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Investigation of Sustainable Design Strategies and Energy Performance in Prof. Chike Edozie Secretariat Office Building

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Abstract.

Global warming is presently one of the main concerns of human beings, office building stock represents a significant potential in tackling both worldwide energy and thermal built environment challenges. This has induced major problems in terms of environment and energy consumption, including overexploitation and depletion of energy resources, environmental pollution, and climatic changes. Environmental problems and energy conservation issues have increased interest in climate responsive design strategies to achieve better thermal comfort conditions inside buildings without enhancing energy consumption for cooling needs. Environmental performance of buildings is related to various factors including climate. In order to deal with these issues, architects have a greater responsibility to design buildings that are environmentally sustainable. The main goal of the study is to examine the potential for cooling load reduction and thermal comfort enhancement by using natural ventilation techniques in office buildings. Considering a sample of five offices in a multi-story Prof. Chike Edozie secretariat building located in the city of Asaba (southern Nigeria), thermal comfort conditions were analyzed on the basis of a post-occupancy evaluation (POE) survey and in situ recorded measurements campaign. Using interviews, the study also explores social acceptability toward implementing passive roofing techniques. Furthermore, the potential of thermal comfort and energy-efficiency improvements due to natural ventilation was investigated. The research recommendations are to improve the sustainable design of office buildings by effective opening of windows which renders optimal ventilation in single side ventilation and cross ventilation. This will aid the next generation of architecture and construction professionals in achieving effective ventilation, comfortable indoor environment, energy efficiency and sustainable future.

Keywords: *Energy Performance, Natural Ventilation, Occupant Thermal Comfort, Office Building, and Sustainable Design Strategies.*

1. Introduction

Creating suitable living spaces is greatly influenced by the physical structure of the built environment in different levels of design including climate characteristics, site integration, urban planning and envelope features. In return, occupant's interaction with the building should not be underestimated. Therefore, energy usage of office does not only depend on the performance of the building air conditioners and ventilation systems but also on the activity of the occupants. A building must be energy-efficient and provide comfortable indoor environment to the occupants. If suitable indoor conditions are not provided, the occupants take alternative measures to achieve the desired environment. Such measures include cooling the space by using air conditioners and ventilation systems. In all cases, these adjustment measures increase the energy consumption and the cost of electricity and bills. While discussing thermal comfort, it is remarkable to notice the amount of literature devoted to this subject, on the other hand, the energy consumption behaviour of the residents to achieve satisfactory levels of comfort remains a relatively under-studied topic.

Considering the harsh climate of Nigeria, air conditioning, ventilation and electric lighting, account for up to 40% of building energy and national electricity consumption (Lakhdari,et al., 2021). In southern Nigeria where a warm humid climate prevails, cooling energy demand accounts for the highest share of energy consumption in buildings. Furthermore, there is no policy or measures relating to energy efficiency and thermal comfort and most of the buildings are not designed by professionals. As a consequence, the existing building stock does not provide optimal indoor thermal comfort. This situation is further exacerbated by the poor thermal performance of exterior building envelope; in particular, solar radiations and heat gain through windows, exterior walls and roofs represent a significant component of the cooling load and consequently a major contributor to energy consumption in warm humid climates (Adebamowo & Adeyemi, 2013 Atolagbe, 2014; Olanipekun, 2014). As a result, domestic energy efficiency improvements are commonly encouraged to mitigate their contribution to climate change, lower their energy costs, and improve the comfort and health for the residents (Ormandy & Ezratty, 2012). Passive design strategies at urban and building scales have been largely adapted for building thermal and energy efficiency in various climatic conditions because the indoor environment is affected by surroundings and building design. This motivated this study on sustainable building strategies and energy performance in Prof. Chike Edozie secretariat office building in Asaba, Nigeria.

