IJSES
International Journal of Scientific Engineering and Science
Volume 6, Issue 3, pp. 50-55, 2022.
ISSN (Online): 2456-7361

Assessment of Bioclimatic Design Elements in Library Buildings of Hot-Dry Climatic Region of Nigeria

HAMZA Musa[1], ADAMU Mohammed Babayo[2], SAEED Abbas Elnafaty[3]
Department of Architecture, Faculty of Environmental Technology, Abubakar Tafawa Balewa University, Bauchi-Nigeria

Abstract *— Buildings in hot-dry climates are constantly exposed to solar radiation almost every day. As a result, building designs should aim at minimizing heat gain and maximizing evaporative cooling so that users of these facilities can have adequate thermal comfort. Climate has a major effect on the performance of the building and its energy consumption thereby making the bioclimatic design approach relevant in hot-dry climate. One of the main goals of a building is to offer protection against harsh outdoor climatic conditions and to provide both physiological and psychological comfort. In view of the above, this study aimed at exploring the principles of bioclimatic design and their applicability in library buildings. The method used in carrying out this research is basically qualitative. The study suggests that climatic responsive design is being accomplished by the reliance on some principles which are; building form, building orientation, site planning and landscaping, spatial organization, shading devices, daylighting strategies, use of materials, and also, the building techniques must be evaluated and the final product should be able to perform well during its whole service life. In conclusion, the research highlights that, study into bioclimatic architecture should go beyond offering solutions to the climate alone, but the concept should be given more meaning in relation to the design.*

Keywords *— Bioclimatic Design, Energy-Efficiency, Hot-Dry Climate, Thermal Comfort.*

I. INTRODUCTION

The scientific breakthrough in architecture has shown the development of responses to the specific environmental and climatic conditions, within the constraints of technological advances, resource availability, awareness, and diverse expectations of indoor and outdoor environmental qualities. The relationship between architecture, climate, and human comfort is a major concern in energy-efficient designs. The word bioclimatic is the amalgamation of two (2) words, "bio" means life or natural form of living things, and "climate" means, the prevailing weather condition of a particular place (Folaranmi et al., 2013; Martinez, 2012). The bioclimatic design concept suggested a logical sequence of analysis through the detection of appropriate strategies and purposeful environmental control in response to the rational use of resources to achieve human thermalcomfort (Hamza et al., 2022). Therefore, the bioclimatic design concept makes judicious use of favourable environmental conditions and moderates the unfavourable aspects through the appropriate design decisions. The need for energy efficiency, environmental protection, thermal comfort, and improved occupants living conditions has led to attention in the implementation of the principles of energy-efficient design (Hussaini et al., 2017). With this objective in mind, it is argued that bioclimatic design concepts allow the architect to optimize the building's occupant thermal comfort and minimize the effects of global climatic problems (Earth Architecture, 2012). The development of bioclimatic design considers the local climatic conditions such as sun, wind, rain, air temperature, mean radiant temperature, humidity, and airflow (Kolawale, 2012). It integrates the concept of environmental consciousness, sustainability, green and organic approaches, local microclimate, and topography to evolve a design solution using minimal energy as its target and enhancing occupants' comfort, environmental and economic benefits. In essence, bioclimatic design takes the advantage of climate through the effective application of various design concepts and building technology to conserve energy. According to Olgyay (2015), the design process in bioclimatic architecture is linear consisting of four stages of development as shown in Figure 1.

