POST CONSTRUCTION EVALUATION OF WINDOW CHARACTERISTICS ON VENTILATION FOR THERMAL COMFORT IN SENATE BUILDINGS: A CASE OF NIGERIA UNIVERSITIES.

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Abstract: The purpose of ventilation is to provide fresh air for comfort and to ensure healthy indoor air quality. Natural ventilation has been argued to be an energy efficient alternative for reducing the energy use in building, for achieving thermal comfort and maintaining a healthy indoor environment. The study examines characteristics of windows in selected senate building of universities in South-West Nigeria. The study identifies the types, sizes and locations of windows of the purposive randomly selected buildings. Based on the survey results, it was found that 31.65% were oriented on South axis, while 23.32% were oriented on west axis, 10.82% were oriented on North-east axis, 9.17% are oriented on the North axis, 7.5% were oriented on North-West axis, 7.5% were oriented on East axis, 6.65% were oriented on South-West axis and 3.32% were oriented on South-East axis. In all the windows physically observed in the study area, 59.18% were poorly orientated. The study shows that only 40.82% of the spaces examined adequately took advantage of the prevailing wind and ventilation comfort in the study area, which is having their openings positioned on north and south walls. The study also showed that window height with respect to floor (sill height) of all the selected buildings were at the normal (0.9m). The study concluded that with adequate location (orientation, positioning and sizes of windows, casement type of window is best used to enhance natural ventilation in office buildings.

Keywords: Senate Buildings, Natural Ventilation, Wind, Casement, South-West Nigeria, Orientation.

Introduction: The purpose of ventilation is to provide fresh (or at least outdoor) air for comfort and to ensure healthy indoor air quality by diluting contaminants. Historically, people have ventilated buildings to provide source control for both combustion products and objectionable odors (Sherman, 2004). Accordingly, natural ventilation has been argued to be an energy efficient alternative for reducing the energy use in buildings, achieving thermal comfort, and maintaining a healthy indoor environment (Busch, 1992; Finnegan et al, 1994; Zhao and Xia, 1998; Allocca et al, 2003). In other words, the increased use of mostly fossil-based energy leads to atmospheric pollution and global warming. Typically, the energy cost of a naturally ventilated building is 40% less than that of an air-conditioned building. Willmert (2001) and Clarke (2001) observed that natural ventilation has become a new trend in building design in architectural community and has been used in many types of buildings, even in highly indoor climate controlled hospitals. However, Levermore, (2002) pointed out that natural ventilation can only be applied to certain climates and it has many limitations, noting that even, local noise and pollution level would limit the applications of natural ventilation. There are two main types of natural ventilation: cross and single-sided ventilation; large and thick building shapes, fire codes, security requirements, and privacy concerns often prevent the design of cross ventilation. Single-sided ventilation is more acceptable than cross ventilation, despite its lower efficiency (Allocca et al, 2003). Natural ventilation as a design and operating strategy can be effective in many climatic zones in the U.S. Unfortunately in Nigeria, though we are blessed with good climatic condition yet, natural ventilation system is currently underutilized in some office buildings. Consequently, drawing upon contemporary accounts of inner city asthma rates and cases of sick buildings, the building professions need more than cursory and inadequate guidance to incorporate indoor air quality considerations into their "healthy building" design. The intention of the scheme is not only to address housing shortage, but to emphasize the need to employ natural ventilation in design process. This will in great measure assist in saving energy and improve environmental quality through reduction of pollution generated by the mechanically driven ventilation in residential buildings. This is because, naturally ventilated building is crucial to improve indoor thermal comfort and consequently, remove the need for active thermal control for buildings. Global campaign against increasing demand for energy and consumption has gained tremendous interest of both policy makers and researchers. Consequently, studies abound on residential thermal comfort and the need to ensure adequately ventilated buildings to avert attendant effects ranging from health to environmental challenges (Givoni, 1994; Clinch and Healy, 2003; Akande and Adebamowo, 2010; Rajasekar and Ramachandraiah, 2010; Sakka, et al, 2010; Fang, et al, 2012; World Bank, 2012 and Bojić, et al, 2013. Issues raised by these studies include efficiency of mechanically driven ventilation, contribution of mechanical devices for thermal comfort to global warming and environmental changes, awareness of thermal discomfort in buildings under various environmental conditions, building energy simulations, effects of construction materials for optimum ventilation, subjective and experimental evaluation of thermal comfort characteristics among others. Nonetheless, succinct concern and investigation into conscious effort towards the utilisation of natural ventilation for thermal comfort and satisfaction in the design process of these buildings is not prominent, especially in the office buildings.