2. Literature Review

The ingenious climate-responsive design strategies have been evolved over the course of time to mitigate the effects of climate and to provide acceptable comfort conditions only by making the best use of locally available materials and resources. The climate has been the foremost factor that influenced that building design. The built environment developed by the inhabitants resulted from their long experiences about climate effects. Their dwelling was intrinsically related to the prevailing conditions. Furthermore, strategies implemented in vernacular constructions are usually passive and not dependent on fossil energy, which makes them suitable for contemporary construction (Amraoui et al., 2021). The building sector is responsible for around 40% of the world's annual energy consumption and nearly 30% of all greenhouse gas (GHG) emissions (Boumerzoug et al., 2022). This has induced major problems in terms of environment and energy consumption, including overexploitation and depletion of energy resources, environmental pollution, and climatic changes (Atolagbe, 2011).

In this regard, architectural research on climatic constraints and socio-cultural expectations in a given place are valuable in promoting climate-specific passive technologies to contemporary buildings. And it offers sound models for sustainable design. Accordingly, human thermal comfort conditions derive from adequate constructive choices, architectural components and specific design features implemented in the form, orientation and materiality of buildings. This also demonstrates an economical use of local resources including available materials and known construction technologies. Many studies have looked at climatic- climatic-responsive building design to enhance thermal comfort conditions in living space and at the same time to reduce the energy consumption. Accordingly, several researchers investigated dwellings in warm humid zone (Adebamowo & Adeyemi, 2013 Atolagbe, 2014; Olanipekun, 2014).

The objective of the drive is to achieve natural ventilation and maintain body heat comfort in the house with little or no expenditure of energy, in Nigeria, a country in the Third world. This is a region in which Brew-Graves (1995) asserted that 30-60 percent of the populations live in grossly inadequate conditions of congested and poorly ventilated houses; or with poor urban housing conditions replete with overcrowding congestion and overstretch in urban facilities and services (Arayela, 2000; Diogu and Okwankwo, 2005). Energy is now considered a serious economic and sustainability issue in the built environment (Chapman 1974; Haseltine, 1975; Gatner and Smith 1989). It is now regarded as a scarce resource in technology and specifically, Architecture where virtually, all building materials and the technology for their production are driven by one form of energy or the other (Atolagbe and Fadamiro 2005). Energy is indispensible in sourcing, manufacture, transportation and assemblage, and in cooling, warming and cleaning of built spaces. It is important in aiding users' goals and aspirations (Atolagbe, 2011). Indeed, energy may be regarded as the reason, and its control, the ultimate goal of Architecture. It is, today, a key design tool in the achievement of sustainable building the World over; and modern buildings are considered as being responsible for more than 40 percent of global energy consumption (Ohajuruka, 2013).

In general, they focused on their design characteristics and how traditional housing developed adaptation strategies to cope with the local environment based on social and cultural factors, as well as, thermal comfort (Boumerzoug et al., 2021; Kaihoul, et al., 2022). In this respect, the relevant literature states that in warm humid zone the focus was to minimize heat gains during dry season. Comfort threshold in warm humid climates like that of Asaba, would be limited by high humidity, which will restrict the evaporative heat loss from the skin and cause discomfort (Szokolay, 2004). But increasing the air flow speed around occupants can boost the evaporative heat loss from the skin; it would replace the humid saturated air around the skin with fresh and unsaturated air (Diogu & Okonkwo, 2005; Szokolay, 2013). So, increasing air flow speed can help occupants to achieve thermal comfort. Thermal comfort would be influenced by the ambient environment, cultural context and occupant experience. People would adapt and tolerate the local climate condition when they live in this region for a long time. Thus, people who live in the warm humid climate can accept a higher humid and hot environment than those people from other climate conditions. Givoni (1994) explained that it is because of the acclimatization. In the warm humid climate, the upper boundary of acceptability of humidity and temperature is higher than the comfort threshold upper limit of 26ºC identified by ASHRAE (2004). Air movement can increase the heat convection between the human body and the ambient environment, so that it takes away the heat by evaporating perspiration. The average skin temperature is 32°C-34°C when people are doing light activity, and the physical evaporation rate is based on air velocity and vapour press. The increase of air velocity can speed up the evaporation rate; while the evaporation rate will be decreased merely under high vapour pressure. Providing a cooling effect by increasing air movement can be achieved as the air temperature is lower than skin temperature (Diogu & Okonkwo, 2005; Szokolay, 2013). Allard (2002) pointed out that increasing the indoor air flow rate (within occupants' acceptable limit of course) can reduce the indoor pollution level. A large amount of incoming air through windows could drop the indoor temperature and increase the window performance Figure 1. Therefore, providing air movement is an important method to reduce cooling load and achieve comfort, especially in warm humid climates (Adebamowo et al., 2010).

