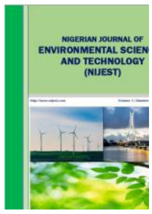
Nigerian Journal of Environmental Sciences and Technology
(NIJEST)
www.nijest.com
ISSN (Print): 2734-259X | ISSN (electronic): 2734-2603
Vol 9, No. 2 October 2025, pp 106 - 124



Climate and Environmentally Responsive Building Characteristics for Buildings in Selected Cities in Osun State, Nigeria

David S. A.[1,] * Orola B. A.[2]; and Olayeni K. P.[3]
[1, 2 & 3] Department of Architecture, Obafemi Awolowo University, Ile-Ife, Osun State. Nigeria

Corresponding author: aderemidavid@oauife.edu.ng

https://doi.org/10.36263/nijest.2025.02.58

ABSTRACT

In view of the multiplicity of tools used by designers to stem the rising trend of energy use in buildings, this study attempts to synchronize the various tools into one. The climatic data of selected cities in Osun State, Nigeria was used as a case study. The cities are Ile-Ife, Ipetumodu, Ede, Ilesa, Iree, Ila-Orangun, Iwo, Ikeji-Arakeji, Esa-Oke and Osogbo. The climatic data of each of the cities was collected. These are Air Temperature, Relative Humidity, Air velocity, Solar radiation, and Illumination. A 30-year average of the climatic data for one of the cities, Osogbo was collected from the Nigeria Meteorology Agency, while a one-year hourly data, that is a Typical Meteorological Year data, was collected for other cities using Amber Weather Software. These data were analyzed using three climatic analytical tools. These are Psychrometric chart with PsycPro software for Control Potential Zones, Mahoney Tables, and Sun-path Diagram. The results of each of the climatic analysis using the three different tools were then synchronized to develop context specific indices to guide designers in the production of climate and environmentally responsive buildings within the climatic region. This study concluded that the developed context specific indices would save time when taking design decisions regarding building characteristics relevant to energy use in buildings within the cities as well as similar climatic regions.

Keywords: Building Energy Consumption, Building Characteristics, Local Climate Data, Environmentally Responsive Buildings, Sustainable Buildings

1.0. Introduction

The idea that the requirement to keep building occupants comfortable indoors is driving increased energy demand, is no longer speculative. Buildings are recognized as significant global energy consumers, given the energy needed for their construction and operations. According to a broad review, buildings account for 40% of the energy use worldwide (Lippiatt, 1999; European Commission, 2005; World Business Council for Sustainable Development, 2009.; Naseer, 2013; Ochedi and Taki, 2019; Okonta, 2023). This is with submission that Green House Gas (GHG), black carbon, and F-gas emissions are expected to double or triple by mid-century due to various factors (Lucon et al, 2014). All these views raise concerns that the situation will be more alarming by the next two decades, if steps are not taken to reduce energy demand in buildings.
There are several obstacles in the way of the global energy reduction efforts. It was observed that the global primary energy consumption grew rapidly in 2018, and almost doubled its ten-year average; even with necessary measures taken. These include efforts to meet energy demands largely by gas and renewable resources, maintaining moderate global GDP growth, and strengthening oil prices. These notwithstanding, the rate of growth experienced, stalled global investment in renewable energy, which triggered demand for coal and other traditional biomass energy sources in developing nations (World Energy Council, 2019). The share of Total Final Energy Consumption (TFEC) in 2010 by the percentage of Nigeria's energy generation by various energy sources, stood at 79.6% for traditional biomass, 8.8% for modern biomass, and 0.4% for Hydro; with almost no contribution from liquid biofuels, Wind, Solar Geothermal and Other sources (International Energy Agency, 2014).

Furthermore, even though the geopolitics of energy no longer pivots on oil and gas, as a result of competitions in technology and data between countries such as US, EU and China, new concerns about social affordability have been triggered by the additional costs of integration, transport and storage of zero-marginal-cost renewable power (World Energy Council, 2019). Because of these challenges, oil and gas have so far proven to be resilient energy sources, particularly in building sector, with persisting prevalence in developing countries like Nigeria, where households, enterprises, corporate organizations and government establishments rely on portable and industrial generators for their daily activities. The affirmed opinion here is that building energy demand is huge and the growth curve gets instantaneously heightened rather than flattened. This trend needs to be stopped before downward redress can be achieved. The huge building loads result in the high installation cost of renewable energy as alternatives, making it unaffordable in Nigeria and other developing nations; hence, reducing these loads calls for practicable and lasting solutions.

Issues relating to energy use and consumption in buildings require a multi-dimensional approach to ensure comfort and efficiency without energy rationing or wastage. *Nigeria electricity generation has been observed to be inconsistent (*Onochie et al, 2015; Olaniyan et al, 2024). The approach to energy availability in Nigeria includes rationing the available Megawatts of energy from the national grid, which fluctuates between 3000 and 6000 Megawatts making Nigerians rely majorly, on oil and gas for the operation of buildings' activities. The Transmission Company of Nigeria (TCN) informs the public that, Nigeria recorded its highest ever, 5,377 Megawatts (MW) generation on August 1, 2020 (Adebulu, 2020). It was revealed that Nigeria has the potential capacity to generate about 12,500MegaWatts (MW) of electric power from the plants, but most days is only able to generate around 4000MW, which is insufficient (US Agency for International Development, 2019). An end-use monitoring study conducted in the Federal Capital Territory (FCT) Abuja, showed that electricity supply was available for 63% of the monitored period and power outage accounts for 37% of the period; and confirmed that power supply to the houses was unstable (Uyigue et al, 2015). With this scenario at the Federal Capital Territory, Abuja, situations in other major cities and towns in Nigeria, which includes Osun state, are unlikely to be better or perhaps, may be worse.

The use of electrical appliances to ensure comfort in all building types amplifies the inclination of households, corporate organizations, and government establishments to accumulate these energy-load builders. 51% of houses in FCT have been established to use air conditioners as predominant appliances to ensure thermally comfortable spaces in surveyed buildings, resulting in annual power consumption of 1387kWh; with the submission that a large portion of industrial activities, businesses and households rely on crude oil products for generators as a primary or back-up source for electricity (Uyigue et al, 2015). These actions are implemented with the absorbed negative consequences of GHG, black carbon, F-gases emissions, and related Particulate Matters (Lucon et al, 2014). Governments of developed nations are proactive in canvassing for renewables alternatives, through policies, regulations, incentives, etc., to cut down on non-renewable energy use in electrified and non-electrified sectors; that is, aviation, freight, land transport, and energy-intensive construction materials (World Energy Council, 2019).

On the other hand, the Nigerian government continues to face difficulties in producing enough energy from its overloaded hydro and gas turbine plants, and the nation's electricity generation has been achieved mainly by thermal and hydro energy sources, even though, there are opportunities for solar, wind and other renewable energy sources, which are sustainable (International Energy Agency, 2014; US Agency for International Development, 2019; Şalvarlı, 2023). The amount of power produced by these renewable energy sources can be adjusted to suit the demands of various user categories. In addition, it is free from the bureaucratic logistics of regulating bodies, especially for small businesses, households, and remote rural areas. This allows for a decentralized power supply, which would help to avoid total reliance on the national grid and failures that may be experienced from grid collapses, resulting in better energy management. This, therefore, helps the world to achieve the goal and the objectives of "Sustainable Energy for All" as declared by the UN General Assembly (International Energy Agency, 2014).

The energy required to operate a building can be kept at a minimum through building envelope design at the conception, design and construction stages of a building without compromising on indoor comfort. This dictates that the building and its envelope are designed and constructed to utilize passive building components, along with optimized renewable energy resources within its local environment. By doing this, the building would be able to exhibit a comfortable indoor environment by embracing passive and passive-to-active energy strategies. Through this approach, minimal supplementary energy will be required from the national grids to offset the energy deficit for the operation of buildings. In situations where passive-active strategies are well executed, it has resulted in a Net Zero Energy Building (NZEB), which is an energy-efficient building that uses nearly zero nonrenewable energy for its operation by producing enough energy through renewable energy resources to cover its annual energy consumption requirements (Peterson et al, 2015). In addition, it may also result in a Positive Energy Building (PEB) which is an energy-efficient building that, over the course of a year, generates more energy than it consumes from renewable sources, maintaining high self-consumption rate, and offers a high degree of energy flexibility (Ala-Juusela et al, 2021).

The opinion of this study is that global policies and declarations are key, and represent top-down approaches, which are insufficient to achieve the goal and global objectives of Sustainable Energy for All (SE4ALL) (International Energy Agency, 2014). It, therefore, requires complementary bottom-up approaches simultaneously, to realize the goal and objectives of SE4ALL. The bottom-up approach as far as sustainable building is concerned, is synonymous with Climate and Environmentally Responsive Building (CERB). Therefore, its features must be defined based on a systematic analysis of the building's local climate data and environmental variables, leading to the synthesis of the features that are expected in its design and construction to reduce non-renewable energy demands, to ensure efficient operation and maintained human comfort in building's interior.