Among these studies, Rajasekar and Ramachandraiah (2010) did a comparative study of the thermal performance of buildings with respect to Fanger's extended adaptation theory and the constraints for adaptation like outdoor noise levels and their influence on the thermal comfort perception. The study concluded that factors like age, thermal expectation, economic status and past experience with thermal comfort play a significant role in determining the comfort perception. However, comfort and acceptability limits of environmental parameters under these conditions were evaluated on the basis of adaptive comfort theory only. The study focused on the coping strategy and occupants' coping capacity, but failed to consider the contribution of building design as a significant factor to achieve thermal comfort and measure of adaptability in office buildings which this study will explore. Furthermore, the study by Akande and Adebamowo (2010) and Haruna et al (2014) assessed the indoor thermal comfort for residential buildings in hot-dry climate of Nigeria and observed that more than 80% of the respondents found their thermal indoor conditions acceptable; though the thermal sensation votes exceeded acceptable thermal conditions set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers' standard (ASHRAE 55:2004). This was attributed to factors such as the types of clothing used in the tropics, poor building design, use of high heat emitting lighting devices, the size and insufficient number of window openings that can provide adequate ventilation in the residences and low level ceiling height. Hence, global attention has been on the increase on issues of energy demand and consumption, environmental sustainability, functional and quality building design, cost of building maintenance, thermal comfort, human healthy living and housing satisfaction among others (Rangsiraksa, 2006; Tablada et al, 2009; Kristian, and Tronchin, 2011; Taleghani, et al, 2012). Succinctly, the quality of lives of human beings to a very large extent depends on the quality of the indoor environments (Akande and Adebamowo, 2010). In other words, indoor thermal comfort is essential for occupants' well-being, productivity and efficiency (Haruna et al, 2014). However, there has not been much research work on window characteristic on ventilation in this warm humid climatic region like Nigeria. With this view, the study aims at post construction evaluation of window characteristics on ventilation for thermal comfort in senate buildings in South – West (Figure 1) Nigeria Universities. There is the need therefore, to achieve thermal comfort with minimum cost and sustainability in Senate buildings which is primarily attainable through natural ventilation. Thus, in line with this study, an attempt is made to provide answer to the following question: (i) How to locate and position windows? (ii) How windows should be oriented with respect to prevailing wind in relation to Nigeria climate?