CLIMATE ⟶ BIOLOGY ⟶ TECHNOLOGY ⟶ ARCHITECTURE

Figure 1: Design Process for Bioclimatic Architecture

Bioclimatic design features are primarily centered on the climate of an area to be developed. The major principles of bioclimatic design are divided into environmental sustainability and thermal comfort (Sergi, 2011). These principles are further broken down into; Building form and orientation, building envelope and material, integration of renewable energies, green roofs, water bodies, daylight strategies, sun shading devices, indoor air quality, cross ventilation, and use of passive design techniques

In a constantly changing world due to climate change, and in a society under almost daily transformation, education is increasingly called upon to play a decisive role. A library is the heart of a university. It exists to serve the objectives of its parent organization and aim to advance the function of its university. Thus, research is the major function of a university library. In other words, it circulates knowledge to generate new knowledge. A University's library infrastructure must create an appropriate environment for education and the transmission of

International Journal of Scientific Engineering and Science
Volume 6, Issue 3, pp. 50-55, 2022. ISSN (Online): 2456-7361

knowledge while respecting cultural factors and social sensitivities. According to Building Energy Efficiency Guidelines for Nigeria (BEEG), globally, buildings account for 60% of total energy consumption (BEEG, 2017). This has called for architects and other allied professionals to aggressively face the critical challenges of reducing energy usage in buildings (Sun & Hong, 2017), through the utilization of energy-efficient ways of designing and constructing buildings. Although, several studies have been conducted on bioclimatic architectural concepts on different building types in different parts of the world suitable to their local climate. However, studies on the application of bioclimatic design principles in library buildings of the tropical hot-dry climate of Nigeria is still limited, which suggests a gap in the literature and requires more scientific evidence to understand the applicability and suitability of the bioclimatic architectural principles in library design. The aim of this paper is to explore the principles of bioclimatic design and their applicability in university library buildings of the tropical hot-dry climatic region of Nigeria. In order to achieve that, the following objectives were considered;

i. To analyze the various principles of bioclimatic design suitable for use in hot-dry climate
ii. To assess the level of applicability of bioclimatic design principles in library buildings in the hot-dry climate of Nigeria.

II. Methodology

The purpose of research methodology is to provide a detailed explanation of the procedures used in carrying out the research (Issa, 2004). A case study research approach was used in carrying out this research. It involves studying a case in relation to the complex dynamics with which it intersects. It was therefore conducted only for a specific case with related peculiarities to the subject attitude of the study, through the objective method of observation.

Two University Library Complexes were selected in Nigeria in which all of them are from the same climatic region (hot-dry climate). The basis for the selection of case studies is their potential to supply the necessary information on contemporary trends in bioclimatic design concepts and their relevance to Architecture. The purposive sampling technique was the method adopted based on the following criteria:

1. The bases of being a university Library
2. Climatic similarities or Bioclimatic Design Concept as the Design Philosophy
3. Presence of bioclimatic design features.

The bioclimatic features considered in this study were derived from an all-inclusive variables of bioclimatic design principles (Kyritsi and Micheal, 2020; Sergi, 2008; Omer, 2008; Fang *et al.*, 2004). This includes; building orientation and form, building materials, site planning and landscaping, construction technology, enhancing natural features, accessibility, cross ventilation efficiency, shading devices to reduce direct glare from the sun, and the use of passive design techniques to enhance comfort.

III. Data Presentation

The use of case studies as a learning tool has helped in revealing problems as well as solutions inherent in existing buildings to serve as a guide in design formation (Hamza et al., 2022). Architectural case studies take into consideration such aspects as function, structures, site, and economy, with a view to identifying the intricacies inherent in them in order to find ways of incorporating or rejecting some ideas within the pursued project scope.

Case Study One

Name: Kashim Ibrahim Library Complex (K I L)
Location: Ahmadu Bello University, Zaria-Samaru Campus
Construction Date: (1976)
Present State: Functional

The beginning of what is now known as Kashim Ibrahim Library dates back to 1955 when the Nigerian College of Arts, Science, and Technology (The forerunner of Ahmadu Bello University) was established. In 1963, a more modern and larger Library building was formally commissioned. It was built at the cost of €39,000 consisting of a total area of 7500sqm and was designed to house a book capacity of 70,000 volumes and a seating capacity of 120 readers. The numerous increases in staff and students' population made it necessary for expansion. The new Kashim Ibrahim Library as commissioned in 1976 was considered the largest library Building in Tropical Africa with a total area coverage of 41,937sqm and capable of housing 500,000 volumes of books and seating 2,000 readers.