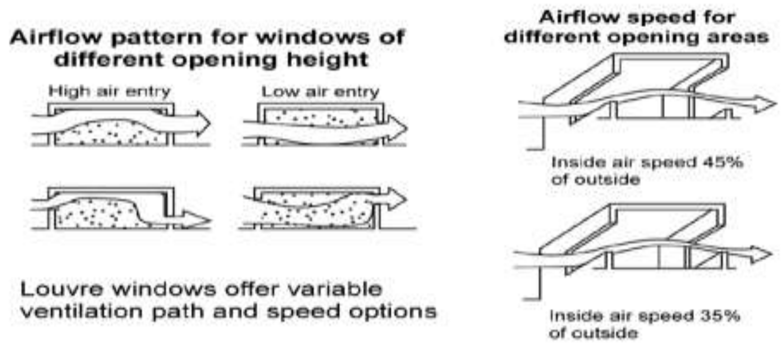

Figure 1: Air flow pattern and speed for different opening areas (Szokolay, 2013).

The alternative to natural ventilation for indoor body heat comfort is the use of mechanical or electrical driven fans and air-conditioners, usually operated with cost-laden artificial energy. Thus, cooling by natural ventilation presents a welcome option not only for saving cost of energy and mechanical hardware, but also for its freedom from electricity hazards like electrocution, fire outbreak and fungal and bacterial health afflictions associated with air-conditioner condensates. The aim of ventilation, either natural or mechanical is generally the same - to keep indoor temperature at the level of users' body comfort. The objective however, may and often differs with climatic differences. Whereas it is to keep the heat 'out' in warm humid tropical climate, it is to keep it 'in' in the cold temperate regions of the world. Based on outside climate factors such as relative humidity and dry bulb temperature and by performing qualitative analysis, the tools indicate suitable passive design strategies, i.e. solar radiation, air movement and evaporative cooling, for specific climatic conditions (Kaihoul, et al., 2021).With this purpose, several cooling design strategies were developed, such as, urban compactness, proper orientation facing north and south, avoiding exposure to the west, self-shading forms, clustering buildings, high thermal inertia, small windows, curved or flat roofs and light colors, and sun shading devices. These studies are very important in the investigation of sustainable design strategies and energy performance in office buildings, in order to improve the indoor comfort conditions and satisfaction of the occupants inside the buildings.

2.1 Study Area:

The study area is Asaba in Delta State, Nigeria. It is located in south-eastern and Nigeria lies within 4^0N to 14^0N latitudes and 2^0E to 14.5^0E longitude. Asaba lies in Latitudes 6.2^0N of the Equator and longitude 6.73^0E of the Greenwich Meridian. It is the state capital of Delta State and located on the banks of the lower Niger Delta. The climate of Asaba is humid sub-equatorial with long wet season lasting from March to October that alternates with a shorter dry season that last from November to February. The climate is influenced by two prevailing air masses namely the south-west monsoon wind and then North-east trade wind. Annual rainfall in the Asaba area is up to 2500mm with double peak rainfall regime which takes place both in June and September. Annual average temperature is about 27^0C with no marked seasonal departure from the average. The natural vegetation of the area is rainforest with swamp forest occurring in flat-floured valleys and adjoining low lying areas that are seasonally or permanently water logged (NiMet's, 2016).