Several studies have affirmed that the development of buildings should be focused in the direction of CERB as one step, among many others, towards achieving sustainable buildings. The necessity of asking building designers to adopt low-energy building design strategies and technologies, which are inherent in the building's structure, envelope, interiors, and services, rather than relying solely on the application of advanced technology to control the intricate balance of factors affecting indoor comfort levels, had been emphasized (Adebamowo and Ilesanmi, 2012). A key principle of climate-resilient architecture is the adaptation of buildings to suit their local climatic conditions (Umana et al, 2024). It has also been confirmed that thermal, visual and acoustic comfort need to be balanced within the context of climate, amongst others perspectives (Altomonte, 2008).

A well-implemented CERB comes with huge benefits; but, will not appear out of nowhere. It has been observed that the skills and knowledge being learned remain in the technical and theoretical realm and need larger goals of creative and actual application in designs and construction processes, in a responsive and performative way (Dytoc, 2016). A good deal of effort will be required to achieve this bottom-up approach, that is, climate data analysis, synthesis, and implementation of Climate and Environmentally Responsive Building Characteristics (CERBC), at the level of individual buildings and the persons who are most responsible for these are the architects, engineers, other design professionals, as well as developers in the building industry.

As a result of assertions by researchers, that designers lack the skills to integrate design ideas with local climates, resulting in designs that rely only on costly mechanical controls for comfort and the observed deficiencies in architectural training curriculum, which may be specific to Nigeria, with Osun as one of the states within its geographical boundaries, it is crucial to bridge this gap by examining the methods of adapting buildings in Osun state to their climatic inheritance and prescribe specific guides that would help designers when taking design decisions about building characteristics that are germane to efficient energy use and reduction in buildings within the cities in the state. The tools adopted include the CPZ chart, Mahoney Tables, and the addition of the Sunpath Diagram, which was not included in previous studies reviewed in this study. To surmount the challenges, it becomes necessary to approach the design of buildings through analysis of the local climate data and other environmental variables to create CERBC, its implementation at the construction stage, and the need for policies, byelaws and regulations to ensure it is applied at the Local, State and Federal levels, to reduce the cost of energy required to operate buildings during their useful life.

1.1 The Concept of CERB

The idea of comfort is linked to several aspects of the environment. For all building typologies, the thermal aspect of the environment is germane; Likewise, the acoustic variables must be kept within the human comfort range, while in practical terms, the visual harmony and users' needs cannot be compromised on their indoor activities, among others. For the thermal, visual, and other aspects to be established, the unavoidable impact of climate and environmental elements on the building and its occupants' comfort must be underscored to determine the building ensembles through various design strategies. The need to synthesize CERBC will usually precede design considerations and require the adoption of the concept of Climate-Responsive Building (CRB).

Approaching the definition from a design perspective, it is based on how a building's form and structure moderate the climate for human good and well-being (Hyde, 2000). Consequently, a CRB is a construction; (house, library, office, school, warehouse, laboratory, church, halls, etc.) designed to moderate, that is, sieve and/or admit the desirable influences into the indoor of buildings, at the same time, reject the undesirable effects of environment for human good and well-being. This is projecting the idea that climate should determine the building form to achieve indoor comfort. It has been affirmed that architecture and climate have always been linked in a pattern of mutual influence, with the explanation that architecture had modified deliberately, the climate of an immediate region, while its design has conventionally been shaped by favourable and unfavourable elements, inherent in the regional environment (Pearlmutter, 2007). Another opinion asserts that environmentally-responsive architecture is a building aimed at achieving occupants' thermal and visual comfort with little or no recourse to non-renewable energy sources (Yannas, 2003).
A CERB must represent a sieve, the building ensemble must be able to receive both the wanted and the unwanted influences from the environment, admit desirable elements in required quantities and simultaneously, reject unpleasant environmental elements from the building's indoor environment. In summary, a building is environmentally responsive when it is sensitive to the dynamics of environmental elements within its environs by minimizing energy consumption, without compromising on human comfort. Modifying the building idea to local conditions reduces energy use and improves user comfort (Liedl et al, 2012).

The inherent deportment of CERB as the embodiment of a filter depends strictly, on the prevailing climatic and environmental parameters of the area, where it would be situated. These parameters are defined by the elements of climate. Climate has been defined as the atmospheric conditions or variations of temperature, humidity, pressure, wind, sunshine, cloud, precipitation, light and vegetation, specific to a geographical location and observed over long period (Hyde, 2000; Mc Mullan, 2002). Temperature, solar radiation, absolute air humidity and wind speed have been asserted to have overbearing influence on building concepts (Liedl et al, 2012). Also, the effectiveness of vegetation concepts in the built environment depends strongly on climatic factors such as temperature, relative humidity, solar radiation, sky condition, radiation distribution and wind velocity (Raji, 2018). Climate has been acknowledged to vary from place to place on earth's surface and creates varieties of environments (Mc Mullan, 2002). Consequently, the building form that will provide acceptable indoor comfort conditions for man would vary with geographical localities.

In addition to these parameters, solar altitude, solar azimuth, solar intensity and sky luminance are equally germane to situate CERB within its local environment; all of these parameters vary with latitudinal peculiarities to climatic regions. The Luminance of the sky is not constant because the sky conditions can be significantly variable; due to changing density, with movement of cloud cover and turbidity resulting in overcast, clear and composite sky conditions that vary with global latitude (Lechner, 1990; Ruck, 2006). Regarding obtainable sky illumination, the prevailing values that characterized respective latitudes, with the Equator having the highest values and the Polar regions (north or south,) having the lowest values have been established (Koenigsberger et al, 1978). However, other environmental variables such as greenhouse gases, CO_2, particulate matter, etc., exist in literature to capture a broader idea of the environment. They are due to anthropogenic activities and are not directly derived from the natural environment. Hence, this study is delimited to CERB and variables relating to climate and the natural environment as highlighted above.
With the elements of climate in the earth's environment, dynamically oscillating in values from time to time, the goal of CERB is to guarantee comfort for human activities in buildings, regardless of the fluctuations in the values of these elements. Human comfort is not only inherent in the definition of CERB, it occupies the centre of the whole concept. The adaptations being carried out by applying CERBCs are principally for achieving human comfort. For this reason, comfort must not be bargained for other requirements such as functionality, aesthetics of indoor spaces and that of the entire building, which are usually the primary focus of most architects. A lot of time, the factors contributing to the productivity of users occupying a workspace are overlooked, but providing a comfortable environment for employees enhances motivation and contributes considerably to their performance. In a study on the effects of office environments on worker performance, it was observed that one of the fundamental requirements of humans is a working environment that allows people to perform their work optimally, under comfortable conditions, in which improvements to the indoor environment were responsible for 10% increase in productivity (Roelofsen, 2002).

The effective design and operation of buildings to support human activities require understanding the relationships between indoor environmental parameters and human perception and performance (Tiller et al, 2010). This relationship requires more attention in the design of educational buildings, because, high degrees of thermal, visual and acoustic comforts are not negotiable for knowledge assimilation to take effect. It is necessary to study elements of climate and the local environment to determine buildings' forms, with the benefit of ensuring that the required level of comfort would be achieved; especially, when non-renewable energy sources become unreliable and expensive for building operation. CERB can improve human comfort and, in doing so, improve human living conditions, in all parts of the world (Sharma and Sharma, 2013). Its achievement will substantially reduce the economic and environmental costs of building operations. CERB has been observed to be essential, not only because of its comfort and energy-saving implications for its users, but also because it helps preserve valuable resources on our planet (La Roche and Liggett, 2001). These benefits, associated with CERB, cannot be forfeited in higher educational institutions' buildings.

Building as a potential saver of the world's energy, if designed with the consideration of the local climate and environment, could help reduce over-dependence on non-renewable resources. Thus, presenting CERB as a pathway to mitigation of the world's energy consumption. This important goal may be difficult to realize without guided or informed knowledge in the development of environmentally responsive buildings and the built environment in general. For many designers, the challenge is articulating the know-how in the area of climate-architecture analysis and synthesis that will inform environmentally adaptable buildings; therefore, the concept of CERB must be revealed. Achieving environmentally responsive buildings comes from both the timing of the consideration of climatic issues in the design process and the procedure by which it is synthesized with other design issues, which require architects' analytical and synthesis skills. The conventional design processes followed by most design firms are not only linear in approach, but also lack the vision to foresee the integrated environmental, economic, and social impacts of decisions, because, architects give building forms and pass predetermined architectural design decisions to service consultants who are constrained to generate design alternatives specific to their specialization which results in less flexible and sub-optimal solutions (Kanagaraj and Mahalingam, 2011).

For most designers, indoor requirements for thermal, visual, and acoustic comfort are secondary concerns and are seen as mainly supplementary, rather than generative aspects of building designs. Therefore, these are not incorporated as user needs and aspirations at the conceptual stage. These users' needs and aspirations include providing environmental controls and comfort, among other things (Ehrenkrantz, 1992). The design of buildings must incorporate users' needs and definite objectives relating to environmental controls and comfort, amongst other design considerations, from the onset.

2.0. Methodology

2.1. Materials

Several researchers have worked on the Bioclimatic approach to CERB and highlighted various methods by which climatic and environmental elements can be adapted to create favourable indoor conditions for humans. These methods were applied at the pre-design stage of climate data analysis to assess the environment in which a building is to be situated. The analyses are projected to help define the building fabric to ensure comfort in indoor spaces of passive energy-oriented buildings.