Building Form and orientation: The building form employed is rectangular in shape with the long sides on the East-West axis (Figure 2). Most windows are placed on the North and South facing walls. This has intensively reduced the admittance of solar radiation into the building. Rectangular form buildings are found to be more effective and energy-efficient (Elshafei *et al.*, 2021). The building enhances unity in form as similar forms are repeated throughout. It is designed on a grid of 6m centers in both the length and the width. Vertical and horizontal shading devices are employed to reduce the effect of solar radiation.

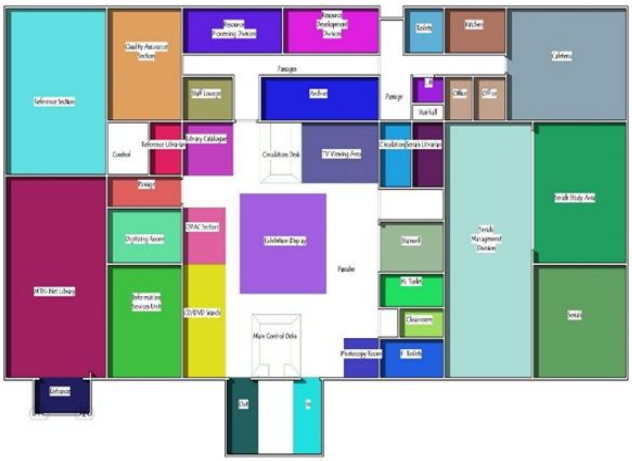

Figure 2: KIL Functional flow chart

Building Materials

i. Walls: The walls were made up of hollow sandcrete blocks of sizes 230X230X460mm thick for load-bearing

International Journal of Scientific Engineering and Science
Volume 6, Issue 3, pp. 50-55, 2022. ISSN (Online): 2456-7361

walls and 150X230X460mm thick for non-load bearing walls. Some partitions are made of MDF plywood and glass in a few places. All sandcrete walls were prepared in cement/sand screeds and finished with emulsion paints.

ii. Floors: The library floor was made up 150mm thick concrete floor slab and finished with terrazzo floor finish.

iii. Ceiling: The ceiling used is perforated acoustic Celotex ceiling boards.

iv. Roofing: The roof construction is a structural steel girder covered with aluminium roofing sheets. The roof pattern is a shell.

Site Planning and Landscaping: The Kashim Ibrahim Library Complex is located in the heart of the Ahmadu Bello University, Samaru campus. It is bounded by the departments of microbiology, Faculty of Environmental Design, and Professor Iya Abubakar resource center from the east, west, and south respectively (Figure 3). It is strategically located. The library is surrounded by soft landscaping elements with the presents of some hard landscape features. Proper landscaping of the immediate library environment will significantly affect the thermal comfort of the library users by making the building interior cooler through effective microclimate control. The use of landscape to moderate the effects of microclimate is one of the principles of climate-responsive designs (Alibaba, 2017).

Construction Technology and spatial organization: The building construction type is a structural frame (reinforced concrete) beam and columns construction. This allows for flexibility and adaptability of the library spaces. Kashim Ibrahim Library Complex is a monolithic 3-story structure (Ground, first, and Second floors) with no single courtyard or sky lighting. The spaces are adequately utilized but are faced with serious challenges in the zoning of function which according to the findings of this study is a result of the inadequacy of spaces in the library. Kashim Ibrahim Library calls for immediate attention as it demands expansion. The internal spatial arrangement of the library is a double banking system with a central corridor of 2.4m width.