3. Research Methodology

This paper reports on the investigation using questionnaire and physical measurement with data loggers. Data on the indoor air temperature in five different window openings in purposively selected rooms were used. The multi-purpose Air Flow Digital anemometer was used to measures air velocity, air temperature & humidity. The instruments were placed at 0.6m, 0.9m, and 2.1m from the floor to record the thermal comfort variables simultaneously, as the subjects filled in the thermal comfort questionnaire. The instruments were placed at 0.6m, 0.9m, and 2.1m from the floor to record the thermal comfort variables simultaneously, as the subjects filled in the thermal comfort questionnaire. The measuring apparatus for field study and data documentation is shown in Figure 2.

Figure 2: measuring apparatus (field work 2023).

3.1 Data Presentation and Analysis:

This section present the data generated from the field work. The data generated from the various sources will be sorted and arranged a way that is adequately fit for statistical analysis and interpretation using tables, bar charts, graphs, frequency distributions and percentages. This measurement was carried out from October 2022 (11th to 24th) and during this period the outdoor temperature varied from a minimum of 21.5°C to a maximum of 36.1°C, with the mean daily average temperature of 27.3°C. There were large temperature fluctuations during the measuring time, which was because of high solar radiation, and the highest temperature of each day was above 30°C. However, the prevailing wind was from the south-west and the wind speed was between 0.05m/s and 5.75m/s, with an average wind speed of 1.47m/s.

Plate 1: Main entrance view of Prof. Chike Edozie Secretariat, Asaba; Shewing window opening patterns. (field work, 2023).

Plate 2: Aproach view of Prof. Chike Edozie Secretariat, Asaba; Shewing window. (field work, 2023).

Plate 3: Perspective view of Prof. Chike Edozie Secretariat, Asaba; Shewing the Landscape. (field work, 2023).

Question 10: Occupant perception of air flow

This question was asked to know the distribution of how respondent feel about air flow. The Table 1 shows the occupant preference of air flow distribution of the respondents. The result has shown that about 0.92% of respondents were feeling cold, 1.38% cool, 1.53% slightly cool, 3.23% neutral, 4.92% slightly warm, 15.84% warm and 67.53% feeling hot. This shows that more of the respondents are feeling hot as shown in Figure 3.

Occupant perception of air flow	**Frequency**	**Percentage**
Cold	6	0.09%
Cool	9	1.38%
Slightly cool	10	1.53%
Neutral	21	3.23%
Slightly warm	32	4.92%
Warm	103	67.53%
Hot	439	15.84%
Total	**650**	**100%**

Source: field work (2023).

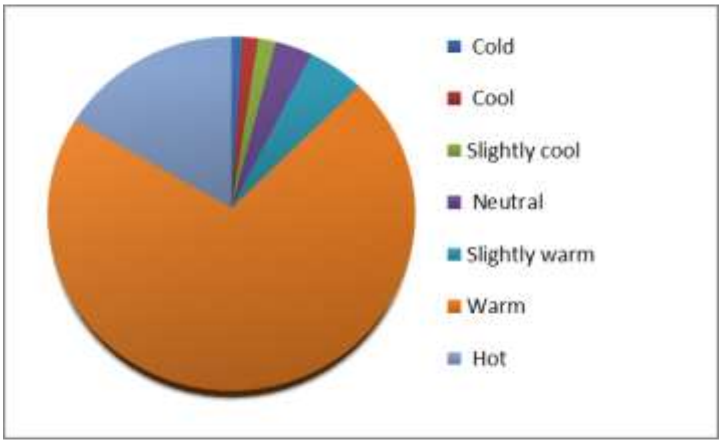

Figure 3.: Occupant perception of air flow distribution (field work 2023).

Based on the occupants feeling warmth most time they switch on the Air Conditioners to cool the offices thereby increasing the energy consumption.