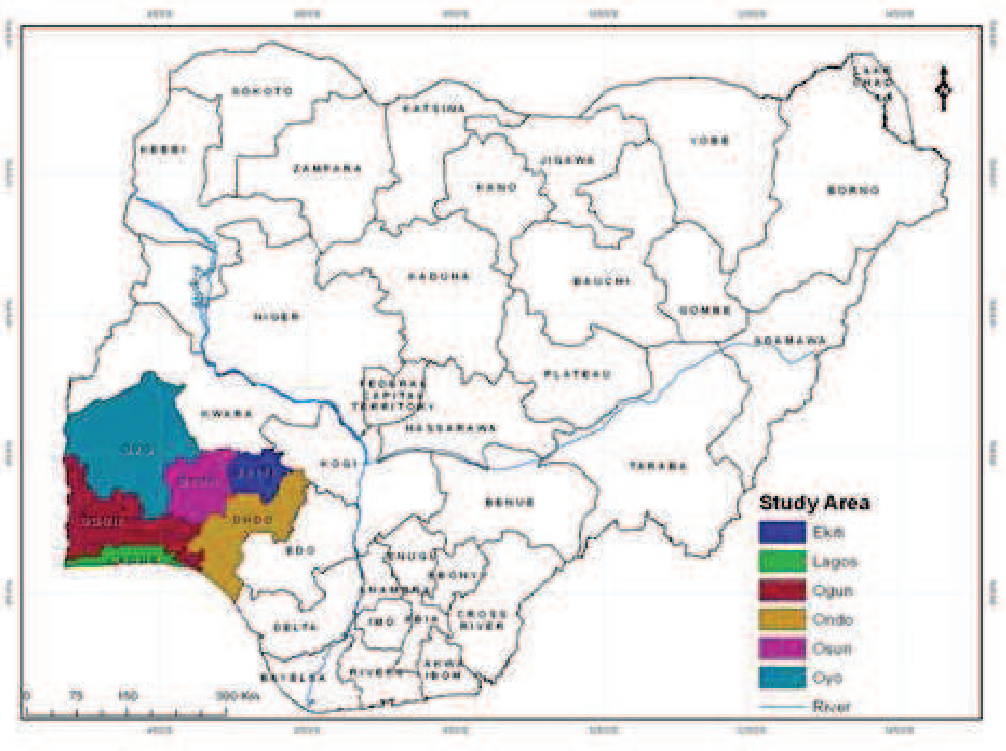


Figure 1: Map of Nigeria, showing South-West Nigeria

Literature Review: There are a lot of literatures on the influence of opening configurations on ventilation performance. They focus mainly on the opening combinations, area and relative locations, but rarely on the types of opening, i.e. the window types. For instance, Hassan et al (2007) investigated the effects of window combinations on ventilation characteristics in buildings by Computational Fluid Dynamics CFD simulation and wind-tunnel experiments; El-Agouz (2008) studied the effect of internal heat source and opening locations on natural ventilation. A conclusion was drawn that two openings with longer horizontal distance is better than shorter as far as single-sided ventilation performance is concerned. Furthermore, Evola and Popov (2006) analyzed the wind driven natural ventilation in buildings by CFD-based programs. Three opening configurations, single-sided ventilation with an opening on the windward wall, single sided ventilation with an opening on the leeward wall, and cross ventilation, were investigated. It was concluded that, when dealing with single-opening ventilation, positioning the opening on the leeward side will result in a larger ventilation rate inside the building than on the windward side. With respect to opening area for cross ventilation, Tantasavasdi et al (2001) found that, the ventilation performance is better with a larger inlet than with a larger outlet. It is noted that literature on opening configurations provided much information for the designers and researchers, but for window types, some are regarded as better than others just based on qualitative evaluation. However, little works have been done so far to evaluate the quantitative difference in ventilation performance for the use of individual window types. Heiselberg (2001) for example, investigated the characteristics of side-hung window and bottom hung window. It was concluded that, for the single-sided strategy and cross-ventilation strategy, the bottom hung window is better in winter as air needs to travel longer distance before reaching the occupied zone; while in summer, side-hung window is preferred to bottom-hung window in admitting enough air into the indoor space. Unlike the cold climate regions, the aim of ventilation in Hong Kong is season-independent. It is because, the climate in Hong Kong is hot summer and warm winter; thus, natural ventilation as an efficient approach to improve indoor air quality is often aspired to get more and window design that can incur more natural ventilation is always preferred. Moreover, window size determines the average wind speed flowing through the room and this effect varies, depending on whether the room is cross ventilated. In ventilated room, increase in the size of windows has a greater effect on average indoor air. Various guidelines for the determination of window sizes in warm humid climate have been proposed; hence, Energy Research for the Building code of Australia Vol.1 have prescribed the minimum opening (window) for natural ventilation in warm humid climate to be 15% of the floor area. Chand (1976) also recommended that the opening should be between 30 - 50% of the exposed wall area and between 20 – 30% of the floor area of the room.

Naturally Ventilated Building Design: During warm and hot weather periods, naturally ventilated buildings rely almost completely on wind to generate the required fresh air movement through the building. Building orientation is best determined using local wind patterns. To take advantage of warm weather winds, the building fenestrations should be perpendicular to the prevailing warm weather winds. In lieu of localized wind patterns, 'wind roses' can be used to position naturally ventilated buildings so as to take advantage of warm weather winds. Wind roses are the summaries of wind patterns and wind speeds for various weather stations across any country. Since winds generally shift between seasons of the year, it is important that patterns for summer winds be selected. The percent time of calm days is a very important parameter in relation to naturally ventilated buildings. Significant periods of calm days combined with warm temperatures result in inadequate fresh air entering the building and an unacceptable increase of inside temperature. (WHO,2009).