Figure 3: Layout of KIL Complex

Shading Devices: In tropical hot-dry climates, sunlight occurs mostly throughout the day for most periods of the year (Nimet, 2022). This necessitates the use of external shading elements to reduce the adverse effects of solar radiation on the building's interior (Hamza et al., 2022; Ghassan et al., 2021; Ishaq and Alibaba, 2017). Louvers shading devices were used to control the effect of intense solar radiation in the KIL complex (Figure 4).

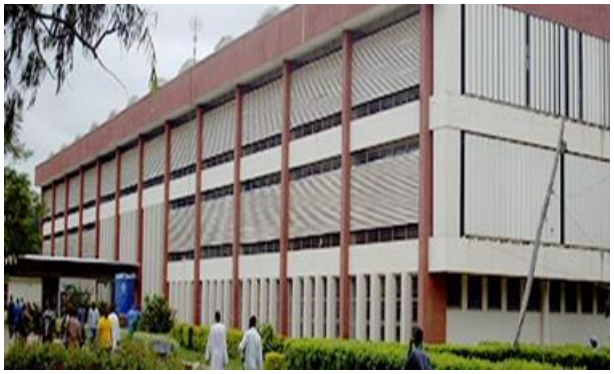

Figure 4: Shading elements in KIL

TABLE 1: Checklist for the Assessment of Bioclimatic Design Concept in the KIL

S/N	Variables	Checklist	Level of application 1	2	3	4	5	Remark
1	Building Form	Complexity of design			√			It is a simple form Structure
		Architectural expression			√			
		Composition of Form			√			
2	Orientation	Positioning of building in relation to climate				√		The building is properly oriented
3	Building materials	Local materials	√					Fewer local materials are used in the building
		Modern materials				√		
4	Site planning and landscaping	Use of soft landscape			√			The building is rationally landscaped
		Building relationship with the site					√	
5	Construction technology	Flexibility of construction method				√		It has a flexible construction method.
		Suitability to climate and environment				√		
6	Spatial organization	Utilization of spaces			√			Through stairways and walkways
		Proper zoning of activities				√		
7	Shading devices	Use of shading devices					√	It is properly utilized
8	Passive design	Day lighting			√			Less considerations to passive design
		Cross ventilation			√			
		Alternate power source		√				
9	Accessibility	Easily accessible to the users			√			It is horizontally accessible but no vertical considerations for the disables

Source: Fieldwork, 2017

International Journal of Scientific Engineering and Science
Volume 6, Issue 3, pp. 50-55, 2022. ISSN (Online): 2456-7361

Case Study Two

Name: Bayero University Library
Location: Bayero University-Main Campus (New Site)
Construction Date: (2001)
Present State: Functional

The new Bayero University Library is located in the University's main campus and was commissioned in 2001. It accommodates Administration, Technical Services, and Automation units. The faculties and departments (branch) libraries are more or less like subject libraries with the exception of the old campus and Mumbayya Libraries. The library houses about 300,000 collections and has a seating capacity of about 5,000 users.

Building Form and orientation: The building form employed is the combination of squares and rectangles. The building enhances unity as similar forms like arches and domes are repeated throughout. It is designed on a grid of 6m centers in both the length and the width. The building is poorly oriented with no considerations to the sun path. The longer side of the building is placed on the South-North axis and most windows are placed on the East and West facing walls. But the effect of intense solar radiation is controlled by the use of Egg Crete shading devices and also some flying buttresses.

Building Materials

a. Walls: The walls are made up of sandcrete hollow blocks 230X230X460mm thick for load-bearing walls and 150X230X460mm thick for non-load bearing walls. few partitions are made of glasses. Walls are prepared in cement/sand screeds and finished with emulsion paints.
b. Floors: All floors are made up of 150mm thick concrete floor slab and finished with ceramic tile floor finish.
c. Ceiling: The ceiling used is a gypsum board suspended ceiling.
d. Roofing: The roof construction is a structural steel girder covered with long-span aluminium roofing sheets. The roof pattern is a flat roof covered in parapet walling.

