

**HARNESSING DAYLIGHTING AND SOLAR GAINS AS SUSTAINABLE
ARCHITECTURAL DESIGN METHODS IN MIXED-USE DEVELOPMENTS IN LAGOS,
NIGERIA.**

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Abstract

The built environment contributes around 40% of the world's total carbon footprint, resulting in high building energy costs and pollution, as well as detrimental effects on the environment through the use of engines. Energy consumption can be very high in buildings, especially in mixed-use facilities. This paper seeks to analyse and contribute to the existing knowledge on daylighting and solar gain measures, resulting to a sustainable method of achieving energy efficiency in buildings. The methodology adopted for this study involves the use of case studies of two national and one international buildings of mixed-use typology which were appraised by evaluating and criticizing. Critical analyses of physical and daylighting measures of existing developments were evaluated, pointing out merits and demerits of existing strategies as adopted in the cases. Findings from this study evince that the need for office and residential spaces despite the unavailability of land in Lagos resulted in the concept of mixed-use developments. Also, some daylighting and solar gains strategies have been adopted but not fully maximized in Nigeria, especially the use of light shelves to enhance day lighting. This paper recommends that the techniques to be used to enhance daylighting and solar gains, materials and designs; the placements and orientations, should be determined right from conceptualization, through to the architecture process (design and construction).

Keywords- Daylighting, Energy Efficiency, Mixed-Use Developments, Solar Gains, Sustainable-Architecture.

1.0 Introduction

United Nations statistics states that the proportion of urban inhabitants rose from 30% in 1950 to 40% in 2000, and by 2030, it is anticipated to achieve 60% increase. Lagos State's total population and urban sprawl continue to rise. The metropolitan area of Lagos is home to about 33 percent of the total population of Lagos State.¹ Geetha and Velraj² posit that the increasing economic growth in populated nations has led to the utilization of sustainable energy sources and adoption of energy conservation methods for the purpose of environmental protection.

The absence of land accessibility for the planned diverse land use has become a restrictive reality,³ especially in Lagos state and this has resulted in combining the various land use into a sole high-rise development known as mixed-use development. However, these buildings' share of total direct and indirect carbon footprints is between 30-40%,⁴ which accounts for nearly half of the greenhouse effects.⁵ For cooling and lighting, the household sector accounts for the largest share of energy usage in the country,⁶ therefore, sustainability in high rise mixed-use buildings' design cannot be overemphasized.

Daylighting and solar gains are seen as passive methods of achieving energy efficiency and this will help the world reduce carbon emissions from fossil-fuel-based electricity production, as it uses natural light to illuminate the interior of buildings when it absorbs incident solar radiation, reducing the need for electric lighting. Solar energy is a viable renewable energy source in Nigeria due to its environment, infrastructure, economic, and societal conditions. Nigeria's northern region has the greatest solar capacity. The northern part of the country receives 2200 kWh/m² on average, while the southern part (Lagos) receives 1800 kWh/m²⁽⁷⁾ which shows that these strategies could be harnessed for better efficiency in these areas. More day lighting and transparency have been brought into the buildings by the architectural trends of glazed facades. While wide glazed areas bring a lot of solar radiation, it can be used carefully for more environmentally friendly building construction. This is mostly concerned with areas such as energy consumption and indoor air quality. Their evaluation is equally important particularly in this region with tropical climatic conditions, as Ekoe, Aloys, Njomo, and Agrawal⁸ listed the African countries with tropical climatic conditions in which Nigeria was listed, where the likelihood of overheating and glare is proportional to the area of glazing. These modernistic glass and steel high-rises which are massive consumers of energy raises a need of rethinking the design of tall buildings so that the design takes energy efficiency into considerations during the process, thereby relating energy performance and design. Adequate day lighting

throughout the building can be achieved through its passive solar design features, particularly with its south facing active facade under bright and clear sky conditions by maximizing natural day lighting over the open plan spaces. However, day lighting and solar gains of mixed use building in Lagos state will be evaluated as case studies, the need to integrate sustainable daylight and solar gain techniques for saving energy would be considered, leading to a sustainable architectural practice which becomes architecture that meets current needs without jeopardizing future generations' capacity to fulfill their own.⁹

This paper therefore aims at investigating the application of daylight and solar gain techniques in mixed-use buildings in Lagos state and abroad, and generating effective integration and development of advanced daylight strategies in the building process so as to decrease energy consumption to achieve a user friendly built environment as the quality and quantity of light in the built environment intensively influences occupant's productivity and psychological performances.

2.0 Review of Literature

2.1 Mixed Use Developments

Grant and Susan¹⁰ describes the concept of mixed uses as a form of urban development that incorporates residential, commercial, cultural, institutional or industrial uses where those functions are physically and functionally integrated and provide pedestrian connections, which all happens to be an essential aspect in creating sustainable communities. Mixed-use facilities also brighten communities and present opportunities for building efficiency, energy efficiency, and sustainability. In separate parts of the same building, a mixed-use building can contain offices, studios, apartments, and hotel rooms. It is a walkable real estate initiative that reduces space, offers infrastructure and architectural expressions, and reduces congestion by incorporating some mix of shopping, office, housing, resort, recreation, or other purposes which incorporates the aspects of a lively-work-play environment.¹¹

2.2 Sustainability and Energy Efficiency

According to WCED⁹ Sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future. Sustainable development is fundamentally a phase of transition in which the use of capital, the path of investment, the focus of technological development, and structural change are all in balance, maximizing both the present and future capacity to meet human needs and expectations. Energy efficiency is the use of technologies to perform the same task with less energy.¹² As asserted by Ralph Knowles,¹³ the aim of energy

conversion is to enhance wellbeing of individuals. Energy is synonymous with everything people want because virtually every amenity and service in the world is based on cheap fossil fuel availability. Energy efficiency can also be seen as a decrease in the amount of energy used to manufacture goods and services.¹⁴