A Psychrometric chart was presented as the basis for establishing the thermal control task of buildings, determining climatic stress using the appropriate climate plots of data, that is, relative humidity (am/pm), and mean monthly temperatures (minimum/maximum). The term Control-Potential Zone (CPZ) was introduced to describe the range of outdoor atmospheric conditions within which indoor comfort could be achieved by recommended passive control techniques, which include passive solar heating, mass effect, mass effect with night ventilation, air movement effect, evaporative cooling and indirect evaporative cooling. The CPZs are bundles of prescriptions, which are made up of components, defining the building fabric as well as its surroundings to ensure occupants' comfort (Szokolay, 1986). This method only caters for the thermal aspect of indoor comfort in buildings, making it insufficient for detailed analysis and results. Other tools of analysis include bioclimatic charts of Olygay, building bioclimatic chart of Givoni and Mahoney Tables by Carl

Mahoney as reviewed and adopted by several authors (Koenigsberger et al, 1978; Alajlan and Sayigh, 1993; Olgyay, 1963; Givoni, 1976; Lawal, 2013; Xia, 2013; Lawal et al, 2017; Hebbal et al, 2021).

These tools were adopted in analysis and development of CERB for the climate of the Hot-Arid region of Ar-Rihadh in Saudi Arabia. Olygay's Chart presented solar heating and cooling, air movement and evaporative cooling as strategies. Mahoney Tables offered Orientation, Spacing, Air movement, opening sizes, Wall types, Roof types, Outdoor sleeping space and Rain protection as strategies. Givoni Bioclimatic Chart, more like the foundation work for Szokolay's Psychrometric chart, presented High Thermal mass, High Thermal Mass with Night Ventilation, Evaporative Cooling and Natural Ventilation as strategies for indoor comfort. These tools were adopted with the submission that employing one of the bioclimatic tools may not be sufficient to adapt building to its local climate, to accomplish indoor comfort in the region (Alajlan and Sayigh, 1993). Despite the combination of these tools for the generation of CERBC, the focus was still on the thermal aspect of the building, the visual aspect was not considered.

Similarly, other studies have employed one of these highlighted tools at different times to examine climate-responsive approach to building design. This includes investigation of climate responsive approach to building design for comfort in the warm-humid climate of South-western Nigeria, using the CPZ approach. The work only provided graphical information on the general climatic stress that the buildings in southwestern Nigeria would need to take into account in their designs, establishing CERBC was not the focus of the work. Thus, limiting the application of CPZ as a tool for building development (Lawal, 2013). The choice of a tool in the study negates the earlier submission that a combination of techniques would be the best option for detailed analysis and creation of CERB (Szokolay, 1986). Another study adopted a bioclimatic design approach focusing more on thermal comfort by applying Mahoney tables in the Shanghai building. The work established the recommendations for the design of the Shanghai building without information on what the visual aspects would look like (Xia, 2013).

In an appraisal of environmentally-responsive architecture, it was reported that some studies claimed that recent buildings are products of a strong environmental agenda, and submitted that they are not as environmentally oriented as claimed. The article underscored three key issues: knowledge, performance and the urban context, to be very importance to the advancement of environmentally-responsive architecture, with an affirmation that specialist knowledge and tools, which derived their foundations from good theoretical grounding, are essential and required to provide designers with the ability to conceive the ways by which building physics can translate into architecture (Yannas, 2003). This suggests that, technical know-how, in the analysis and creation of CERBC on the part of Architects, other building professionals and urban planners, is one critical challenge faced by the development of CERB. The accessibility of local climate data, deficient and availability of up-to-date climate records is another task that needs urgent redress. In summary, the appraisal represents advocacy for architectural education for environmentally responsive architecture.

To a reasonable extent, several advocacy studies on CERB have been registered. They approached their studies from expert opinions, based on comparative studies, observations, documentation and descriptions of architectural features. Their works represent strong advocacy for the preservation of vernacular and traditional architecture, with a conclusion that they represent the best examples of sustainable architecture, for their abilities to answer ecological issues after the passage of many years through stable indicators. They argue that many of the elements and principles of vernacular and traditional architecture are applicable for today's living conditions, and could be employed to reduce energy consumption and air pollution (A'zami et al, 2005; Singery and Mofidi, 2007). Thus, making knowledge extractions from them essential.

An exploratory study on climate-responsive building design in the Kathmandu Valley of Nepal, observed that building construction methods have changed greatly in the last few decades and modern designers often ignore climate in ensuring indoor comfort, which was identified as a fundamental aspect of CERB. Different Bioclimatic charts and Mahoney Tables were adopted for analysis and provided recommendations for building design considering the climate of Kathmandu Valley, which resulted in design guidelines presented in the study (Upadhyay et al, 2006).

In another study, the application of climate-responsive architecture elements was seen as the driver for high-performance architecture that resolved both comfort and energy issues to a maximum level. With the observation that the application of CERBC in building design practice is still limited, lacking dedicated knowledge on the analysis, synthesis and implementation in the design processes (Looman, 2007). Therefore, the development and application of CERBC through dedicated knowledge, which should be considered essential in the transitional path towards a sustainable energy economy in the built environment was advocated for.

In a field study on climate-responsive vernacular architecture of Jharkhand, India, aimed at exploring and assessing passive solar design techniques that promote high thermal comfort in vernacular houses that were constructed without any mechanical elements and in such a manner as to create micro-climates inside them. The study adopted interviews in the experiment using brickbat coba and lime mortar as key materials for constructing high thermal-mass walls and concluded that a universal approach adopted in understanding and defining comfort conditions failed because the users of the houses were comfortable in conditions defined as uncomfortable by ASHRAE (Gautam, 2008). The research was an experimental undertaking about passive solar design techniques to promote thermal comfort in vernacular houses with high thermal-mass walls, an aspect of environmental strategies as indicated by (Givoni, 1976; Szokolay, 1986).

In Southern India, a study was carried out and aimed at demonstrating that a well-understood external and internal environment can result in a successfully executed passive architecture, which can help reduce energy demand and create significantly healthy and innovative building. The author asserts that the process of creating healthy and sustainable buildings begins at the concept design stage of any project. As a matter of priority, the author started with discussion on defining acceptable comfort zones, focusing on internal environmental requirements and concluding that, when considerable thought is given to environmental issues at the design concept stage of a project, the architecture will almost naturally respond to its conditions and needs. He therefore offered a conceptual diagram for environmentally responsive design that would lead to CERB (Kohli, 2007). Even though, the conceptual diagram needs to be expanded to include methods and tools of bioclimatic analysis and synthesis of CERBC, which are specific to local climates.

Through observations, documentations, and expert judgments, an assessment was carried out on climate-sensitive vernacular architecture of Marikal, in Andhra Pradesh, India. It was affirmed that Marikal's forms and structures were results of centuries of evolutionary process and knowledge transfer, that reflect a set of varying physical and non-physical determinant forces such as climate and geology among other factors, that necessitated advocacy for preservation and integration of climate oriented solutions of local buildings features with modern developments and represents a critique of behavioural patterns and attitudes of modern architecture that are disrespectful to climate and context (Mahdavi and Kumar, 1996).

The design process of contemporary architectural practice on climate responsive architecture in Nigeria, was appraised by focusing on creating greater design awareness among architects on designing climate responsive architecture. He canvassed for architectural design process that suggest to architects, an organized approach to building designs to suit specific climate. The author conjectured that architects are not properly equipped to effectively marry designs with local climatic conditions resulting in designs that rely totally on mechanical controls to achieve comfort (Daroda, 2001). The work's advocacy was focused on seeking amends to the observed inadequacies in architectural training curriculum in Nigeria based on the submission that architects are not properly equipped with knowledge to effectively adapt designs to local conditions, resulting in designs that generally rely on active, non-renewable energy to achieve comfort in buildings, that are devoid of cost saving and energy efficiency benefits in buildings (Sa'ad, 2001). The advocated awareness did not reveal the requisite, conceptual bioclimatic approaches and methods to the design of CERB.

A preservation advocacy study on ecologically sensitive and climate responsive designs was carried out on traditional and vernacular buildings in Himachal Pradesh. The authors adopted observation as a method of study and concluded that the traditional architecture of the state was the outcome of the prevailing topography, extremes of the climate and other natural forces, which should be preserved (Sharma and Sharma, 2013). From the outcome of an exploratory study, it has been affirmed that Climate-responsive architecture is the direct influence behind zero and low-energy buildings, with the explanation that men's exploitation of limited energy resources in the pursuit of comforts and luxuries of life can no longer be tolerated by the earth's environment and may result in disaster. The authors submitted that having energy-efficient buildings is vital to attain the objective of sustainable development, by incorporating climatology in architecture through the concept of low and zero energy buildings, which depends greatly on climate responsive design principles. They adopted Leadership in Energy and Environmental Design (LEED) and Energy Conservation Building Code (ECBC) for energy performance rating benchmarks and concluded that, integration of eco-friendly components and techniques into designs of buildings will reduce energy consumption and, consequently enhance energy conservation and renewable energy harvest (Shivani et al, 2013).

