

## Bioclimatic Design Strategies for Residential Buildings in Warm Humid Tropical Climate of Enugu, Nigeria

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### Abstract

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**A** Bioclimatic designed building responds to the climatic conditions within its environment as they are modified with appropriate design strategies to create a conducive environment that provides thermal and visual comforts to its users at the lowest energy consumption. The study is carried out to review bioclimatic design strategies for residential buildings in a warm humid climate of Enugu using the Psychrometric chart adapted from Giovanni to analyze the climate of the study area and identify the bioclimatic design strategy that will aid energy efficiency. The research methodology adopted is a review of existing literature for warm humid climate and finally, a proposal that can be applied to residential building design in Enugu was developed. This study helps us conclude that some bioclimatic design strategies can be used in countries with similar climates and therefore, advocates for more incorporation of bioclimatic design strategies for energy-efficient buildings.

**Keywords:** *Bioclimatic design strategies, Energy Efficiency, Residential Buildings, Warm Humid Climate*

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Bioclimatic architecture is defined as a design that has a connection with nature. It considers the climate and environmental conditions to favour the thermal comfort of users (Liebard, & Traité 2005). There is integration between the design and natural elements; the sun, wind, rain and vegetation, which optimizes resources. A bioclimatic design considers climate and environmental conditions to help achieve optimal thermal comfort indoors (Chayaamor-Heil, & Hannachi-Belkadi, 2017) was coined by the Olgyay's in the early 1960s. The bioclimatic design approach could be simply described as architecture design methods that take advantage of the climate through the right application of design elements and building technology for energy savings, as well as to ensure comfortable conditions in buildings (Olgyay, 1973). It refers to the study of climate when applied to Architecture, to improve the conditions of thermal comfort of the occupants using appropriate design strategies, which differs from place to place based on the prevailing climate of that place. Researchers have identified that buildings are responsible for approximately 40% of the total world annual energy consumption of which most of the energy consumed is for the provision of lighting, heating, cooling, and air conditioning (HVAC). The heating and cooling of a space to maintain thermal comfort are an energy-intensive process that represents up to 60–70% of the total energy consumption in non-industrial buildings (Omer, 2008). In Nigeria, energy consumed by residential buildings accounts for more than 50% of the total energy consumed in the country (Energy Commission of Nigeria, 2014). Hence, the concept of green development through bioclimatic building designs.

### **Problem Definition**

Nowadays, Architects design buildings using the principles of sustainable design (Akadiri, (2016). But there is a challenge in integrating climate control and building functionality to achieve thermal comfort in the environment while reducing the effect of solar radiation, wind, and rain. Many architects do not integrate the bioclimatic approach into their designs because of their lack of confidence (Wei Zhu & Zhuo Wang, 2016). This is because of their notion that the integration of bioclimatic design requires the knowledge of “green technology”. Other architects complete the design process before passing the whole scheme to the engineers. Therefore, a study of bioclimatic architecture will expose them to the bioclimatic design strategies (Maeiel & Lamberts, 2007).

### **Aim and Objectives of the Study**

the research aims to is to study bioclimatic principles and their application in the design of residential buildings in a warm humid climate to achieve adequate thermal comfort of occupants, with specific objectives as follows:

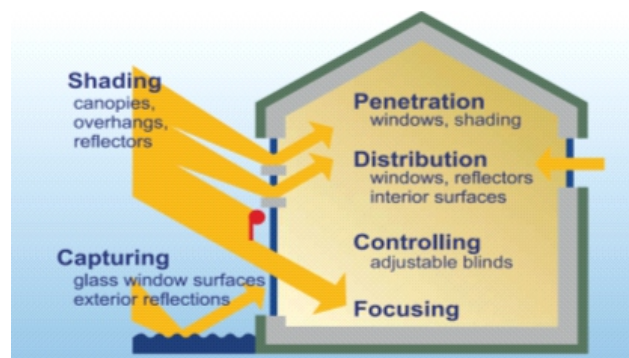
- i. To review the concept and principles of bioclimatic designs.
- ii. To analyze various Bioclimatic Principles and individual application
- iii. To relate bioclimatic principles to building design in a warm-humid zone.
- iv. To propose a framework that will be adopted for residential buildings in Enugu.

### Bioclimatic Design Strategies

The principle behind the bioclimatic design is the understanding of the climatic factors of a site by analyzing the influence of microclimate; including solar radiation, sunshine, temperature, humidity, rainfall, wind velocity and direction (Hyde 2000). Bioclimatic structures are constructed in such a way that, during winter months, exposure to cold temperatures is minimized and solar gains are maximized; during the summer, bioclimatic structures are shaded from the sun and various cooling techniques are employed, often with the aid of renewable energy sources (Manzano-Agugliaro *et al*, 2015).