Site planning and Landscaping: The Bayero University, Library Complex is located in the new site of the University along Kano-Gwarzo Road. The complex is bounded by the Faculty of Islamic Studies, Faculty of Education, Professors Offices, and Students Garden from the South, East, West, and North respectively (Figure 5). It is strategically located. The library is surrounded by soft landscaping elements. Proper landscaping of the immediate library environment (micro-climate control) is significantly affecting the thermal comfort of the library users based on the findings of this study.

Construction Technology: The building construction type is a structural frame (reinforced concrete) beam and columns construction. This allows for flexibility and adaptability of the library spaces.

Spatial Organization: The Bayero University Library Complex is a 5-story structure with court yards and sky lightings placed at strategic locations to enhance natural lighting and ventilation. The spaces are adequately utilized and function properly zoned based on their relationships. The internal spatial arrangement of the library is a double banking system with a central corridor of 2.4m width.

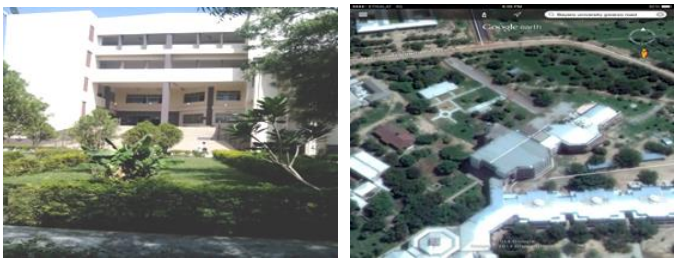

Figure 5: Microclimate control in Bayero University Library

Shading Devices: Egg Crete shading devices (Figure 6) and some flying buttresses are used to control the effect of intense solar radiation.

Figure 6: External shading device on Bayero University, Library

Passive Design: Bayero University Library Complex is designed with adequate considerations to natural lighting and ventilation. The effect of ventilation (natural) in the Bayero University, Library Complex is good as the lighting and ventilation system does not depend majorly on electricity. It incorporates the use of courtyards and sky lighting (Figure 7). Also, inverters were provided to power the automation unit of the library.

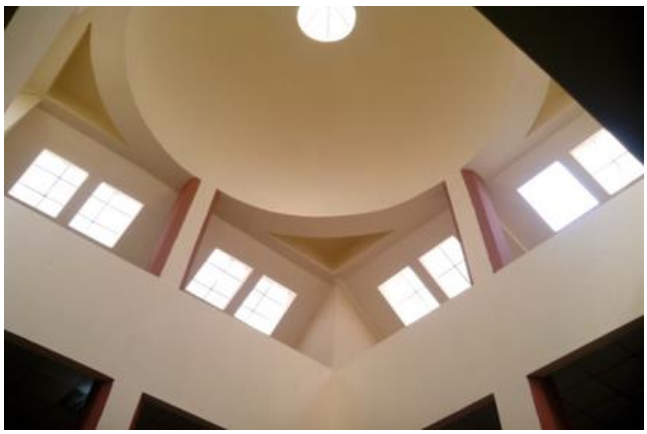

Figure 7: Sky lighting in Bayero University Library

International Journal of Scientific Engineering and Science
Volume 6, Issue 3, pp. 50-55, 2022. ISSN (Online): 2456-7361

IV. Data Analysis

The case studies carried out and discussed above are summarized in Table 3 below in order to compute and analyze the data properly. The level of application of each variable in each case study is shown together with the sum total of the level of application for each case study.

The following frequencies of scores were established to compute the above data in Table 4 below. It shows the number of times, the key rating for scores of the case studies appeared, and X stands for the case studies. Table 5 presents the mean of the case studies.