2.2. Methods

This study was carried out to define hypothetical CERBC for buildings in selected cities and towns in Osun State. To align the methodology of this study with the recommendation that, employing one of the bioclimatic tools will not be sufficient to define CERBC and adapt buildings to their local climate, this work adopted an expanded list of tools that rely on local climate and environmental data such as temperature, relative humidity, air velocity, radiation, latitude and longitude coordinates, outdoor illumination values, etc. for the purpose of analysis, determination and application of CERBC in new building designs and as retrofits in existing buildings in the state (Alajlan and Sayigh, 1993). The CPZ chart, Mahoney Tables, and Sunpath Diagram were combined for analysis and investigation of relevant climate and environmental data to determine CERBC as a necessary path to the achievement of CERB. The data used for this analysis is the Average of 30-Year Climate Data of Oshogbo, Table 1, obtained from the Nigeria Meteorology Agency (NIMET) and an average of the author’s self-monitored data for one year, using Amber Weather Software (AWS) in Table 2, (from February 2016 to January 2017). A total of fourteen (14) different towns and cities were documented. Ten (10) most popular towns and cities, with higher educational institutions situated in them as a catalyst for housing growth and development were purposively selected. The selected towns and cities were found between 4° 09′ 0″ E - 4° 55′ 0″ E and 7° 20′ 0″ N - 8° 01′ 0″ N longitudes and latitudes coordinate respectively, in terms of geographic locations. The cities are Ile-Ife, Ipetumodu, Ede, Ilesa, Iree, Ila-Orangun, Iwo, Ikeji-Arakeji, Esa-Oke and Osogbo.

Before these set of data were adopted and applied using Mahoney Tables, CPZ chart and Sunpath Diagram, a comparison of Oshogbo Data from NIMET and AWS, author’s self-monitored data for selected towns and cities were carried out for reliability. The observed similarity, Figure 1- Figure 6 attest to the fact that the data from the two sources NIMET, Table1 and AWS, Table 2 are suitable for further analysis and synthesis of CERBC for buildings the study area.

Table 2: Average of the Amber Weather Software (AWS) data for towns in Osun state.

AWS AVE.	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN
T MAX. (^{O}C)	34.1	34	32.3	31	29.1	27.7	27.1	28.5	29.7	32	32.7	32.3
TMIN. (^{O}C)	21.6	22.8	22.3	22	21.3	20.8	20.6	20.6	21	21.4	20	19.6
PPTN(MM)	16.5	107.8	156.9	200.7	207.5	208.5	169.3	211.3	209.6	55.9	10.4	9.9
PPTN DAY	6.1	12.7	16.2	18.6	19.4	20.5	16.7	23.4	23.6	8.1	2	3.1
RH (AM).	69	83	87	88	90	91	85	88	86	76	66	69
RH (PM)	36	60	66	67	68	77	68	70	69	53	35	35
WIND SPEED	2.9	2.9	3.2	3.2	3.3	3.3	4.4	3.5	3.5	3.3	2.3	2.6
WIND DIRECTION	N	SW	SW	SW	SW	S	S	SW	SW	SW	NE	NE

Source: Authors’ Self- monitored of Amber Weather Software February 2016 - January 2017

Table 1: 30 Years Average of Oshogbo Climate Data

OS. AV. (NIMET)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T MAX. (^{O}C)	35.3	35.8	32.5	31.6	29.5	28.5	27.7	27.5	29.1	30.5	32.3	33.6
TMIN. (^{O}C)	21.9	23.3	22.9	22.6	21.5	21.1	21.1	20.7	21.2	21.3	22.4	20.1
PPTN(MM)	9.6	18.9	81.6	144.2	220.8	206.6	105.6	61.6	183.4	201.9	51.8	10.6
RH (AM)	69	65	82	82	85	88	70	90	88	84	86	76
RH (PM)	35	35	59	65	70	73	76	75	72	59	40	35
WIND SPEED (m/s)	2.4	3.8	3.5	4.3	3.4	3.1	4.4	5.2	4.4	3.3	3.1	2.7
WIND DIRECTION	S	SW	SW	SW	SW	S	SW	SW	SW	SW	SW	SW
RADIATION (w/m^2)	13.2	16.4	14.2	15	13.2	13.5	11.4	9.5	12.1	11.4	13.3	12.9

Source: Nigeria Meteorology Agency (NIMET), Osogbo.

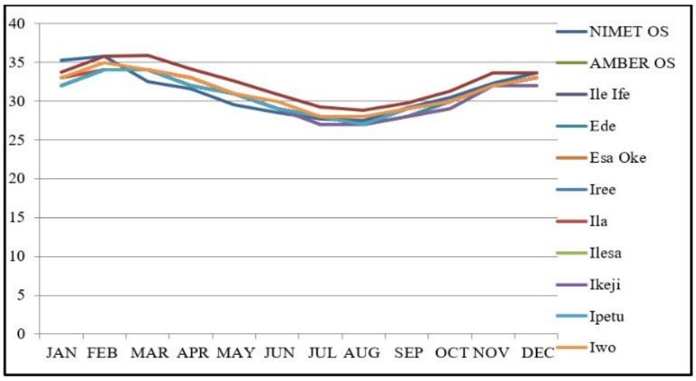


Figure 1: Comparison of Monthly Mean Maximum Temperature in Selected Towns

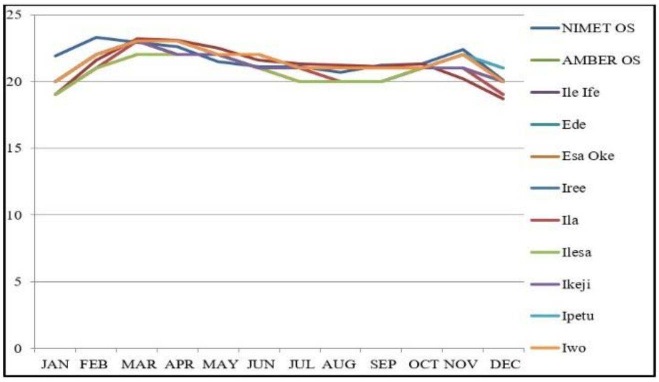


Figure 2: Comparison of Monthly Mean Minimum Temperature in Selected Towns

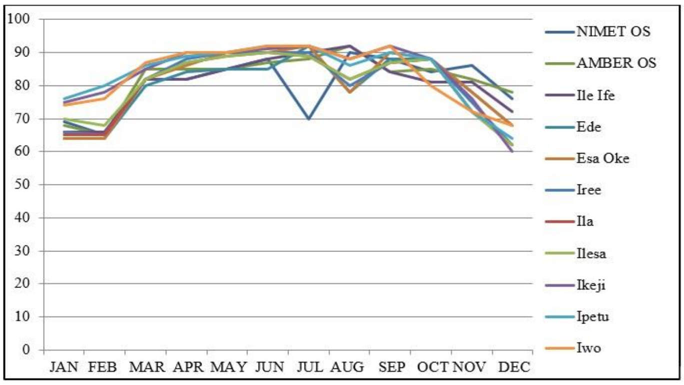


Figure 3: Comparison of Monthly Relative Humidity (AM) in Selected Towns

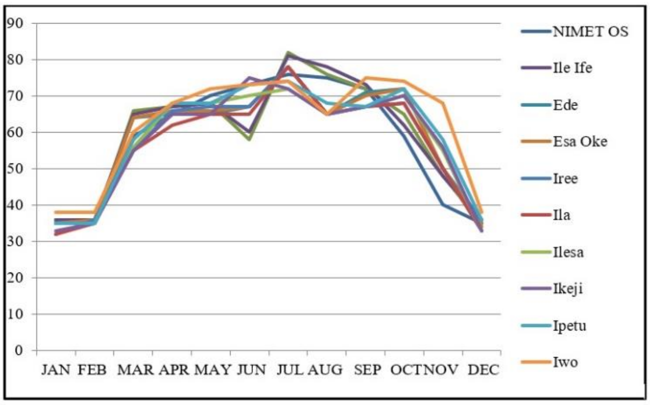


Figure 4: Comparison of Monthly Relative Humidity (PM) in Selected Towns

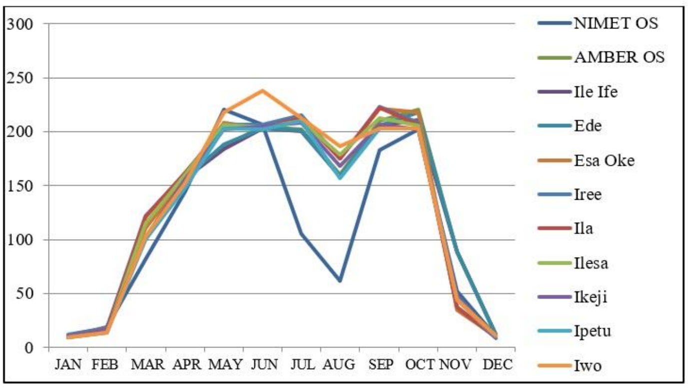


Figure 5: Comparison of Monthly Precipitation in Selected Towns les Analysis

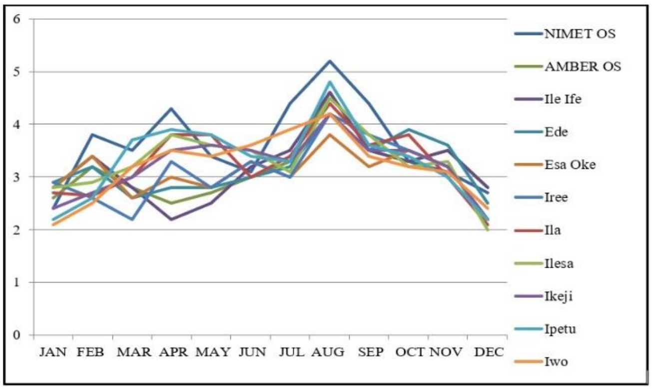


Figure 6: Comparison of Monthly Wind Speed in Selected Towns

The Climate data, Table 1 and Table 2 were inputted into the Mahoney Tables for procedural computations as indicated by (Koenigsberger et al, 1978; Alajlan and Sayigh, 1993; Olgyay, 1963; Givoni, 1976; Lawal, 2013; Xia, 2013; Lawal et al, 2017; Hebbal et al, 2021). The results for these data sets, gave absolute correlation, Table 3. The Mahoney Tables analysis was carried out to help in determining suitable building conditions of layout, orientation, shape, spacing, air movement, openings, walls, roofs, outdoor spaces and rain protection that are specific to Osun State climate; hence, the recommendations of climate-oriented building attributes emerged from the analysis. These are bundles of prescriptions that were simplified and described as architectural components for effective integration and implementation into designs and construction processes of buildings for Osun state. Table 4 indicates the expected components of these split bundles of prescriptions.