- **Offices in Cluster (A)**

The cooling effect in office with window position on East and west wall panel on room temperature, rate and pattern of air flow with different percentage of open area as shown in Figure 4.

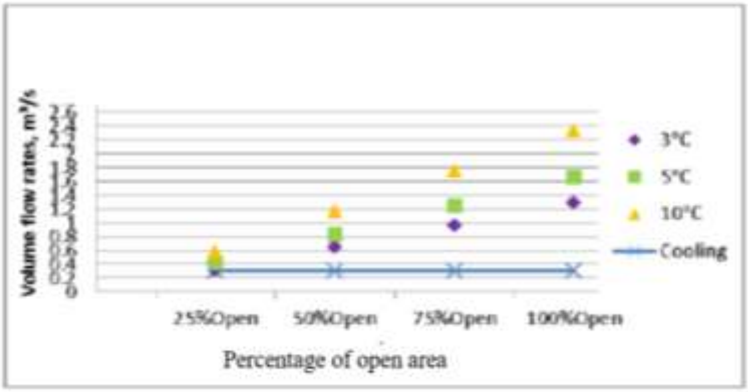

Figure 4: Cooling Effect in offices at cluster (A) windows in East and West facing wall on room temperature and air volume flow rate (Field work, 2023).

- **Offices in Cluster (B)**

The cooling effect in office with window position on East and west wall panel on room temperature, rate and pattern of air flow with different percentage of open area as shown in Figure 5.

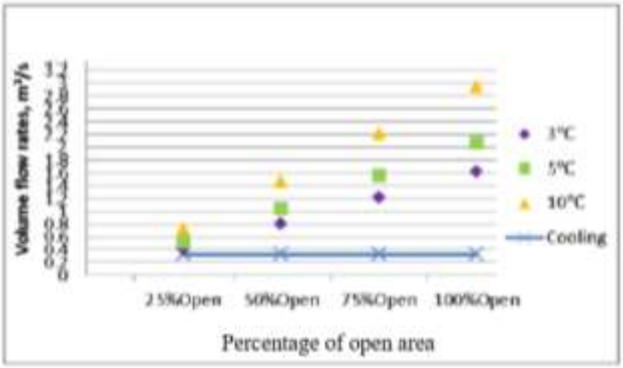

Figure 5: Cooling Effect in offices at cluster (B) with windows in East and West facing wall on room temperature and air volume flow rate (Field work, 2023).

- **Offices in Cluster (C)**

The cooling effect in office with window position on East and west wall panel on room temperature, rate and pattern of air flow with different percentage of open area as shown in Figure 6.

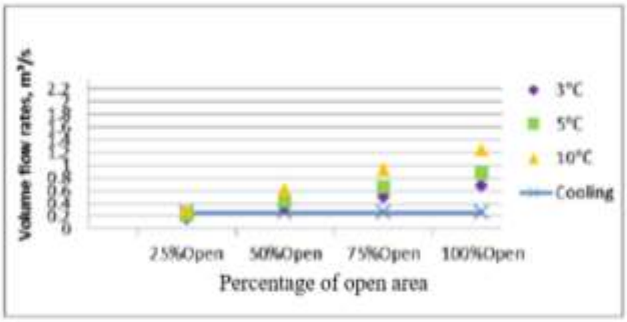

Figure 6: Cooling Effect in offices at cluster (C) with windows in East and West facing wall on room temperature and air volume flow rate (Field work, 2023).

- **Offices in Cluster (D)**

The cooling effect in office with window position on East and west wall panel on room temperature, rate and pattern of air flow with different percentage of open area as shown in Figure 7.