Advantages of Natural Ventilation: The use of natural ventilation is definitely an advantage with the raising concerns regarding the cost and environmental impact of energy use. Not only does natural ventilation provide ventilation (outdoor air) to ensure safe, healthy and comfortable conditions for building occupants without the use of fans, it also provides free cooling without the use of mechanical systems. When carefully designed, natural ventilation can reduce building construction costs and operation costs and reduce the energy consumption for air-conditioning and circulating fans. An additional bonus is that, no longer will any noisy fan be of concern and if well installed and maintained, there are several advantages of a natural ventilation system, compared with mechanical ventilation systems. Natural ventilation can generally provide a high ventilation rate more economically, due to the use of natural forces and large openings and can be more energy efficient, particularly if heating is not required. Also well-designed natural ventilation openings could be used to access higher levels of daylight. From a technology point of view, natural ventilation may be classified into simple natural ventilation systems and high-tech natural ventilation systems. The latter are computer controlled, and may be assisted by mechanical ventilation systems (i.e. hybrid or mixed mode systems) (WHO,2009). High-technology natural ventilation may have the same limitations as mechanical ventilation systems; however, it also has the benefits of both mechanical and natural ventilation systems. If properly designed, natural ventilation can be reliable, particularly, when combined with a mechanical system using the hybrid (mixed-mode) ventilation principle; although, some of these modern natural ventilation systems may be more expensive to construct and design than mechanical systems. In general, the advantage of natural ventilation is its ability to provide a very high air change rate at low cost, with a very simple system. The air-change rate can vary significantly, buildings with modern natural ventilation systems (that are designed and operated properly) can achieve very high air-change rates by natural forces, which can greatly exceed minimum ventilation requirements. However, there are a number of drawbacks to a natural ventilation system which include: It is variable and dependence on outside climatic conditions relative to the indoor environment. The two driving forces that generate the airflow rate (i.e. wind and temperature difference) vary stochastically. Natural ventilation may be difficult to control, with airflow being uncomfortably high in some locations and stagnant in others. There is a possibility of having a low air-change rate during certain unfavourable climate conditions. Also, there can be difficulty in controlling the airflow direction due to the absence of a well-sustained negative pressure; contamination of corridors and adjacent rooms is therefore a risk. Natural ventilation precludes the use of particulate filters. Climate, security and cultural criteria may dictate that windows and vents remain closed; in these circumstances, ventilation rates may be much lower. However, natural ventilation only works when natural forces are available; when a high ventilation rate is required, the requirement for the availability of natural forces is also correspondingly high. Furthermore, natural ventilation systems often do not work as expected, and normal operation may be interrupted for numerous reasons, including windows or doors not open, equipment failure and utility service interruption (if it is a high-technology system), poor design, poor maintenance or incorrect management. Although the maintenance cost of simple natural ventilation systems can be very low, if the system is not installed properly or maintained due to a shortage of funds, its performance can be compromised, causing an increase in the risk of the transmission of airborne pathogens. However, these difficulties can be overcome, for example, by using a better design or hybrid (mixed-mode) ventilation. Other possible drawbacks such as noise, air pollution, insect vectors and security also need to be considered. Because of these problems, natural ventilation systems may result in the spread of infectious diseases through health-care facilities, instead of being an important tool for infection control.

Classification of Natural Ventilation: Natural ventilation may be classified into two; these are wind driven ventilation and stack ventilation.

(i) **Wind Driven Ventilation (Figure 2):** Wind driven ventilation or roof mounted ventilation design in buildings provides ventilation to occupants using the least amount of resources. Drawbacks include the use of equipment that is high in embodied energy and the consumption of energy during operation. By utilizing the design of the building, Wind driven ventilation takes advantage of the natural passage of air without the need for high energy consuming equipment. Wind catchers are able to aid Wind driven ventilation by directing air in and out of buildings.