### Natural Lighting Strategy

The natural lighting strategy aims to improve how natural light is captured and allowed to penetrate a building and enhance how it is then diffused and focused (Chayaamor-Heil&Hannachi-Belkadi,2017) The Control of light to avoid visual discomfort therefore must be considered because excessive natural light penetration can cause visual discomfort and glare which can be controlled by constructing fixed architectural features such as overhangs, roof lights or light-shelves, roof eaves, etc. in conjunction with adjustable screens (awnings, shutters, louvre-shutters or blinds) as illustrated in figure 1. The intelligent use of natural light enables the reduction of electricity consumption for lighting. Lateral lighting provides a directed light that highlights outlines but is limited in-depth unlike top lighting which is more uniform but possible only on the top floor of buildings.



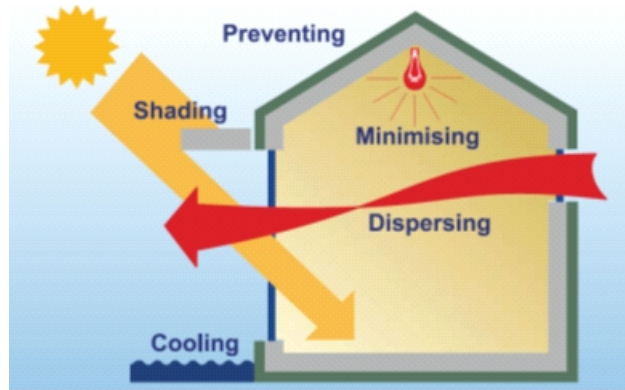
**Figure 1:** Strategies to Control the Entry of Natural Light

**Source:** Liebard *et al*, 2005.

The amount of light captured in a room depends on the position, orientation, angle, size, nature and the type of glazing surface, its roughness and thickness. The construction of the window surrounds may also create a barrier to direct sunlight into the building while reflective ground surfaces like paving or swimming pool may contribute to capturing more light. The way light penetrates a building creates very diverse lighting effects and depends on the type of sky, atmospheric disturbances, season, time of day, and how open the site is.

### Cooling Strategy

The cooling strategy is a response to the need for thermal comfort. This can be achieved by shading from solar radiation and heat gain, minimizing internal heat sources, dissipating excess heat and cooling down naturally. The minimizing of internal heat sources is aimed at avoiding excessive heat in buildings due to the occupants and their equipment.



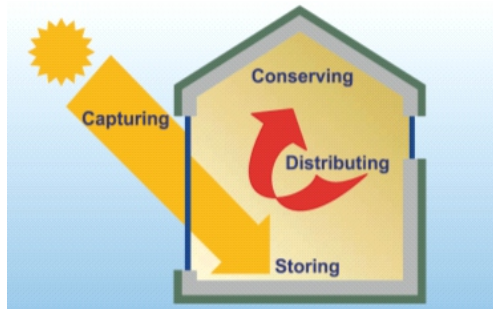
**Figure 2:** Strategies for Cooling In Buildings

**Source:** Liebard et al, 2005.

Shading is required to shield the building openings from direct sunlight to limit direct heat by using screens, window hood or fins also shown in figure 2. Also, walls can be prevented from heating up by insulation. Cooling in buildings can easily be achieved by natural means of ensuring good ventilation (especially at night, to eliminate heat stored up during the day) or to increase the speed of air circulation (the Venturi effect, wind towers, etc.). Other means of cooling is by using water features like fountains and swimming pool, trees, landscape and underground ducting.

### The Heating Strategy

The heating strategy is a response to winter comfort. Heat is captured from solar radiation and stored in the mass of the building. It is then retained and distributed around the building. The solar radiation received by a building depends on the climate with its daily and seasonal variations, the orientation of the building, the nature of its surfaces and the materials used, on the topography of the site, on the shade, etc.