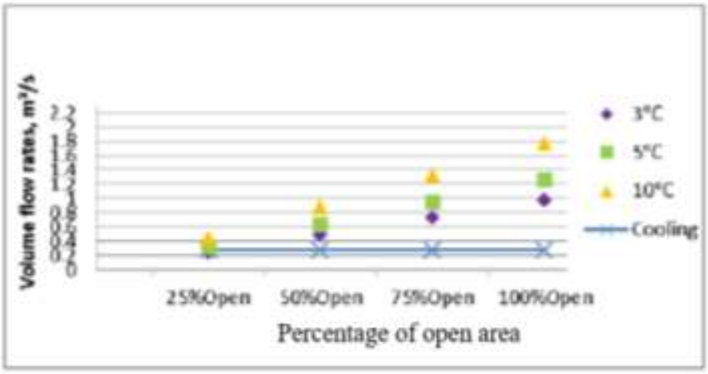

Figure 7: Cooling Effect in offices at cluster (D) windows in East and West facing wall on room temperature and air volume flow rate (Field work, 2023).

- **Offices in Cluster (E)**

The cooling effect in office with window position on East and west wall panel on room temperature, rate and pattern of air flow with different percentage of open area as shown in Figure 8.

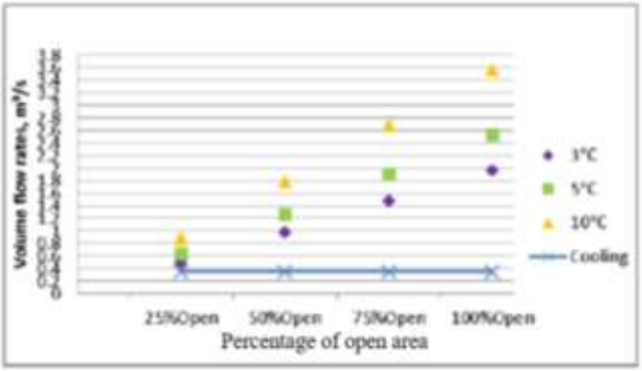

Figure 8: Cooling Effect in offices at cluster (E) with windows in East and West facing wall on room temperature and air volume flow rate (Field work, 2023).

4. Discussion of Results

The main goal of the study is to examine the potential for cooling load reduction and thermal comfort enhancement by using natural ventilation techniques in office buildings. Therefore, this paper reports on the investigation done using physical measurements and questionnaire survey to determine the effects of sustainable design strategies on energy performance in Prof. Chike Edozie secretariat office building in Asaba, Nigeria. Data on the indoor airflow were recorded through data loggers mounted in the purposively selected offices in use. While occupants comfort perception were obtained with questionnaire as shown in Table 1, and Figure 3. The variable measured comprises the indoor air temperature which is influenced by the air volume flow rates and Percentage of open area of window as shown in Figure 4, Figure 5, Figure 6, Figure 7, and Figure 8, respectively. When the wind and temperature are combined, the results show that change in temperature difference has a large impact on the air flow rate and pattern.

In warm humid climates, the exterior envelope components are the most significant contributors to the comfort parameters and the energy performance of the buildings (Adebamowo & Adeyemi, 2013 Atolagbe, 2014; Olanipekun, 2014). In this regard, natural ventilation are considered to be the main sources of cooling inside spaces. Therefore, using efficient design strategies can leads to an increase in indoor thermal comfort and a consequent reduction in ambient air temperatures that in turn results in energy saving by reducing cooling loads.

5. Conclusions

In particular, applying passive cooling strategies through opening of windows have proven to be very effective in maintaining indoor well-being, controlling heat dissipation, as well as reducing cooling demand. The analysis of variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the rates of air flows for the different office types thus: f=34.335; *p*=.000. The cooling effect in offices at cluster (A) had a maximum value of air volume flow rate at 2.4m/s^3; offices at cluster (B) air volume flow rate at 3.0m/s^3; offices at cluster (C) air volume flow rate at 1.4m/s^3; offices at cluster (D) air volume flow rate at 1.8m/s^3; offices at cluster (F) air volume flow rate at 3.6m/s^3.

The research recommendations are to improve the sustainable design of office buildings by effective opening of windows which renders optimal ventilation in single side ventilation and cross ventilation.

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