Table 3: Comparison of Mahoney Tables Recommendations for CERB in Osun State: NIMET Data versus Amber Weather Software data.

S/N	BUILDING ASPECTS	NIMET DATA	AWS DATA	RECOMMENDATIONS
1	LAYOUT	X	X	Building orientation on east-west axis to reduce exposure to sun
2	SPACING	X	X	Open spacing for breeze penetration; but protect from cold and hot wind
3	AIR MOVEMENT	X	X	Rooms single banked. Permanent provision for air movement
4	OPENINGS	X	X	Large openings, 40 – 80% of North and South Walls
5	WALLS	X	X	Heavy external and internal walls
6	ROOFS	X	X	Light insulated roofs
7	OUTDOOR SPACES	--	--	Not applicable
8	RAIN PROTECTION	X	X	Protection from heavy rain needed

Table 4: Operationalized and Componentized Mahoney Tables Recommendations for Climate-Responsive Buildings

S/N	BUILDING ASPECTS / RECOMMENDATIONS	S.S/N	INDICATED CLIMATE-RESPONSIVE BUILDING CHARACTERISTICS
1	**LAYOUT**: Building orientation on east-west axis to reduce exposure to sun	1	East-west Orientation: Shorter East-west Elevations
		2	Rectangular Shape or Form, with wider elevations avoiding East and West directions
		3	East-west Solar shading and openings protection from direct sunlight / solar radiation
2	**SPACING:** Open spacing for breeze penetration; but protect from cold and hot wind required	4	Adequate Spacing between buildings for airflow
		5	Landscape / vegetation buffers for heat / CO2 absorption & replenishment of atmospheric Oxygen
		6	Adequate spacing for daylight integration and optimization
3	**AIR MOVEMENT:** Rooms single-banked. Permanent provision for air movement	7	Single-loaded corridor configuration for prevailing air movement utilization and optimization
		8	Integration of screen walls, vents, high-level windows, etc. for effective ventilation
		9	Linear arrangement of rooms / spaces for optimized ventilation through windows & other openings
		10	High Floor-to-Ceiling height to optimize stack effect
4	**OPENINGS:** Large openings, 40 – 80% of North and South Walls	11	0.4 – 0.8 Window-to-Wall Ratio (WWR) for effective ventilation and daylighting
		12	North and South Walls window placement to avoid direct sunlight & for soft skylight indoors
		13	100% Airflow practicable window types integration
5	**WALLS:** Heavy external and internal walls	14	≥ 225mm Heavy external walls to delay heat flow
		15	≥ 225mm internal walls to delay heat flow
		16	≥350mm Cavity wall or High thermal-resistant on East & West facing walls to create time lag for outdoor-to-indoor heat flow
		17	Heat-resistant finishes on external walls

6	**ROOFS:**	18	Light reflective roofs to prevent overhead solar heat load
		19	Insulated roof soffits to reduce overhead solar heat load
	Light insulated roofs	20	Roof with air spaces and vents for heat dissipation
7	**RAIN PROTECTION:**	21	Roof gutters, drainage pipes, water collectors, tanks and reservoirs
		22	High-pitch roofs for enhanced roof water flow
		23	≥ 600mm Water-repellant plinths from ground level
	Protection from heavy rain needed	24	Site drainages for run-off & water management
		25	Damp Proof Course (DPC) and over-site concrete slab to prevent water capillary action

3.2. Control Potential Zone (CPZ) Analysis

With the aid of PSYCPRO software (Linric (2023), the Climate data Table 1 and Table 2 were analyzed using Control Potential Zones (CPZ) approach. Comfort Zones (CZ), the degree of the climatic stress and the needed interventions, that is, prescription of strategies to define CERBC were determined for CERB in the Osun State. The process demonstrated by Szokolay, (1986), climate data of selected cities in the state were plugged into relevant equations which resulted in the plotting of psychometric chart and recommendations were obtained. The results for NIMET and AWS data sets have absolute correlation. Hence, single chart, Figure 7 represents the results for both data sources.

The CPZ analysis was carried out to help in determining the optimal conditions of Passive Solar Heating, Mass Effect, Mass Effect with Night Ventilation, Air Movement Effect, Evaporative Cooling and Indirect Evaporative Cooling that are related to Osun state climate. Thus, represent climate-oriented recommendations to define CERBC for creation of CERB in Osun state. Table 5 compares the results of suitable strategies prescribed by the procedural undertakings of CPZs analyses for NIMET and AWS data. These recommendations are additional packets of specifications that must be broken down into parts, described and be presented as architectural components for effective integration and implementation in designs, as well as, in the construction of CERBs in the state. Table 6 indicates how the results were divided into parts for ease of understanding and integration in building designs.

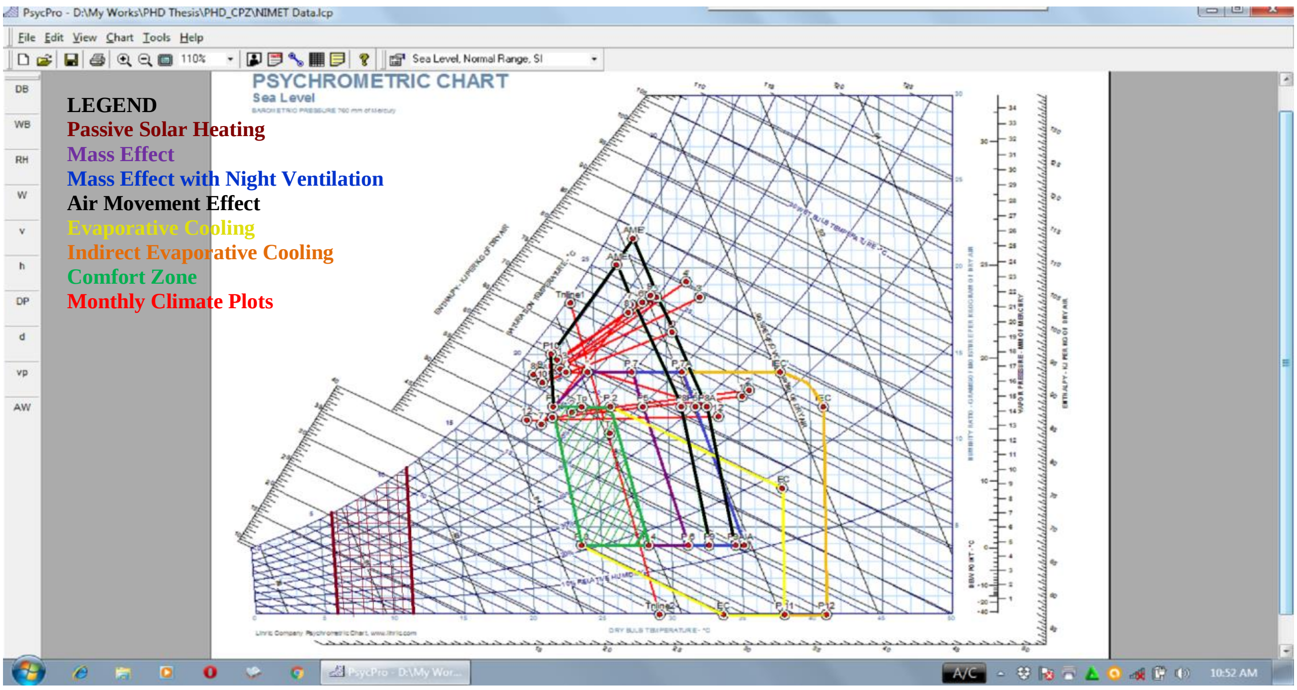


Figure 7: Control Potential Zone (CPZs) Chart result for CERD in Osun State, using PSYCPRO software.