TABLE 2: Checklist for the Assessment of bioclimatic Design Concept in the Bayero University Library Complex

S/N	Variables	Checklist	Level of application 1	2	3	4	5	Remark
1	Building Form	Complexity of design					√	It is a complex form of Structure
		Architectural expression				√		
		Composition of Form				√		
2	Orientation	Positioning of building in relation to climate			√			The building is not properly oriented
3	Building materials	Local materials			√			Fewer local materials are used in the building
		Modern materials				√		
4	Site planning and landscaping	Use of soft landscape				√		The building is rationally landscaped
		Building relationships with the site					√	
5	Construction technology	The flexibility of the construction method					√	It has a flexible construction method.
		Suitability to climate and environment				√		
6	Spatial organization	Utilization of spaces				√		Through stairways and walkways
		Proper zoning of activities				√		
7	Shading devices	Use of shading devices				√		It is properly utilized
8	Passive design	Daylighting				√		Considered passive design
		Cross ventilation				√		
		Alternate power source		√				
9	Accessibility	Easily accessible to the users	√					No considerations to disable and aged persons

Source: Fieldwork, 2017

TABLE 3: Summary of the Assessment of Bioclimatic Design Concepts in the studied Libraries

S/N	Variables	Checklist	A.B.U	B.U.K	Sum total for the case study
1.	Building form	Complexity of design	3	5	8
		Architectural expression	3	4	7
		Composition of form	3	4	7
2	Building orientation	Position of building in relation to climate	4	3	7
3	Building materials	Use of local materials	1	3	4
		Use of modern materials	4	4	8
4	Site planning and landscaping	Use of soft landscape	4	4	8
		Building relation to the site	5	4	9
5	Construction technology	The flexibility of the construction method	4	5	9
		Suitability to climate	4	4	8
6	Spatial organization	Utilization of space	3	4	7
		Proper zoning of activities	4	4	8
7	Shading device	Use of shading device	5	4	9
8	Passive design	Daylighting	3	4	7
		Cross ventilation	3	4	7
		Alternate power source	2	2	4
9	Accessibility	Easily accessible	3	1	4
Total			**58**	**63**	**121**

TABLE 4: Frequencies of Scores for the Case Studies

X	Excellent (5)	Very good (4)	Good (3)	Fairly good (2)	Poor (1)	Sum total
A.B.U	2	6	7	1	1	17
B.U.K	2	11	2	1	1	17
Frequency (f)	4	17	9	2	2	34

TABLE 5: Mean of the Case-Studies

X	F	XF
5	4	20
4	17	68
3	9	27
2	2	4
1	2	2
Total	**34**	**121 mean,** $\bar{x} = {}^{XF}/_{F}$ $= {}^{121}/_{34} = 3.55 \simeq 3.6$

TABLE 6: Summary of case-study variables

Variables	Characteristics and recommendation
Facilities	The Kashim Ibrahim Library having been designed and commissioned in 1976 when the universities population and power supply was not a problem is currently battling with accommodation and lack of passive design problems. This has to be addressed so as to conform to the current International best practice in library design and usage and to meet up the requirements for NUC BMAS on University library design standards. B.U.K library is fairly satisfactory only that it does not conform to the disability discrimination act which states that; all public buildings shall be fully accessed by all persons.
Building Form	All the cased libraries tend to solve the architectural problems regarding library design and made some conscious effort in creating amassing that is not necessarily dictated by the shape of the plan but the external form concept.
Building Orientation	Kashim Ibrahim library is properly oriented as the longer side of the building lies on the sun-path (East-West) axis, thereby having most of the windows on the north and south-facing. This has reduced the intensity of solar radiation admittance into the building. However, the BUK library has an irregular shape pattern but has efficiently utilized the combination of vertical and horizontal shading elements.
Building Materials	For a good library design, care should be taken in the selection of the type of building materials to be used, as this will affect the lighting, acoustics, and thermal performance of the building interior. Materials such as concrete, steel, glass, titanium, acrylic polymers are commonly used building materials in contemporary design. However, the use of PCVs should be reduced to a minimum as much as possible
Site Planning & Landscaping	A good site provides room for proper landscaping. From the above cases, most of the libraries have a larger percentage of soft landscape to hard landscape. Hence, they have a good microclimate control strategy.
Construction Technology	All the cased libraries adopt a structural framed construction method either concrete or steel structural members.
Spartial Organization	Circulations in both the libraries are adequate as most of them are double banking (use of lobbies and corridors). Natural lighting is achieved using court-yards and atriums in the BUK library.
Accessibility	Good access into and out of the library is very essential for any successful design. The access shall be for both pedestrian and vehicular properly designed without conflict.