One of such methods used in achieving energy efficiency for sustainability in mixed use buildings through design is the concept of daylighting and solar gains. The principal functions of windows are the admission of daylights and the provision of views. If daylight can be used to replace artificial lighting to a greater degree, it may be called "renewable" lighting. Also, solar gain devices are another energy-efficient technology, which are used together with windows.¹⁵

2.3 Energy Efficiency of High-Rise Buildings

The main principles of energy-efficient construction are maximum usage of alternative renewable sources of energy such as thermal energy of earth, energy of sun, wind, and reducing the negative impact on the environment. As the first phase of energy conservation in high-rise buildings, energy saving comprises a range of creative architectural, structural and engineering steps aimed at minimizing consumption and the fair use of energy used in lighting, heating, ventilation, air conditioning and elevator operations, while retaining a comfortable microclimate in the premises. Zhigulina and Ponomarenko¹⁶ found that heating, ventilation, air-conditioning and other services of high-rise buildings need about 70 percent of energy, lighting - 20 percent and elevator maintenance - 10 percent. The importance of this direction is determined by the increase in the urbanization phase of the energy consumption of cities. Reduction of energy consumption can be obtained by the use of enclosed systems with ideal thermal characteristics for the climatic zone of the building site and the full use of natural lighting supplies through the use of larger windows. This is supported by the use of automated systems for climate control, reducing the temperature of the indoor air in the absence of people in the room; the device of night ventilation during the warm period of the year; installation of systems with variable air flow; the use of process heat to heat the cold zones and other activities.

2.4 Benefits Of Daylighting

Studies have shown that a building's proper daylighting will improve efficiency, minimize sick building syndromes and even enhance productivity.¹⁷ By offering regular shifts in focal distance, which helps to relax eye muscles, views offered by windows contribute to eye health. For both students and teachers, daylight, whether associated with a view or not, may also minimize tension. Research in Sweden has shown that work in daylight-free classrooms can disrupt the basic hormone cycle, which in turn can affect the ability of children to focus or cooperate and ultimately have an

effect on average body growth and sick leave.¹⁸ In terms of energy savings, if electric lights are switched off or dimmed when daylight is sufficient, daylighting will save energy and decrease peak electricity demand. The biggest energy consumption is electric lights for most school buildings. Also, the highest quality light source for visual tasks is provided by Daylight. It improves objects' color and visual appearance, and allows students better see minor details. Finally, by providing data on the time of day, season, and weather conditions, daylight provides a connection to the natural world. It enriches the learning experience by doing so and also makes learning more memorable. Since bright sunlight is commonly believed to make people more involved, and well-daylit spaces are generally considered by users to be "better" than dark gloomy ones, the consistent range of daylight quality and quantity often tends to make students and staff more alert.¹⁹

2.5 Concept of a Light Shelf

A light shelf is a horizontal surface that directly reflects daylight into a house. Light shelves are positioned above the eye level and have upper surfaces of high reflectance, which helps to reflect daylight on the ceiling and deeper into the room (figure 1). As referenced by Lee, Gim, Seo and Kim,²⁰ light shelf is a natural lighting device that is mounted on a window and reflects natural light from the outside onto the ceiling surface of the indoor room, minimizing the amount of energy required for lighting. By preventing the direct introduction of external natural light into the interior room, a light shelf improves the problems of glare or illumination imbalance. The height, width, angle, and material of the light shelf are the variables for determining the performance of a light shelf; adequate variable control is needed to optimize the light shelf's performance. In high-rise and low-rise office buildings, as well as institutional buildings, light shelves are usually used. This design is usually used on the side of the building facing the equator, which is where maximum sunlight is found and is most successful.²¹ Not only do light shelves allow light to penetrate into the house, due to the overhang of the shelf, they are also built to shade near the windows, and help minimize glare. The combination of outer and inner shelves (Figure2) will work best to provide an even gradient of lighting.