Table 5: Comparison of CPZ Recommendations for CERBs in Osun State: NIMET Data versus AWS data

S/N	BUILDING CONDITIONS	NIMET DATA	AWS DATA	CPZ RECOMMENDATIONS
1	Low Solar Radiation Region	--	--	Passive Solar Heating
2	High Solar Radiation Region	X	X	Mass Effect
3	High Night Radiation Region	X	X	Mass Effect with Night Ventilation
4	High temperature/ Humid Region	X	X	Air Movement Effect
5	High temperature/Arid Region	--	--	Evaporative Cooling
6	High temperature/Arid or Dry Conditions	X	X	Indirect Evaporative Cooling

Table 6: Operationalized and Componentized Control Potential Zone Recommendations for CERBs in Osun state

S/N	BUILDING ASPECTS / RECOMMENDATIONS	S.S/N	EXPECTED CPZ CLIMATE-RESPONSIVE BUILDING CHARACTERISTICS
1	Mass Effect	1	East-west Orientation: Shorter East-west Elevations
		14	≥ 225mm Heavy external walls to delay heat flow
		15	≥ 225mm internal walls to delay heat flow
		16	≥350mm Cavity wall or High thermal-resistant on East & West facing walls to create time lag for outdoor-to-indoor heat flow
		18	Light reflective roofs to prevent overhead solar heat load
		19	Insulated roof soffits to reduce overhead solar heat load
2	Mass Effect with Night Ventilation	13	100% Airflow practicable window types integration
		4	Adequate Spacing between buildings for airflow
		5	Landscape / vegetation buffers for heat / CO2 absorption & replenishment of atmospheric Oxygen
		20	Roof with air spaces and vents for heat dissipation
3	Air Movement Effect	8	Integration of screen walls, vents, high-level windows, etc. for effective ventilation
		9	Linear arrangement of rooms / spaces for optimized ventilation through windows & other openings
		10	High Floor-to-Ceiling height to optimize stack effect
		11	0.4 – 0.8 Window-to-Wall Ratio (WWR) for effective ventilation and daylighting
4	Indirect Evaporative Cooling	26	Roof gardens integration
		27	Roof ponds integration
		28	Diode roof, roof spray or wetted pads integration

3.3. Sunpath Diagram Analysis for Osun State

Using the method presented by (Wilkinson, 2002), the Sunpath Diagram for Osun state, Figure 7 was determined based on latitude 7° 30′ 0″ N and longitude 4° 30′ 0″ E global parameters. The solar window (that is, hatched yellow part) was determined as daily period for effective solar harvest and solar shading, taking place between 9am and 3pm all year round. The Sunpath Diagram, shows an overlay, (a black rectangular block represents a hypothetical building, assuming latitude and longitude global parameters for Osun State. The chart was observed to be similar to the charts presented for latitude 8^{o}N as the state is very close to the latitude (Koenigsberger et al, 1978; Ogunsote,1991). Using DMV-1308 light meter, the average of all recorded outdoor illumination values 23,490 lux was obtained within the solar window (9am – 3pm) at the locations of selected towns and cities in Osun State (David et al, 2011).

With respect to the Sunpath Diagram, the overlays are indicative of design and construction solutions that are specific to the local climate of Osun state. The recommended strategies for synthesizing CERBC were established in Table 7. These include: East-West Orientation, Optimized Daylighting Elements, Solar Harvest with Tracking Elements and Solar Shading Devices, which were prescribed to take care of building conditions such as exposed building elevations to solar radiation, area characterized by high outdoor illumination, high overhead solar load on roof and exposed openings, circulation and other auxiliary spaces to solar radiation respectively. Table 4.8 indicates how the recommendations were divided into parts for ease of understanding and integration into new building designs and benchmark by which higher institution buildings in the state could be evaluated for good design decisions or integration of retrofits into existing buildings.

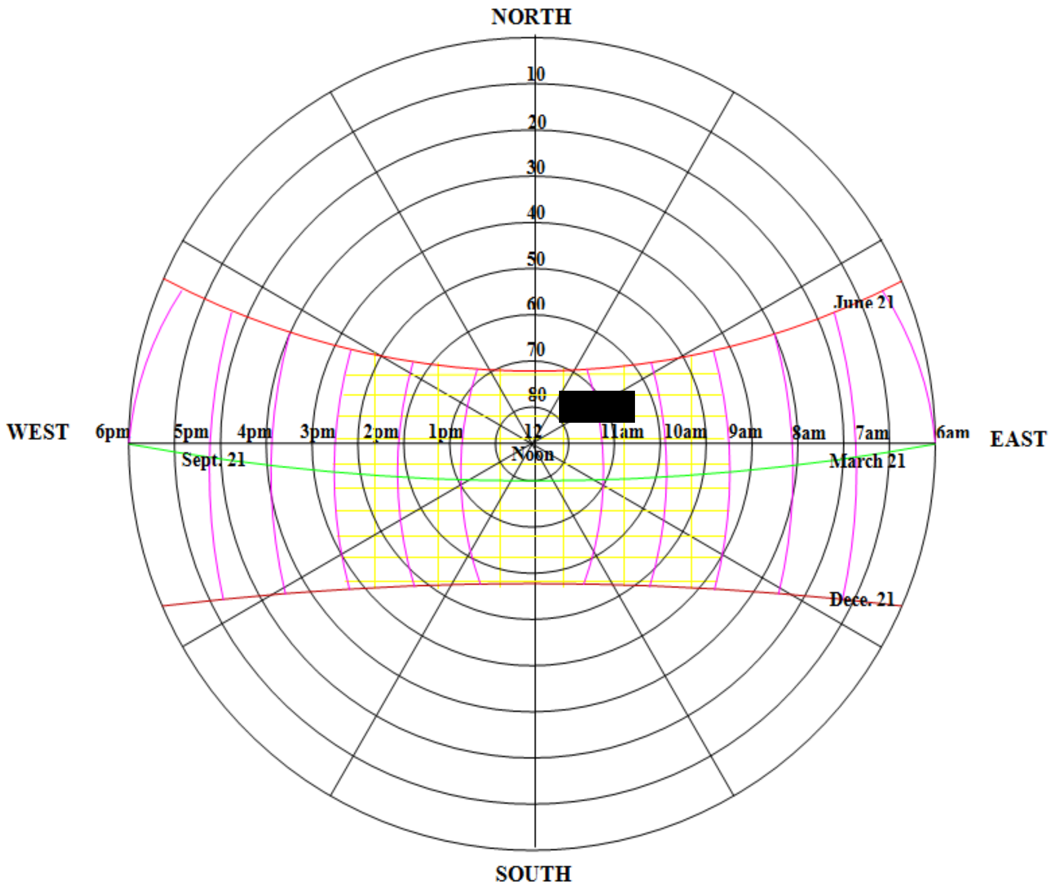


Figure 7: Sunpath Diagram Plot for Osun State Based on Latitude 7° 30′ 0″ N Plotted by authors

Table 7: Sunpath Diagram Recommended strategies for CERB in Osun State

S/N	Building conditions	Recommendations of Sun path diagram analysis
1	Exposed Building Elevations to Solar Radiation	East-West Orientation to reduce exposure to Solar radiation
2	Prevalent High Outdoor Illumination	Optimized Daylighting Elements
3	High Overhead Solar Heat load on Roof	Solar Harvest with Tracking Elements
4	Exposed Openings, Circulation and Spaces to Solar Radiation	Solar Shading Devices and Cooling components

Table 8: Operationalized Sunpath Diagram Analysis Recommended strategies for CERB in Osun State

S/N	Building Aspects / Recommendations	S.S/N	Expected SPDA Climate-Responsive Building Characteristics
1	East-West Orientation to reduce exposure to Solar radiation	1	East-west Orientation: Shorter East-west Elevations
		14	≥ 225mm Heavy external walls
		15	≥ 225mm internal walls
		16	≥350mm Cavity wall or High thermal-resistant walls
		18	Light reflective roofs to prevent overhead solar heat load
		19	Insulated roof soffits to reduce overhead solar heat load
		5	Landscape/Vegetation buffers for heat and CO_2 absorption / replenishment of atmospheric Oxygen
2	Optimized Daylighting Elements	29	≥ 2.7m Window Head-to- Floor Surface Height
		30	≥ 1/2 Window Height-to-Room Depth Ratio Side lighting (Observed from both windows in Bilateral sections)
		31	0.75m ≥ X ≤ 1 Window Width-to-Window Wall Ratio Side lighting (Distribution Criteria for Illumination)
		32	≥ 0.85 Glass Transmittance
		33	Specialized Side lighting components: Light shelves, Light pipes, Ceiling baffles, venetian reflectors, etc.
		34	Top lighting: Skylight, Saw-tooth, Roof Monitor, Clerestory, shed light, Light Shaft and Tracking Devices, etc.
3	Solar Harvest with Tracking Elements	35	Fiber optic solar lighting
		36	Solar panels, Storage and inverter systems for lighting and mild ventilation
		37	Solar water heater and related systems
4	Solar Shading Devices and cooling components	38	Roof overhangs to protect building against insolation
		39	Vertical Shading devices (South Elevation)
		40	Horizontal Shading devices (East, west and South Elevations)
		41	Vertical/Horizontal Shading (Egg-crate) devices (South Elevation)
		42	Recessed corridors/verandahs
		43	Screen-Walls on verandahs/corridors/ external lobbies
		26	Roof gardens integration to reduce heat loads
		27	Roof ponds integration to reduce heat loads
		28	Diode roof or roof spray and wetted pads integration

3.4. The CERBC for Buildings in Osun State

To adapt buildings to Osun state climate and environment, a sequential process has been engaged by adopting bioclimatic tools that relied on the climate data of the state. The Mahoney Tables analysis resulted in the synthesis of Twenty-five (25) established characteristics (Table 4) describing CERBC in terms of the expected strategies, components, etc., to be implemented in design and construction of buildings. Going by the opinion that one bioclimatic tool would not be sufficient to establish CERBC to adapt buildings to their local climate and environment, therefore, this set of checklist requires supplementary lists from others tools.