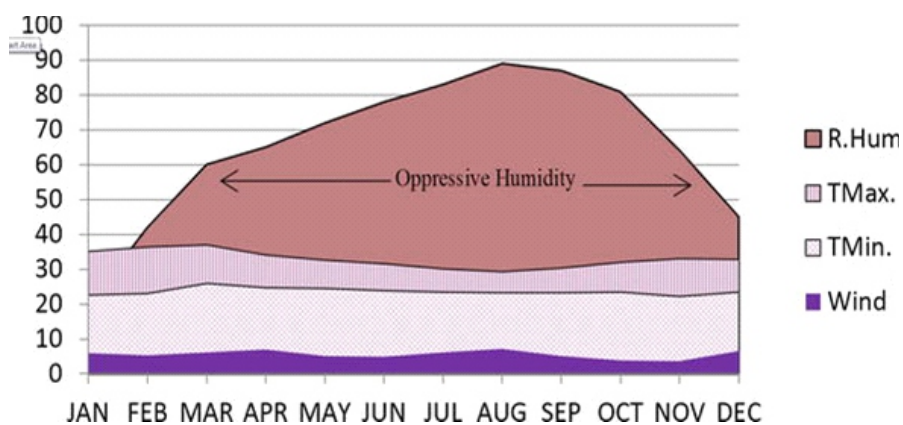


**Figure 3:** The Heating Strategy  
**Source:** Liebard et al, 2005.

Solar radiation is only useful in practice when at right- angles to glazed surfaces, by which it is partly transmitted into the inner space and provides a direct heat gain. Solar radiation often produces heat when not needed. It is therefore, useful to be able to store heat until it is needed. This storage takes place within all types of material according to their capacity to accumulate heat. Distributing heat around a building whilst regulating it means conveying it to the different living spaces where it is desired. This distribution can be carried out naturally when the heat accumulated in materials during periods of the sun is released back into the ambient air by radiation and convection.

**Study area**

Enugu is a city in south-eastern Nigeria, located at 6.26° north and 7.29° east. The climatic data of Enugu as shown in figure 4 can be classified as the tropic rain forest. Enugu covers a total area of 215 sqmi (556 km<sup>2</sup>) with a population density of 3,400/sq mi (1,300/km<sup>2</sup>). Located in the basin of the Cross River and the Benue Trough, it has the best-developed coal in Nigeria. The city is on an altitude of 304.7 m above sea level, its climate is naturally humid, and this humidity is high between March and November [11]. Its average maximum temperature stands at 34.9°C, with average lows of about 22.3°C and its annual mean temperature is about 26.7°C [11].



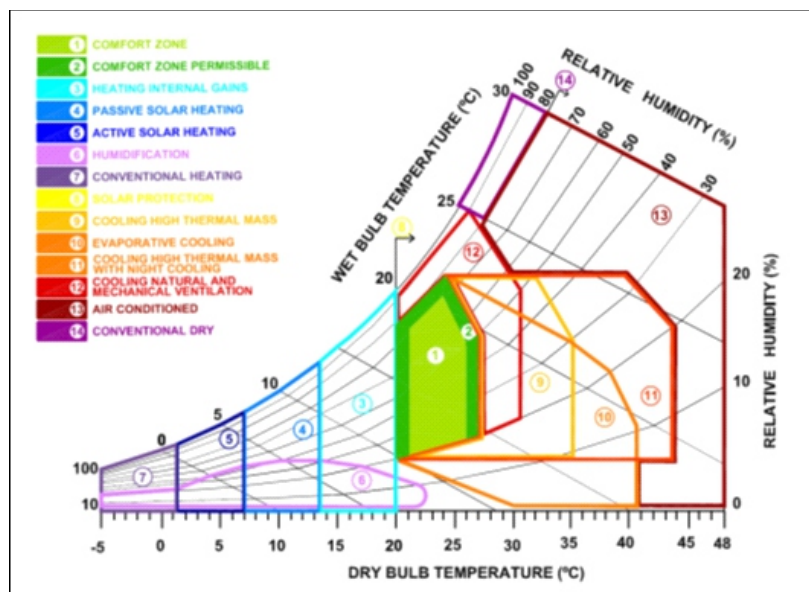
**Figure 4:** Climatic data of Enugu City  
**Source:** NIMET year ended in 2017.

The rainy and dry seasons, particularly with West Africa, are the only weather cycles in Enugu. The mean wind speed is 5.5 m/s between March and September with an average of 7.1 m/s in August. Typical wind path comes relatively from the west for an average of 10 months (termed the monsoon season), ranging from January to November, with a peak percentage of about 75% occurring in July (Akubue, 2019). Also, in the harmattan season, the wind now changes direction to the north from November to January, with 41% occurring in the peak month of January (Akubue, 2019).

### Methodology

The methodology of this study is a review of various literature on bioclimatic strategy in the warm humid climate and relating it to the climate of Enugu. The Psychometric chart, which was adopted from (Givoni, 1992) was used to analyze the climatic condition of the study area. The bioclimatic design strategy that will aid thermal comfort and improve energy efficiency will also be identified.

The Givoni chart shown in figure 5 is a bioclimatic diagram that has been divided into different zones for which it is necessary to use strategies to achieve human comfort within a building. The x-axis represents the dry bulb temperature and the y-axis shows the fresh air humidity; psychometric curves in the graph represent the relative humidity. Here, 14 zones are defined based on definitions of bulb temperature and fresh air humidity.