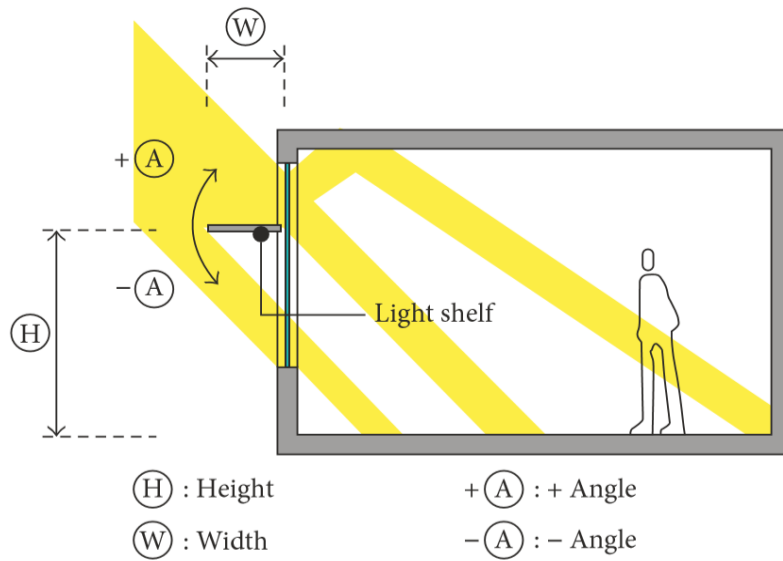


Figure 1. Concept of a Light Shelf ²¹

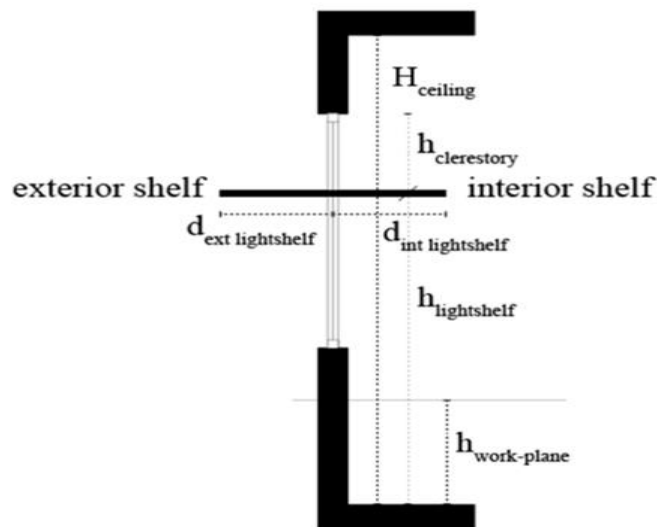


Figure 2. Diagram Showing Combination of Exterior and Interior Light Shelves ²¹

3.0 Research Methodology

3.1 Study Area

Nigeria was listed among the African continents with the tropical climate conditions according to Ekoe et. al.⁸ Abimaje and Akinabohungbe²² also stated that Nigeria has a total land mass of $9.24 \times 10^5 \text{ km}^2$ and receiving 6.25 hours of sunshine per day on average, varying from around 3.5 hours in the coastal areas to 9.0 hours at the far northern boundary. The estimated average solar radiation is 17,459,215.2 million MJ / day.²³ This shows that the Nation enjoys abundance of sunshine, and can carefully harness daylight to prevent overheating and achieve energy efficiency. Lagos State in

Nigeria was created on May 27th, 1967 and located in the South Western geopolitical zone of Nigeria along coordinates $6^{\circ}35' \text{ N } 3^{\circ} 45' \text{ E}$, with a land area of 3,577 square kilometres (Figure 3). According to the 2006 population census²⁴, Lagos state is the second most populous state in the country with total population of 9,013,534 people after Kano state, and the population has doubled in recent years. However, Lagos State is also the most economically important state in Nigeria as it is known as the country's largest urban area. It is also the economic capital of Nigeria and was the capital of the country till 1991. As Lagos State continues to grow in population and urbanization, the need for energy efficiency and sustainability in buildings has become a priority.



Figure 3. Map of Nigeria showing Lagos State²⁵

3.2 Case Studies

Case study is a qualitative method of inquiry in research. It is commonly used by researchers in the field of law, psychology, medicine, architecture, fine arts and other disciplines. Case studies of existing mixed-use developments in Nigeria and abroad were carried out, by critically analyzing its features and deductions of daylighting and solar gains. The mixed use developments considered for critique as regards this paper include;

1. Tower A, Victoria Island, Lagos State, Nigeria
2. Tower B, Dugbe Business District, Ibadan, Oyo State, Nigeria
3. Tower C, Frankfurt, Germany.

Towers A and B were chosen because they are located in Nigeria's most populous states. This demonstrates the importance of mixed-use development since it integrates many activities into a single

structure, maximizing land utilisation. Tower A and B are also located in two States in the Southwest region of Nigeria, which have similar temperatures, and other similar climatic features. Tower C, on the other hand, demonstrates how mixed-use buildings in other parts of the world are planned, as well as how daylighting and passive solar gain tactics were used. Researchers' accessibility and the availability of basic information on individual instances are also important factors in the selection.

3.3 Case Study One: Tower A, Victoria Island, Lagos

Location: Adeola Odeku Road, Victoria Island, Lagos State

Year Commenced: 2000

Year Completed: 2002

Consultant Architect: Design Architecture in Motion

3.3.1 Background Information

Tower A is a privately owned tower of 13 storeys and it is one of the most eye catching landmarks in the city, due to its height, and extensive glass façade that reflects the sun beautifully. The building is located along Adeola Odeku road and the site houses two major oil firms and Telecommunication companies in Nigeria, and also houses workers of the companies and private residences.



Figure 4. Scanned Copy of Residential Apartment Floor Plan

Source: Author's field work, 2021

3.3.2 Architecture and Building Materials

The façade of the office and hotel building is majorly double glazed curtain wall which gives it a visually pleasing look. The residential tower is built with hollow block walls and painted with off white emulsion paint. Also, notable in the residential tower is the use of large window openings and

protruding balconies which gives a clear view of the external surrounding and allows for natural ventilation and daylighting. The floor plan of the residential apartment is shown in Figure 4. Some of the building materials used include; Paint, Double glazing, Reinforced Concrete, Steel railings, Vitrified ceramic floor tiles, Marble floor tiles and Granite floor tiles

3.3.3 Features of Tower A, Lagos

The features of Tower A include a ground floor parking area, office spaces, residential apartments (24 housing Units), power house, sewage and water treatment plants, security system, hotel, water and sewage system, roof garden and balconies. Figure 5 shows the external view of the tower.



Figure 5. External View of Tower A

Source: Authors Field work, 2021

3.3.4 Daylight and Solar Gains Deductions

The following daylight and solar gains attributes were deducted; the use of balconies especially in the residential units, use of large openable windows to allow for natural ventilation and lighting, and use of bright colours to reduce heat gain (Figure 6).



Figure 6. Residential spaces use large window spans and balconies

Source: Authors Photograph, 2021

3.3.5 Critiques

Merits

1. Natural ventilation is achieved in interior spaces.
2. The use of bright colours especially in residential units helps to control heat by spreading the amount of heat gained by the building.
3. Heat gain is controlled through short projecting shading devices and balconies.
4. Effective and efficient fire safety measures.
5. Adequate security.
6. Flexibility of spaces, for instance, residential spaces can be partitioned to accommodate office spaces.

3.4 Case Study Two: Tower B, Ibadan

Location: Dugbe Business District, Ibadan, Oyo State.