By employing the CPZ analysis, seventeen (17) characteristics were established. Fourteen (14) represent overlap prescriptions with Mahoney Tables' analysis. Three (3) additional items (Table 6, Second S/N: 26 - 28) were added to the Mahoney Tables CERBC checklist. Roof gardens, Roof ponds and Diode Roof, Roof Spray or Wetted Pads were listed to cater for indoor comfort in the dry months of December, January and February, when temperature values are high (Figure 1 and 2) combined with low PM relative humidity values (Figure 4), and low Precipitation values (Figure 5). These supplementary measures, that is, Roof gardens, Roof ponds and Diode Roof, Roof Spray or Wetted Pads may seem small as a list, but their integration would result in significant energy reduction, accompanied by huge cost saving, as well as uncompromised indoor comfort for occupants of CERB in Osun state.

To complete the analysis and synthesis of CERBC for buildings in the state, Sunpath Diagram for Osun state was determined. Twenty-Five (25) characteristics were established. Ten (10) represent overlap prescriptions with Mahoney Tables and CPZ analyses results. Fifteen (15) additional specifications (Table 8, Second S/N: 29 – 43) were added to the expected features of CERBs in Osun state. These supplementary items resulting from Sunpath analysis are drivers of change and innovations. The CERBC checklist are strictly tied to solar orientation in defining the building envelope; as well as, integration of high-tech components tailored towards optimized solar energy use in CERBs. The integration of Sunpath analysis recommendations without doubt, would inject new thinking into design and construction processes, because of its influence on buildings to adapt them to clean energy through solar harvest and development of new components, in addition to their integration into CERB. The benefits will not be limited to significant energy reduction that goes with unprecedented cost saving, while ensuring indoor comfort for occupants of CERBs in Osun state.

Table 9: Synchronized Climate and Environmentally Responsive Building Characteristics for Osun State

S/N	Indicators of CERBs For Institutional Buildings in Osun State	S/N	Indicators of CERBs for Institutional Buildings in Osun State
1	East-west Orientation: Shorter East-west Elevations	23	≥ 600mm Water-repellant plinths from ground level
2	Rectangular Shape or Form, with wider elevations avoiding East and West directions	24	Site drainages for run-off & water management
3	East-west Solar shading and openings protection from sun	25	DPC & Over-site concrete slab to prevent water capillary action
4	Adequate Spacing between buildings for airflow	26	Roof gardens
5	Landscape / vegetation buffers for heat / CO2 absorption & replenishment of atmospheric Oxygen	27	Roof ponds
6	Adequate spacing for daylight integration & optimization	28	Diode roof or roof spray and wetted pads
7	Single-loaded corridor configuration for prevailing air movement utilization & optimization	29	≥2.7m Window Head-to- Floor Surface Height
8	Integration of screen walls, vents, high-level windows, etc. for effective ventilation	30	≥1:2 Window Head Height-to-Room Depth Ratio for Side lighting (Observed from both window walls in
9	Linear arrangement of rooms / spaces for optimized ventilation through windows & other openings	31	0.75 ≥ X ≤ 1 Window Width-to-Window Wall Ratio, Side lighting (Distribution Criteria for Illumination)
10	High Floor-to-Ceiling height to optimize stack effect	32	≥ 0.85 Glass Transmittance
11	0.4 – 0.8 Window-to-Wall Ratio (WWR) for effective ventilation and daylighting	33	Specialized Side lighting components: Light shelves, Light pipes, Ceiling baffles, venetian reflectors, etc.
12	North and South Walls Window placement to avoid direct sunlight & for soft skylight indoors	34	Top lighting: Skylight, Saw-tooth, Roof Monitor, Clerestory, shed light, Light Shaft and Tracking Devices
13	100% Airflow practicable window types integration	35	Fibre optic solar lighting
14	≥ 225mm Heavy external walls to delay heat flow	36	Solar panels, Storage and inverter systems for lighting and mild ventilation requirements
15	≥ 225mm internal walls to delay heat flow	37	Solar water heater and related systems
16	≥350mm Cavity wall or High thermal-resistant on East & West facing walls to create time lag for outdoor-to-	38	Roof Overhangs
17	Heat-resistant finishes on external walls	39	Vertical Shading devices
18	Light reflective roofs to prevent overhead solar heat load	40	Horizontal Shading devices
19	Insulated roof soffits to reduce overhead solar heat load	41	Vertical / Horizontal Shading (Egg-crate) devices
20	Roof with air spaces and vents for heat dissipation	42	Recessed corridors or verandahs
21	Roof gutters, drainage pipes, water collectors, tanks and reservoirs	43	Screen-Wall on verandah, corridors or external lobbies
22	High-pitch roofs for enhanced roof water flow		

4.0 Conclusion

This study conclude that the issues of building energy consumption can be mitigated by paying attention to the dictates of buildings' immediate environments. Table 9 presents a comprehensive list of the established CERBC through Mahoney Tables, CPZ and SPD analyses. Forty-three (43) CERBC were established as indicators of CERB for Osun State. These are the combined recommendations and descriptions of strategies, components, etc., from Mahoney Tables, CPZ chart and Sunpath analyses, that designers should adopt and implement in building developments generally, to lower the use of conventional energy through fossil fuel dependent generators and the national grid, in the state. This represents a prescribed guideline for the design and development of new buildings in the study area, that could be described as climate and environmentally responsive buildings, including other related terms climate-sensitive, ecologically sensitive or climate-adaptive buildings that guarantee moderation of outdoor comfort variables within their localities to ensure indoor comfort. It could represent a yardstick by which existing buildings (seeking to implement retrofits for improvement on long-term energy savings without forfeiting the comfort of users,) could be assessed for necessary improvement for comfort and energy-related benefits. Thus, it opens up channels for future studies to adopt the synchronized CERBC as a tool of assessment and to validate it as a benchmark for the expected quality of structures that aim to be CERB in Osun state. This study concludes that implementing CERBCs in the development of buildings requires institutional policies, bylaws and regulations to ensure it is adopted at the Local and State levels, to reduce the energy cost needed to operate buildings during their useful life. This could help in achieving Low-Energy Buildings (LEB) and opens up a pathway to realizing Net-Zero Energy Buildings (NZEB) and Positive-Energy Buildings (PEB) when they generate much more than the little energy they require to operate. The overall gain would be green architecture and sustainable buildings and environment in the state.

References

Adebamowo, M., and Ilesanmi, A. O. (2012). Study of building adaptation in warm humid climate in Nigeria. *Open House International*, *37*(4), pp.72-80. DOI: 10.1108/OHI-04-2012-B0008.

Adebulu, T. (2020, August 3**).** Nigeria records 5,377MW electricity generation-highest ever. *The Cable.* https://www.thecable.ng/nigeria-records-5377mw-electricity-generation-highest-ever. Retrieved: 15/6/2024.

Alajlan, S. A., and Sayigh, A. A. M. (1993). The bioclimatic approach to building design in Ab-Riyadh (hot-arid) region in Saudi Arabia. *SMR Workshop on Materials Science and Physics of Non-Conventional Energy Sources*, pp.704–724.

Ala-Juusela, M., Rehman, H. U., Hukkalainen, M., and Reda, F. (2021). Positive energy building definition with the framework, elements and challenges of the concept. *Energies*, *14*(19), pp.6260. https://doi.org/10.3390/en14196260.

Altomonte, S. (2008). Climate change and architecture: mitigation and adaptation strategies for a sustainable development. *Journal of Sustainable Development*, 1(1), pp.97-112. DOI: 10.5539/jsd.v1n1p97.

A'zami, A., Yasrebi, S. H., and Salehipoor, A. (2005, May). Climatic responsive architecture in hot and dry regions of Iran. In *International conference "passive and low energy cooling for the built environment", Santorin, Greece*.

Daroda, K. S. (2011). Climate responsive architecture: Creating greater design awareness among architects. *Journal of Environmental Issues and agriculture in developing countries*, *3*(1), pp.33.

David S.A., Ajibola K., Ayinla A.K., and Adunola A.O (2011). Integrating Daylight Strategies in Buildings: A case Study of UBE Buildings in Osun State, Nigeria. *Journal of Environmental research and Policies*. 6 (1), pp.1-8.

Dytoc, B. C. (2016). Motivation and Guided Complex Learning of Solar Geometry. *MUHON: A Journal of Architecture, Landscape Architecture, and the Designed Environment*, *2*(5), pp.33-39.

Ehrenkrantz, E. D. (1992). *Architectural system: Needs, resources, and design approach*. McGraw-Hill Publishing Company. New York, USA.

European Commission, (2005). *Doing More with Less: Green Paper on Energy Efficiency*. Office for Official Publications of the European Communities: Luxembourg.

Gautam, **A,** (2008). *Climate responsive vernacular architecture: Jharkhand, India* (Doctoral dissertation, Kansas State University). College of Architecture, Planning and Design). Manhattan, KS, United States.