The mean was calculated by multiplying X, the scores rating and F: Frequency, the number of times the scores appeared in the case studies. From Table 5, the mean$\nearrow =$ 3.6. This is above the 3.0 midway between 1 & 5 which is termed average. Table 6 presents the studies' summary of findings.

REFERENCES

[1]. Earth Architecture. (2012, October 10). Bioclimatic Architecture. Retrieved October 13, 2019, from Eco Homes: http://www.ecohomes.gr
[2]. Elshafei, G., Vilcekova, S., Zelenakova, M., & Negm, A. M. (2021). Towards an Adaptation of Efficient Passive Design for Thermal Comfort Buildings. *Sustainability*, *13*(17), 9570.
[3]. Fergus J.N, Michael A.H (2013): Adaptive thermal comfort and sustainable thermal standards for buildings. Oxford Centre for Sustainable Development, School of Architecture, Oxford Brookes University, Gipsy Lane, Oxford.
[4]. Federal Ministry of Power, Works and Housing (2017). National Building Energy Efficiency Code
[5]. Folaranmi, A. O., Philip, A., Stephen, O., & Amina, B. (2013). Bioclimatic design principle a solution to thermal discomfort in Minna residences, Niger State Nigeria. *Journal of Environment and Earth Science*, *3*(12), 45-51.
[6]. Ghassan, M. L., Sari, L. H., & Munir, A. (2021, February). An evaluation of the tropical architectural concept on the building design for achieving thermal comfort (Case study: engineering faculty of Syiah Kuala university). In *IOP Conference Series: Materials Science and Engineering* (Vol. 1087, No. 1, p. 012013). IOP Publishing.
[7]. Haruna, H., Wakawa, U. B., Isa, A. A., & Umar, A. Energy Conscious Design Elements in Office Buildings in Hot-Dry Climatic Region of Nigeria.
[8]. Hamza, M., Adamu, M.B., Usman, A.J., Usman, B.W. (2022). Evaluation of mixed-mode strategies in office buildings of the tropical savanna climate. *International Journal of Innovative Science and Research Technology*, *7*(3),
[9]. Issa, A. O. (2004). *Practical guides to project writing.* Offa, Kwara, Nigeria: Fed Poly Offa press. Retrieved September 28, 2014
[10]. Ishaq, M., & Alibaba, H. (2017). Effect of shading device on thermal comfort of residential buildings in Northern Nigeria. *International Journal of Scientific & Engineering Research*, *8*(12), 1021-1029.
[11]. Kolawole A (2012): Design for comfort in Nigeria; a bioclimatic approach. *International Journal of renewable energy*, 23, 57-76
[12]. Kyritsi, E., & Michael, A. (2020). An assessment of the impact of natural ventilation strategies and window opening patterns in office buildings in the mediterranean basin. *Building and Environment*, *175*, 106384.
[13]. Martinez, M. P. (2012). Bioclimatic Architecture. Denmark: VIA University College.
[14]. Olgyay, V. (2015). *Design with climate: bioclimatic approach to architectural regionalism-new and expanded edition*. Princeton university press.
[15]. Sargi, C. D. (2011). Green Building 101: Using bioclimatic design to build passive Sustainable building. Retrieved April10, 2015, from http//green building elements.com
[16]. Sun, K., & Hong, T. (2017). A framework for quantifying the impact of occupant behavior on energy savings of energy conservation measures. *Energy and Buildings*, *146*, 383-396.