Site Area: 1.7 Hectares

Use: Commercial, Residential and Offices

Architects: Adebayo and Adebayo

Contractors: Cappa & D'alberto PLC

3.4.1 Background Information

Tower B, also known as Nigeria's first high rise and once the tallest structure in tropical Africa, was originally known as "ile awon agbe," which implies "farmers' house" (Figure 7). Tower B is a 26-

story structure with a height of about 105 meters from ground level and a gross land area of 1.7 hectares. The structure was erected primarily with cocoa earnings by Nigeria's Western States, with no federal funding or oil capital. The tower burned on the 9th of January 1985 exactly 20 years after it was completed. However, by 1992, it was repaired and reopened for business.



Figure 7. Exterior view of Cocoa House Tower

Source: Authors field work, 2021

3.4.2 The Architecture and Building Materials

Adebayo and Adebayo Architects have created a notable design which stands out in its surroundings, and Painted in chocolate colour which communicates the colour of cocoa, which is the source of its finance. The property facilities include; a large entrance and well lit reception space (figure 8), commercial spaces/retail stores, well lit and well ventilated offices with large openable windows (figure 9), residential floor, basement parking (figure 10), basement mechanical/electrical services, Koko-dome restaurant-swimming pool, relaxation bay, onsite parking, 800KVA electricity, fire assembly point, borehole and water cooperation supply scheme, reservoir (overhead and underground), sewage treatment plant, 2 lifts, 2 escape stairs and a fire assembly point.



Figure 8. Large well-lit reception area, security post, and lift area

Source: Authors Field work, 2021



Figure 9. Office Interior with Natural Lighting and Ventilation from Large Openable Windows

Source: Authors Field work, 2021

3.4.3 Daylighting and Solar Gains Deductions

1. Natural ventilation is achieved in the building through large openable windows
2. Use of glazed partitioning for efficient natural lighting to office spaces which helps transfer light to deeper interiors, saving about 33% of energy used on artificial lighting.



Figure 10. Using natural daylight to illuminate the basement parking area

Source: Authors Field work, 2021

3.4.4 Critiques

Merits

1. Natural ventilation helps to remove heat from the interior space.
2. Interior spaces are properly lit due to use of large windows and bright colours on walls
3. Good and efficient security system.
4. Adequate parking Facility

Demerits

1. Poor maintenance of basement area

3.5 Case Study Three: Tower C, Frankfurt, Germany

Type; Mixed –use Development. Commercial offices and other uses

Location; Kaiserplatz 1 Frankfurt Hesse, Germany

Construction started; 1994

Opening; 1997

Height; Antenna spire-300.1 m (985 ft), Roof-258.7 m (849 ft)

Floor count; 56

Floor area; 109,200 m² (1,175,000 sq. ft)

Architect; Norman Foster

Structural engineer; Arup Krebs und Kiefer

Main contractor; Hochtief AG

3.5.1 Background Information and Features

Tower C is located at Kaiserplatz 1 Frankfurt Hesse, Germany. The tower was a significant step forward as the first demonstrably environmentally friendly tower that gained natural light and was structured in interior space modules. This is a building on 56 floors, 259 m high (figure 11 and 12). The building has about 80,000m² of office space with an additional 45,000m² of other uses. It was one of the first efforts in 1991 to be an environmentally friendly building in terms of energy efficiency strategy and natural ventilation. One of the primary reasons for being green was that urban policy was in favor of having an eco-high construction.²⁶ The features of this tower include; 80,000m² office spaces, 45,000m² Other Uses, Nine Windowed House Gardens, Event Building, Car Parks, Shops, Apartments, Glass Covered Plaza and Canteen.



Figure. 11 and 12. Exterior View of Tower C²⁷

3.5.2 Architecture and Building Materials

In comparison to the formal concrete, the skyscraper was constructed with a steel frame. The floors, on the other hand, were built using a mix of steel beams and concrete slabs on metal sheets. Apart from thick cores for vertical service movements, one of the fundamental principles of the building is the central void, which runs the full height of the building as shown on floor plan in figure 13 (Arend, John & Benkert, Mike & Defilippis, Audrey & Tillmaand, Saretta & Shoag, 2021). There is a series of gardens linked to the void that helps to increase both the natural element and the great scenery for offices. So the key concept was to create a triangular plan that allowed one to maneuver around all three corners. However, in each floor, two corners are offices and the third one is a

garden. But the point is that gardens didn't stay fixed on one elevation, they rotate all around the plan in such a way that all the offices are always in contact with one garden or another (figure 14). Furthermore, this building has a double facade with adjustable solar shading. The overall natural ventilation scheme of the building includes these green spaces. The fresh air comes in through the top of the gardens, then moves up through the central atrium saving substantial energy.