Givoni, B. (1976). *Man, Climate and Architecture*. Van Nostrand Reinhold: New York, USA.

Hebbal, B., Marif, Y., Kaddour, A., Belhadj, M. M., and Azizi, A. (2021). Bioclimatic approach of passive cooling techniques for the design of buildings in southern Algeria. *International Journal of Energetica*, *6*(1), pp.13-18.

Hyde, R. (2000). *Climate Responsive Design: A Study of Buildings in Moderate and Hot Humid Climates*. E. and F. N. Spon Press: London.

International Energy Agency (IEA). (2014). *Sustainable energy for all 2013-2014: global tracking framework report*. World Bank.

Kanagaraj, G., and Mahalingam, A. (2011). Designing energy efficient commercial buildings- A systems framework. *Energy and Buildings*, *43*(9), pp. 2329-2343. DOI: 10.1016/j.enbuild.2011.05.023.

Koenigshberger, O. H., Ingersoll, T. G., Mayhew, A., and Szokolay, S. V. (978). *Manual of tropical housing and building* Part I*: climatic design*. *Longman Inc. London U.K.*

Kohli, V. (2007, November). *Environmentally responsive architecture: Passive design for schools in southern India.* In *Proceedings of the 25th Conference on Passive and Low Energy Architecture (PLEA 2007)*. Dublin, Ireland.

La Roche, P., and Liggett, R. (2001). Very simple design tools: a web-based assistant for the design of climate responsive buildings. *Architectural science review*, *44*(4), pp.437-448. DOI: 10.1080/00038628.2001.9696924.

Lawal, A. F. (2013). Climate Responsive Approach to Building Design for Comfort in Warm-Humid Climate. *International Journal of Engineering and Technology, 3*(1). pp.50-58.

Lawal, A., Joseph, A., and Makinde, A. (2017). Analysis of climate of Southwestern Nigeria for building design. *International Journal of Constructive Research in Civil Engineering*, pp.1-7.

Lechner, N. (1990). *Heating, Cooling, Lighting: Design Methods for Architects*. John Wiley & Sons, Inc.: New York, USA.

Liedl, P., Hausladen, G., and Saldanha, M. (2012). *Building to suit the climate: A handbook*. Walter de Gruyter.

Linric Company. (2023). *PsycPro*: Psychrometric chart software for Engineers. Linric Company. [Accessed 09 September 2023]. https://www.linric.com/psycp

Lippiatt, B. C. (1999). Selecting cost-effective green building products: BEES approach. *Journal of construction engineering and management*, *125*(6), pp.448-455. DOI: 10.1061/(ASCE)0733-9364(1999)125:6(448).

Looman, R. H. J. (2007). Design strategy for the integration of climate-responsive building elements in dwellings. In *CIB World building congress, construction for development 2007* (pp. 1106-1114). International council for research and innovation in building and construction.

Lucon, O., Ürge-Vorsatz, D., Zain Ahmed, A., Akbari, H., Bertoldi, P., Cabeza, L. F., Eyre, N., Gadgil, A., Harvey, L. D. D., Jiang, Y., Liphoto, E., Mirasgedis, S., Murakami, S., Parikh, J., Pyke, C., & Vilariño, M. V. (2014). *Buildings*. In O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel, and J. C. Minx (Eds.), *Climate change 2014: Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 671–738). Cambridge University Press.

Mahdavi, A. and Kumar, S. (1996). Implications of indoor climate control for comfort, energy and environment. *Energy and Buildings*, 24, pp.167–177. DOI: 10.1016/S0378-7788(96)00975-9.

McMullan, R. (2002). *Environmental science in building* (6th ed.). Palgrave. New York, USA.

Naseer, M. A. (2013). Energy Efficient Building Design: Revisiting Traditional Architecture. In *The Asian Conference on Sustainability, Energy and the Environment*.

Ochedi, E. T., and Taki, A. (2019). Towards energy efficient buildings in Nigeria: Challenges and opportunities. *Journal of Engineering and Architecture, 7*(2), pp.125-133.

Ogunsote, O. O. (1991). An introduction to building climatology-a basic course for architecture students. *Zaria: Ahmadu Bello University Press Limited*.

Okonta, D. E. (2023). Investigating the impact of building materials on energy efficiency and indoor cooling in Nigerian homes. *Heliyon, 9*(9).

Olaniyan, A., Caux, S. and Maussion, P. (2024). Rural electrification in Nigeria: A review of impacts and effects of frugal energy generation based on some of e-waste components. *Heliyon*, 10, e31300. DOI: 10.1016/j.heliyon.2024.e31300, PubMed: 38832285.

Olgyay, V. (1963). *Design with climate: Bioclimatic approach to architectural regionalism.* Princeton, NJ: Princeton University Press.

Onochie, U. P., Egware, H. O., and Eyakwanor, T. O. (2015). The Nigeria electric power sector (opportunities and challenges). *Journal of Multidisciplinary Engineering Science and Technology, 2*(4), pp.494-502.

Pearlmutter, D. (2007). Architecture and climate: the environmental continuum. *Geography Compass*, *1*(4), pp.752-778. DOI: 10.1111/j.1749-8198.2007. 00045.x.

Peterson, K., Torcellini, P., and Grant, R. (2015). *A common definition for zero energy buildings* (No. DOE/EE-1247). US Department of Energy (USDOE), Washington DC (United States); National Institute of Building Sciences, Washington, DC (United States).

Raji, B. (2018). Sustainable high-rises: design strategies for energy-efficient and comfortable tall office buildings in various climates. *A+ BE| Architecture and the Built Environment*, (19), pp.1-384. DOI: 10.7480/abe.2018.19.

Roelofsen, P. (2002). The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement. *Journal of facilities Management*, *1*(3), pp.247-264. DOI: 10.1108/14725960310807944.

Ruck, N.C. (Eds.) (2006). *Building Design and Human Performance*. Van Nostrand Reinhold: New York, USA.

Sa'ad, H. T. (2001). The Changing role of the Architect and architecture in the Context of the Ever-Changing Technological, Socio-economic and Political Global Environment. *AARCHES Journal*.

Şalvarlı, H. (2023). Some views on clean energy and enabling technologies for sustainable development. *Journal of Sustainable Energy & Environment*, *14*, pp.31-37.

Sharma, S., and Sharma, P. (2013). Traditional and vernacular buildings are ecological sensitive, climate responsive designs-study of Himachal Pradesh. *International Journal of Chemical, Environmental & Biological Sciences (IJCEBS)*, *1*(4), pp.605-609.

Shivani, S. S., Ajanta, D., and Saif, S. (2013). Responsive architecture: The directive influence behind zero and low energy buildings. *International Journal of Sustainable Development and Green Economics*, *2*(Special Issue), pp.2315–4721.

Singery, M., and Mofidi, S. M. (2007, September). Climatic responsive architecture of Tabriz. In *Proc. 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, September, Crete Island, Greece* (pp. 984-987).

Szokolay, S. V. (1986). Climate analysis based on the psychrometric chart. *International journal of ambient energy*, *7*(4), pp.171-182.

Tiller, D.K., Wang, L.M., Musser, A. and Radik, M.J. (2010). Combined effects of noise and temperature on human comfort and performance. *American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE Transactions, 116*(2, Part 2), pp.601–617.

Umana, A. U., Garba, B. M. P., Ologun, A., Olu, J. S., and Umar, M. O. (2024). Architectural design for climate resilience: Adapting buildings to Nigeria's diverse climatic zones. *World Journal of Advanced Research and Reviews*, *23*(03), pp.397-408.

Upadhyay, A. K., Yoshida, H., and Rijal, H. B. (2006). Climate responsive building design in the Kathmandu Valley. *Journal of Asian Architecture and Building Engineering*, *5*(1), pp.169-176. DOI: 10.3130/jaabe.5.169

US Agency for International Development, (2019). Power Africa Fact Sheet: Nigeria.

Uyigue, E., Yapp, J., Lebof, B. and Odele, M. (2015). A Survey of Households Electricity Consumption of End-Use Appliances in Nigeria: End-Use Appliances in Nigeria. *Journal of Energy Policy Research and Development (JEPRD)*, *1*(2), pp.1-7.

Wilkinson, M. A. (2002). *Module 2: Façade engineering* [Lecture notes]. School of Architecture and Building Engineering, University of Bath, United Kingdom.

World Business Council for Sustainable Development. (2009). *Energy efficiency in buildings: Transforming the market.* World Business Council for Sustainable Development.

World Energy Council. (2019). *World energy scenarios: Exploring innovation pathways to 2040.* In collaboration with Accenture Strategy and the Paul Scherrer Institute. World Energy Council.
Xia, B. (2013). Thermal comfort and the Mahoney tables in Shanghai building bioclimatic design. *Advances in Information Sciences and Service Sciences (AISS)*, *5*(9), pp.27.

Yannas, S. (2003). Towards Environmentally-Responsive Architecture. In *Proc. PLEA*. The 20th Conference on Passive and Low Energy Architecture, Santiago - CHILE, pp.9–12.

Cite this article as:

David S. A. Orola B. A.and Olayeni K. P. (2025). Climate and Environmentally Responsive Building Characteristics for Buildings in selected cities in Osun State, Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, 9(2), pp. 106-124. https://doi.org/10.36263/nijest.2025.02.58