**Figure 5:** Psychrometric Chart

**Source:** Givoni (1992)

From there, zones 1 and 2 are the ideal comfort zones. Thus, we can define climatic conditions and the associated architectural strategies to shift the environmental conditions of the home into the comfort zone. Whenever possible, passive strategies will

be proposed, as these consume zero energy. When this is not possible, these strategies will be applied to help reduce the use of energy-consuming devices to the lowest possible levels. To study the possible bioclimatic architectural strategies, we must first evaluate the conditions in which the home is located. The environmental conditions will place us within a zone in the Givoni diagram. If we are in the comfort zone, the architecture will not have to perform any thermal corrections but if we are outside of the comfort zone, architectural strategies can be implemented to reach the comfort zone.

### **Findings**

Through wide literature review, appropriate strategies evolved includes Giovani's Concept, Enugu can be said to be in zone 8 where temperature values are from 20 or higher. In this case, bioclimatic architecture strategies attempt to avoid heat gains through solar radiation and avoid temperature increases to remain in the comfort zone. Protection is focused on all building openings but can also be generally applied to the building envelope. Solar protection can be implemented naturally such as the use of trees or through architectural elements such as pergolas with vegetation, porches, awnings, and blinds.

### **Discussion**

In a hot and dry climate, compact buildings with small windows and a high thermal mass are preferred; in a war humid climate, buildings with more openings and permeable are considered. The two main goals for informing the design decision are:

- a) Minimizing heat gains in building
- b) Enhancing heat loss where possible

### **Bioclimatic Design Strategies in a Warm Humid Area**

Achieving thermal comfort in a warm humid area, heat absorption and heat storage are avoided, while the use of double skin structures, low thermal mass and high reflective outer surfaces is ideal. Indoor temperature is maintained by proper design for ventilation and utilization of air movement at an increased velocity, which takes the advantage of reducing heat and the humidity level.

The bioclimatic approach tends to apply the passive design which saves energy using daylighting and wind passively, without conversion of solar and wind to electrical energy. The passive design in warm humid areas like Enugu, find out ways to prevent building heating caused by solar radiation, without sacrificing the needs of natural lighting. Also, the use of wind as natural ventilation is explored to obtain optimal thermal comfort. This submission agrees with the findings of (Sharma, 2016), who assert that the passive system in bioclimatic design can be attained through the following basic strategies:

1. Understanding of climate and climate zones
2. Identification of the comfort zone
3. Identify the sources of heat
4. Optimization of micro-climatic conditions

5. Defining the characteristics required for the configuration of building and
6. the building envelope

Furthermore, Yeang (1996). mentioned that an important component in bioclimatic design is passive cooling for indoor air condition. This technique provides cooling by using air to carry heat out of the building by convection cooling and, from the human body by physiological cooling. The effectiveness is determined by outdoor conditions, microclimate and characteristics of the building i.e. building orientation, number and sizes of openings. To achieve thermal comfort through natural ventilation, windows will be openable and will be placed adjacent to each other for cross ventilation. Landscape elements like trees can be used to direct the wind. In the case where natural cross ventilation is not possible to achieve, stack effect can be used to get a chimney effect. The framework for bioclimatic design strategies to achieve the optimal thermal comfort in a warm humid environment is summarized as follows:

### **Building Design**

#### **Orientation:**

- Correct building placement and orientation
- Provide overhangs or outward shading for north and south-facing windows
- Good landscape planning
- Windows should open towards the prevailing wind

#### **Building form:**

- Use form that provide Buffer zones and thermal zoning
- Use open and permeable geometry allowing airflow
- Daylighting zones
- Design with Courtyards

#### **Materials:**

- Use roofs with High Solar Reflective Index
- Material with Low thermal mass
- Windows with Visible Light Transmittance > 60% for good daylighting

### **Conclusion and Recommendation**

Bioclimatic design by extension is a Green design building approach. There is no better time other than now for Nigeria to pursue green designs and technologies to combat present and future challenges (Okekeet *al*2018).The premise of the bioclimatic design strategy is that buildings utilize natural heating, cooling, and daylighting in accordance to local climatic conditions. Therefore, we can derive the appropriate bioclimatic design strategies that will be suitable for a warm humid climate by analyzing the design with regards to natural ventilation, daylighting, and passive heating and cooling. By adopting these strategies of bioclimatic building designs, the energy required for cooling and lighting a building will be reduced especially in the residential building type where



people spend most of their time. Residential buildings also will not only benefit from reduced energy usage as a result of these bioclimatic measures, but will provide a more comfortable indoor climate for occupants, reduce the negative environmental impact, and be more economically sustainable.

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