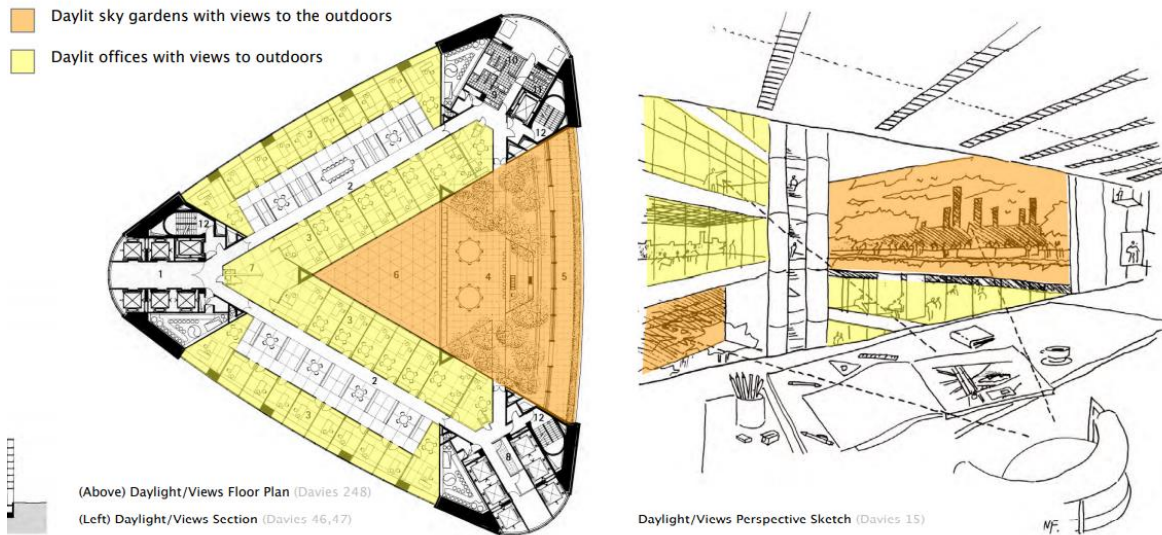


Figure 13. Sectional Floor Plan of Tower C²⁷

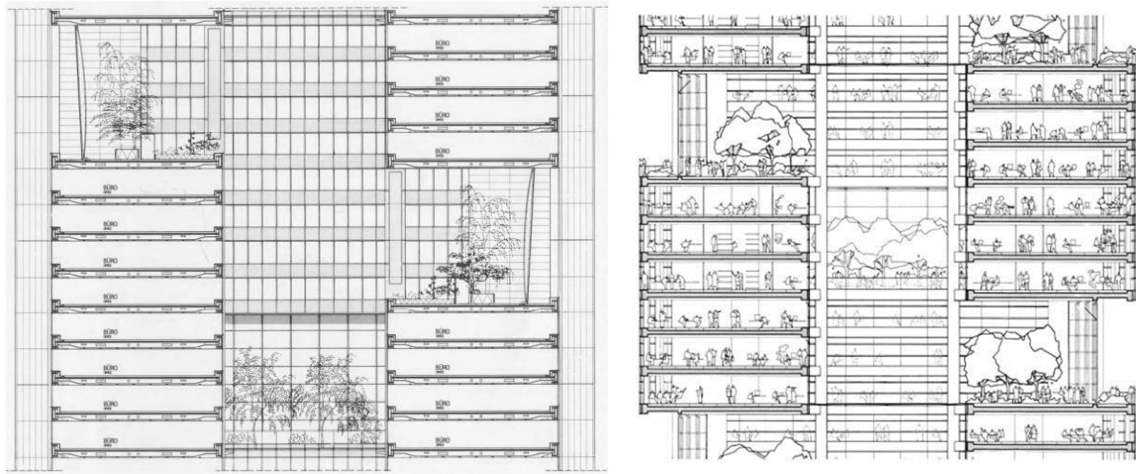


Figure 14. Section of Tower C and rotating views of gardens at different floors²⁷

3.5.3 Daylighting and Solar Gains Deductions

The triangular shape of the skyscraper with the South-West orientation about 16°, causes it to benefit from maximum solar radiations. Winter gardens spiral up around the atrium in order to become the visual and social focus for four-storey office clusters. By offering fresh air and light in the gardens, they assist the main atrium ventilation circulation, which is used as a kind of natural ventilation chimney (figure 15). In addition, the sky gardens and offices are surrounded by large glass facades

and operating windows (figure 16) to benefit from natural ventilation and daylighting. The savings in the heating and cooling systems are estimated to be approximately 20%. The daylighting, heating and cooling passive systems strategies are shown in Table 1 below.

