of their experiences. Third, participants may have difficulty recalling certain events or details related to lived experiences due to when the investigators conducted the interviews. It can affect the reliability and validity of the data collected. Finally, the study provides rich insights but may lack statistical significance. It can be challenging to quantify and measure the magnitude of enhancing thermal comfort in high-rise condominiums through passive design strategies in Lagos, Nigeria, based on the observation schedule used in the case studies and interview methods. Therefore, a mixed-methods research approach can provide a more comprehensive understanding of the research subject.

The research outcome would benefit stakeholders in the built environment and the general public in the following ways: Suggest measures to enhance thermal comfort in high-rise condominiums, literature to researchers for investigating the use of passive design strategies in the design of high-rise condominiums, the data obtained would provide greater awareness of factors that give rise to thermal discomfort in a high-rise condominium and establish passive design criteria in the architectural design and construction of the condominium.

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APPENDIX

Appendix 1- IN-DEPTH INTERVIEWS (IDI) SCHEDULED

Enhancing Thermal Comfort in High-Rise Condominiums through Passive Design Strategies in Lagos, Nigeria.

Instructions: This study used a semi-structured interview schedule with the interviewees who are residents of a high-rise condominium in Lagos, Nigeria - Household heads, built environment professionals (BEPs)-architects, service engineers (mechanical and electrical), civil and structural) and Landscape. The interviewer must build a satisfactory level of rapport with the interviewee first. The researchers briefed the interviewee about the purpose of the study. Participants should note that the data gathered from this interview would be highly confidential and used for academic purposes only.

A. Demographic Information: Area of expertise / Category of the interviewee: ________________

A	Background/ Demographics Questions	Response/ Answers
1.	What is your name?	
2.	What is your age?	
3.	What is your highest educational level?	
5.	What is your gender?	
6.	Are you married?	
7.	What is your profession/occupation?	

B. Questions

1. What factors should be considered by the designers to ensure the thermal comfort of a high-rise Condominium?
2. What are passive design strategies?
3. What are the measures to be ensured to improve the thermal comfort in High-rise residential condominiums?
4. How does high-rise Condominium design affect thermal comfort?
5. What are the factors influencing thermal comfort?
6. What are the factors affecting the thermal performance of buildings?
7. What are the methods to evaluate thermal comfort?
8. How is passive design and efficiency achieved?
9. What are the techniques of passive high-rise condominium cooling?
10. How can thermal comfort conditions be improved?
11. What are some ways that buildings can be designed to improve their thermal mass?
12. What are the parameters of high-rise condominium interior conditions that contribute to human thermal comfort?
13. Why is thermal comfort important in high-rise condominiums?
14. Which are design strategies for high-comfort buildings and towards low energy?
15. What are the principles of thermal design in high-rise condominiums?
16. What are the climatic elements crucial for high-rise condominium thermal design?
17. Why is thermal comfort design important?
18. What factors contribute to thermal comfort in designing buildings in tropical climates?
19. How does building design affect thermal comfort?
20. What is a thermal design?
21. What are the measurable factors affecting thermal comfort?
22. Who were the main authority figures managing the pandemic in Nigeria?
23. How does climate influence building design?
24. What are the problems with thermal comfort?
25. How many environmental factors affect thermal comfort?
26. How does ventilation affect thermal comfort?
27. What is a passive cooling system?
28. Why is thermal comfort important in architecture?
29. How does radiation affect thermal comfort?
30. What is the difference between thermal comfort and indoor air quality?
31. What are the strategies of passive cooling?
32. How can I improve my thermal comfort??
33. How do you control thermal comfort in a building?
34. How can thermal comfort conditions be improved?
35. How does building design affect thermal comfort?
36. Why is thermal comfort important in high-rise condominiums?
37. What are the basic elements of thermal comfort design?

Appendix 2 – OBSERVATION GUIDE

Enhancing Thermal Comfort in High-Rise Condominiums through Passive Design Strategies in Lagos, Nigeria.

Criteria for Selection

Buildings/cases to be studied are High-Rise condominium buildings in Lagos, Nigeria, described thus:

Case Study: **____IT___BWT____AT ____1004ET____ECC____EPT____RRT** (Tick [√] the appropriate

	Roof Eave/ Overhang							Balcony/ Terrace							Shading Device							Wall							Window, Exterior Opening/ Fenestration Element						
	AI	I	SI	N	SA	A	AA	AI	I	SI	N	SA	A	AA	AI	I	SI	N	SA	A	AA	AI	I	SI	N	SA	A	AA	AI	I	SI	N	SA	A	AA
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
Building Form																																			

Day Lighting	Natural Ventilation	Building Material	Landscape	Spatial Organisation	Building Orientation

Note: 1 – Absolutely Inadequate, 2 – Inadequate, 3 – Slightly Inadequate, 4 – Neutral, 5 – Slightly Adequate, 6 – Adequate, 7 – Absolutely Adequate. Infinity Tower (IT), Blue Waters Tower (BWT), Azuri Tower (AT), 1004 Estate Tower (1004ET), Eko Court Complex (ECC), Eko Pearl Tower (EPT), Royal (Eden) Tower (RT)