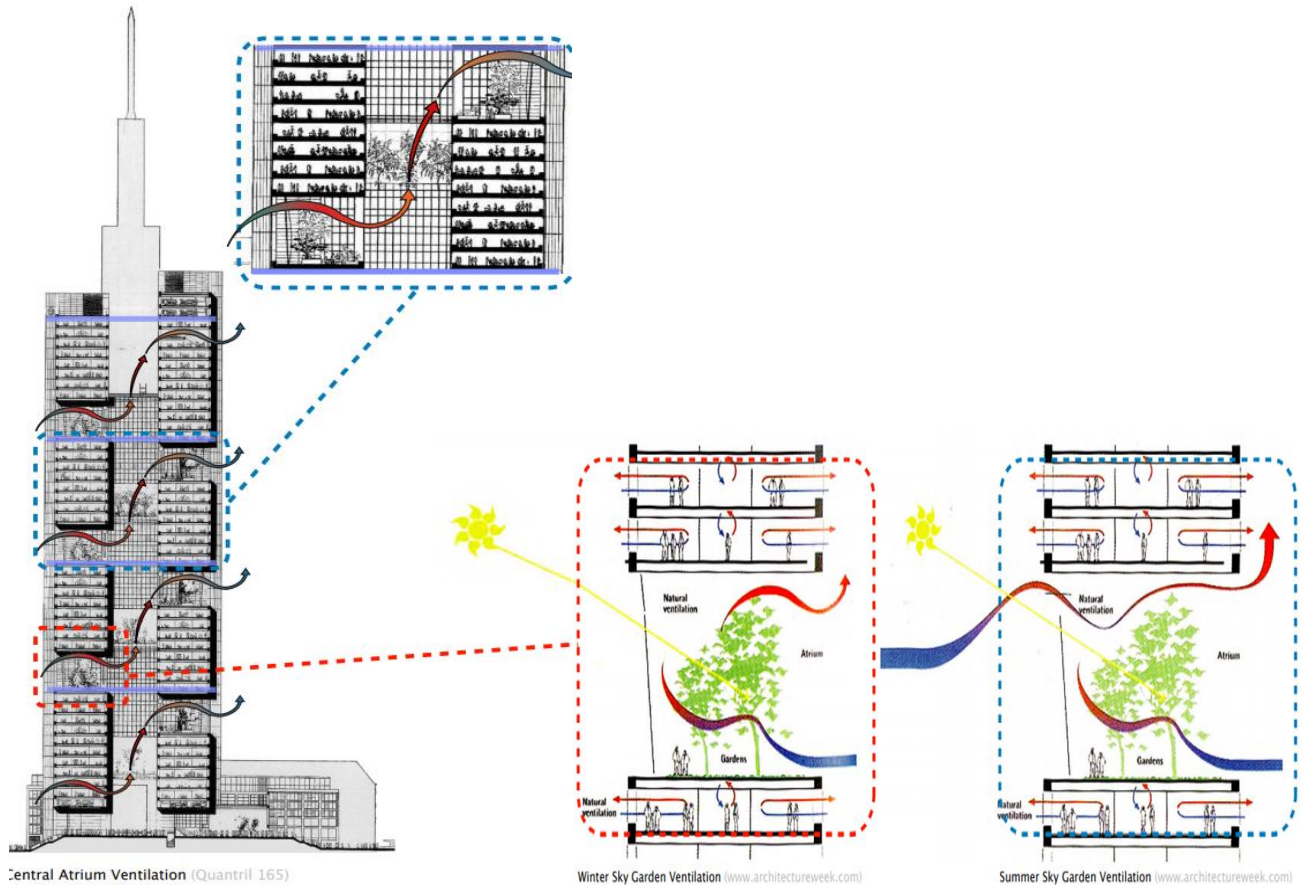


Figure 15. Sectional View of Tower C Showing Natural Light and Ventilation Flow²⁷



Figure 16. Passive Solar: The sky gardens and offices are surrounded by large glass facades that allow for direct and indirect solar benefit for the majority of the year when heating is needed. To avoid overheating, internal shading mechanisms and ventilation systems are used.²⁷

Table 1. Tower C Building Facts²⁷

Building Facts		
Project	Floor Area sq.ft/floor	1.3 mill total (≈23,000 per floor)
	Occupant load	2,100 workers
	Cost	\$300,000,000 US
	Program	53-story high-rise office building
Site	Site Description (acres?)	approximately 3 acres; site shared with old Commerzbank building
	Site Type urban, rural, etc	urban
	Parking spaces #	multi-story parking garage holds 300 cars and 200 bikes
Structure	Foundation type	pile raft foundation
	Gravity force systems type	perforated tube structure (corner columns with link frames)
	Lateral force systems type	vierendeel truss system
	secondary structure/backup	continuous floors at every fourth floor act as a stiffening diaphragm
Envelope	Glazing type, identify	double-glazed operable window w/ outer skin of fixed glass & ventilated cavity
	Skylights	full-height atrium with glass decks every twelve floors
	Cladding type, identify	double-skinned aluminum framed curtain wall
	Roof	glazed roof over plaza & atrium, high albedo concrete above remaining program
Passive Systems	Daylighting	sky gardens, atrium, & floor-to-floor glazing
	Heating	passive solar gain, heat generated from office machinery & building occupants
	Cooling	natural ventilation, stack effect
HVAC	Equipment list	cooling towers, absorption chillers, central building management system (BMS)
	Cooling system type	water-cooled, chilled-panel ceiling system
	Heating system type	thermostatically controlled radiant heating system
	Duct	yes/no yes
	Vertical Chases	yes/no no

3.5.4 Critiques

Merits

1. Maximum Natural ventilation
2. Maximum Daylighting
3. Use of landscape gardens to provide shading and allow for cooling.
4. Use of glass gives the interior a sense of warmth which is suitable for temperate climate and daylight penetration.
5. The use of glass gives the interior a good view to the outside.

4.0 Summary of Findings and Discussions

The problem of non-availability of land and supply is one of the major factors affecting the provision of housing and other basic infrastructure in Lagos state. Following the rapid population growth and urbanization in Lagos State, the demand for land has become a major challenge which also results in housing, employment, environmental and infrastructure challenges. The case of a mixed-use building is considered in this regard because it houses various activities in a whole which includes accommodation, office spaces, recreational spaces and the likes. From case study findings, tall buildings have become the most suitable solution for most cities faced with the challenge of land availability and the need to provide accommodations for its inhabitants. It was revealed that mixed-use buildings also consume a whole lot of energy as it uses about 50% of all the energy produced in the planet for heating, cooling, lighting, industries and building construction. Major strategies adopted for natural lighting in the case studies include; balconies, roof gardens, large glazed areas and large window openings. The study also found that if any daylighting and solar gains benefit techniques are not implemented in buildings, the energy requirement for achieving illumination by mechanical means would be huge, resulting in buildings that are not sustainable. Also, these strategies especially the use of light shelves, have not been fully adopted in existing mixed-use buildings in Lagos state, more energy will be saved if this is considered and properly applied.

4.1 Description of the Proposed Mixed-Use Development (Marina Tower), Lagos

The proposed mixed-use building plan adopts the concept of functionality. The plan (Figure 17) is sectioned in shape with the functional commercial spaces on the left and the multi-level parking on the right, connected by circulation spaces for the first six floors. Part of the building with plain walls are covered with aluminum cladding, office floors with curtain walls made of energy efficient glazing panels and supported by light shelves for adequate natural lighting (Figure 88).

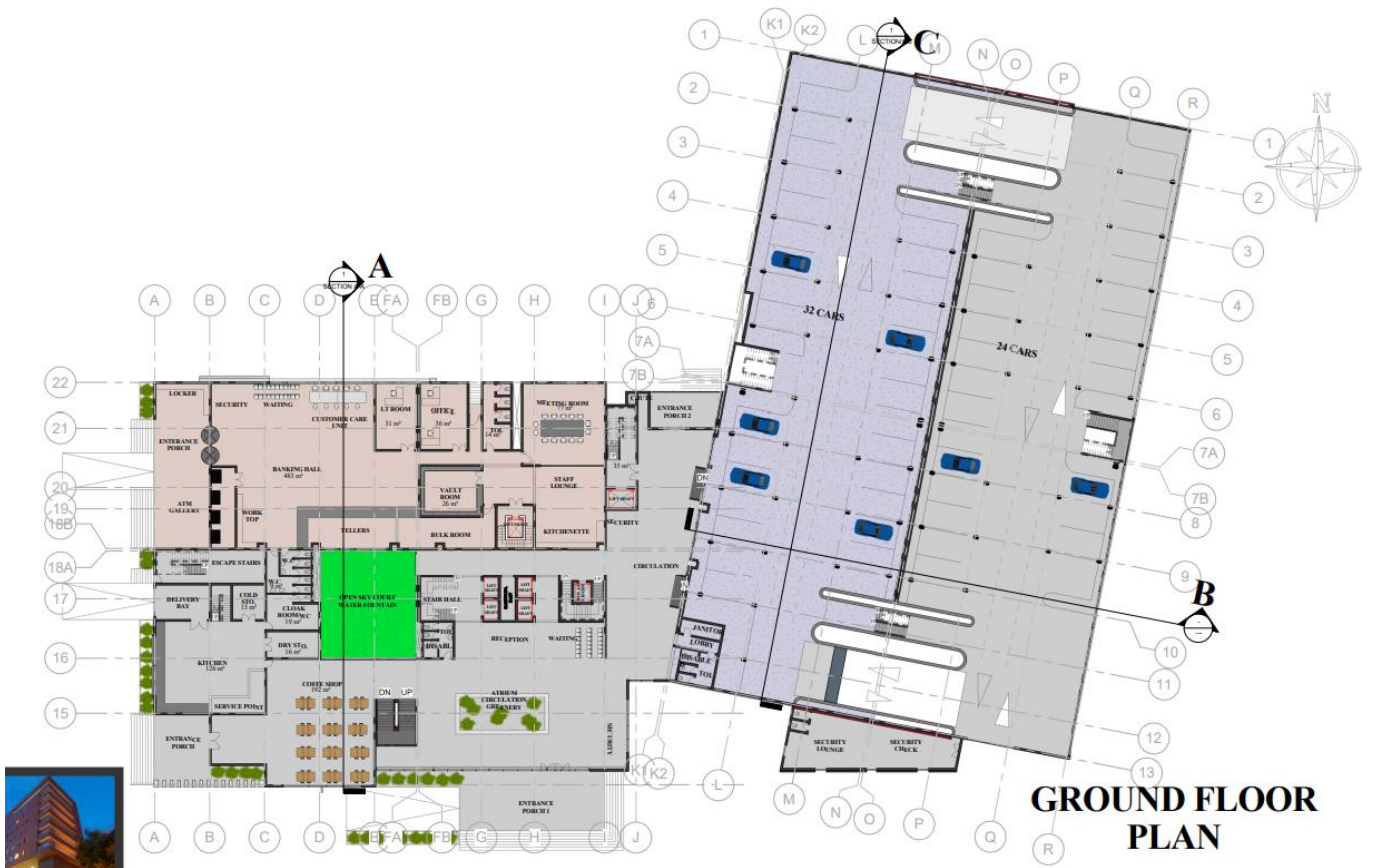


Figure 17. Ground Floor Plan of Marina Tower
 Source; Author's field report, 2021

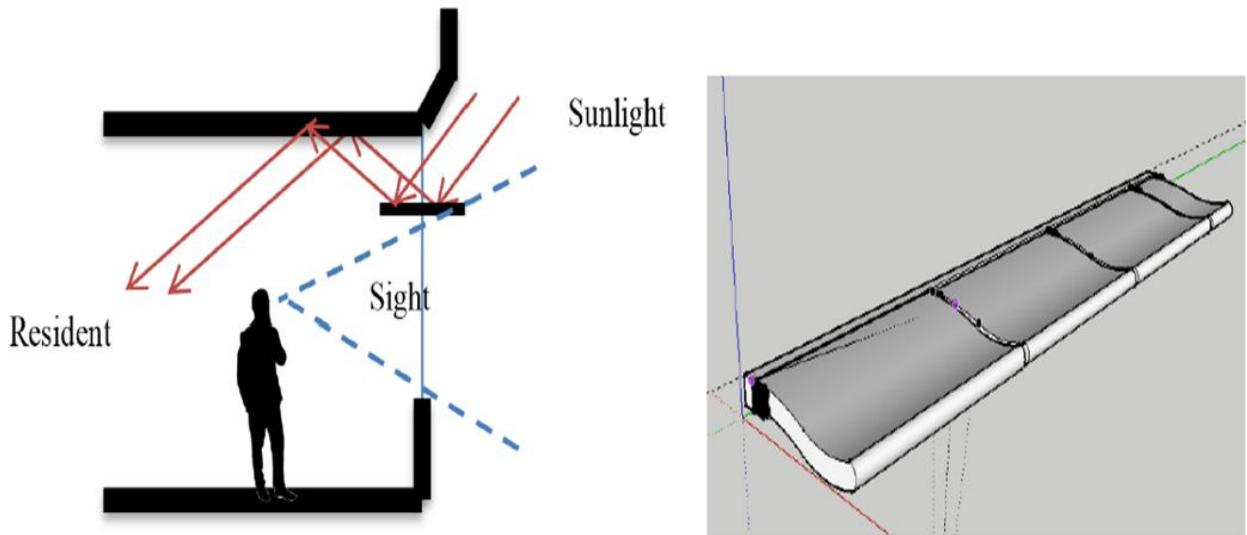


Figure 18. Light Shelf Details²⁸

Several passive design techniques have been integrated into the proposed development to aid in energy efficiency and overall productivity (Figure 19). Precarbonated roofing material allows light to

pass through to the roof garden, and perforated brick faced on residential terraces allows for lighting while still serving as a shading device. For office rooms, the structure considered the use of curtain walls and light shelves, with the light shelves assisting in the transmission of solar gains and illumination into deeper interiors of the office for optimal use through reflections. The use of a courtyard and atrium allowed for additional solar beneficial effects and direct solar penetration into the building.

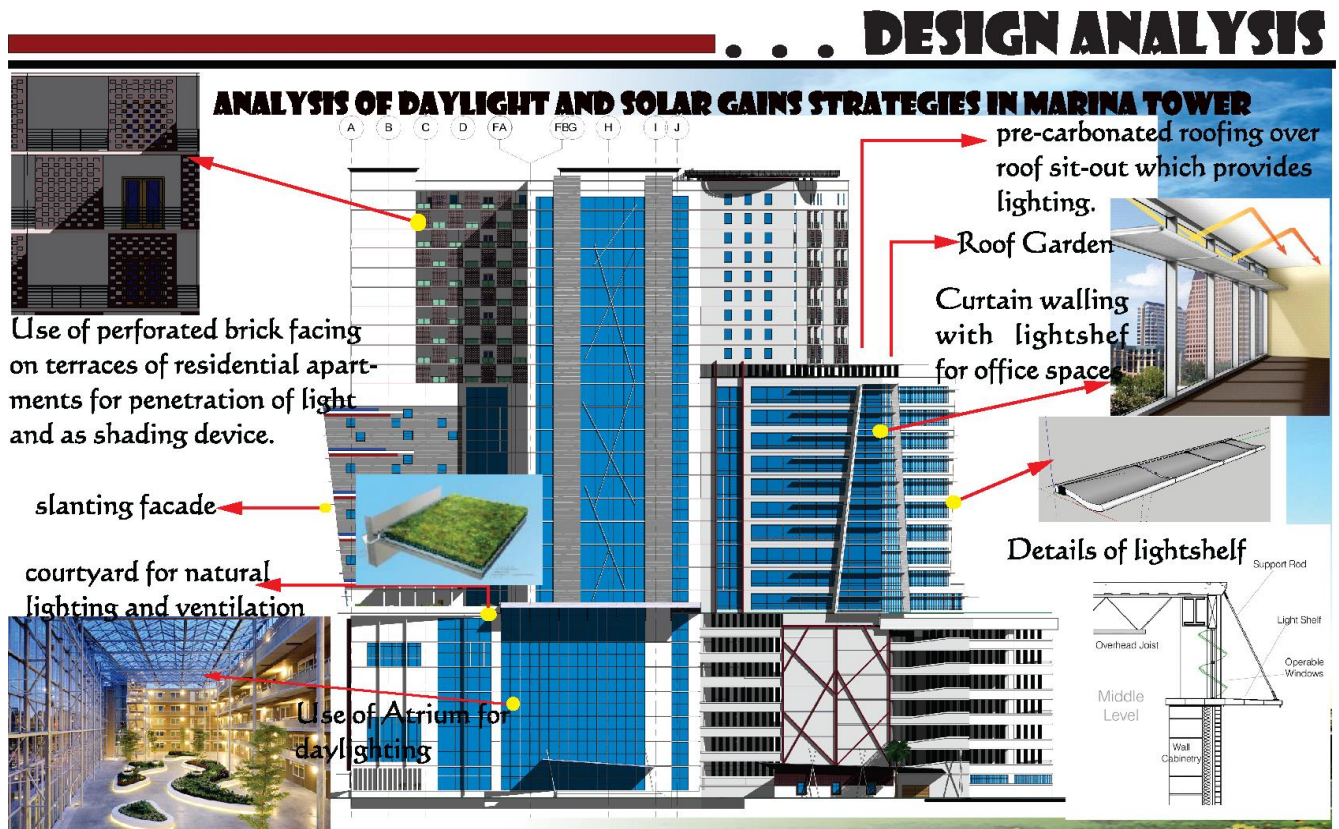


Figure 19. Analysis of Daylight and Solar Gains Strategies in Marina Tower

Source; Authors's field report, 2021

5.0 Recommendations and Conclusions

Mixed-use development is a masterpiece design having some functions that makes it different from other high rise buildings as it combines several functions. However, some of the following recommendations are important in the design of a mixed-use development;

1. Proper considerations should be given to environmental conditions before designs are carried out.
2. The techniques to be used for daylighting and solar gains strategies (materials and designs, its placements and orientations) should be put in place right from the conceptual stage through to the design stage, construction stage and commissioning and post-occupancy stage.

3. Maximum utilization of energy efficient windows, light shelves and light tubes should be considered.
4. The carbon footprint of high-rise building is higher per floor area and this should be considered in urban development of city centre of Lagos state.
5. Finally, high-rise mixed-use developments should be greatly considered in locations of low land availability.

In conclusion, mixed-use developments will continually be in existence and in high demand in Lagos state, due to constant increase in population density, urbanization and scarce land accessibility.

However, mixed-use buildings in Lagos state have not fully adopted the day lighting and solar gains strategies which includes the use of energy efficient windows that absorbs and regulates the solar gains and the use of light shelves and light tubes which transmits natural lighting to dark interiors. These strategies could also be adopted in other tropical countries with similar tropical climate like Liberia, Ghana, Guatemala etc. In conclusion, for a mixed-use development to be energy efficient and sustainable, there must be less dependence on mechanical systems, and this can be achieved by introducing the daylighting and solar gains strategies for natural lighting right from the design stage.

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