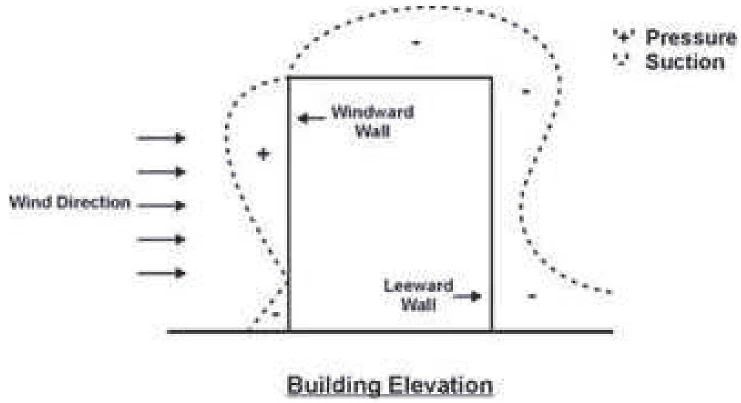


Figure 2: Wind Driven Ventilation
(Source: Etheridge & Sandberg, 1996; Awbi, 2003)

(ii) **Stack Driven Ventilation (Figure 3):** Buoyancy ventilation can be induced by temperature (known as stack ventilation) or by humidity (known as cool tower). Most commonly used is the stack driven ventilation. For stack ventilation to work properly there must be a temperature difference. However, stack driven ventilation is limited to a lower magnitude than wind driven ventilation. It is also very dependent on the inside and outside temperature differences.

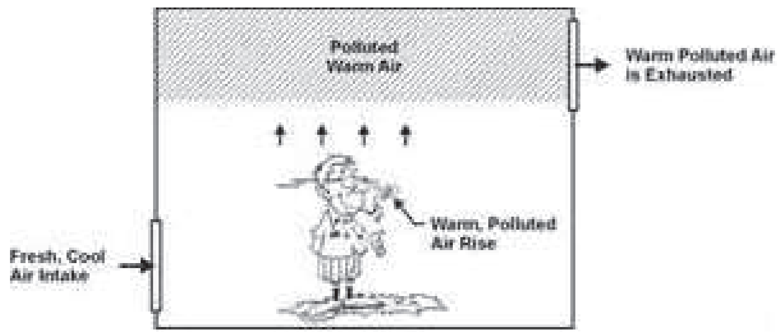


Figure 3: Stack Ventilation
(Source: Etheridge & Sandberg, 1996; Awbi, 2003)

Research Methodology: The research adopted four principle methods namely literature review, questionnaire survey, Interview and case study for this study. A thorough literature search for either primary sources or secondary sources was conducted through academic research Journals, proceedings, dissertations, occasional papers, publications, textbooks, newspapers and online data base. Data from Primary source were collected with help of research instruments such as reconnaissance survey, personal interviews and administration of questionnaires among others. Referring to previous work also enables the author to grasp the problems and issues related to the topic of the study. Preliminary investigation of the existing Senate Building in the study area was considered. This enable the researcher to get familiarize with the study area. This however helped to examine the situation in the study area. Users from the study area were interviewed in the area of natural ventilation in the built Senate Building from the Study area and their Subjective feeling to Senate Building in general. Questionnaire was designed to obtain information on social-economic, characteristics of the respondent and building characteristic adequacy of natural ventilation in the Selected Senate Buildings and as well as the user's perception with regards to preferred window types. It will also assist to solicit information on subjective feelings of the occupants of the selected Senate buildings on the effects of openings on their body comfort. These data also include the capacity spaces and offices of the four Senate Buildings. Direct observation was also carried out to obtain information on physical Characteristics of the Selected Senate Building. Twenty Five users were sampled in each of the Selected Senate Buildings. There are twenty one (21) Senate Buildings in the Universities in South-West Nigeria. This represents the sampling frame. The study randomly selected twenty percent (20%) of the sample frame given a sample size of four (4). In each of the Selected Senate building, twenty five users were randomly selected for questionnaire administration. A total of 100 questionnaires were therefore distributed in the study area.

Objective: To identify types, size and location of windows in the study area.

Type of Data Used: A primary data in the form of window characteristics (types, size, location).
The use of questionnaire and physical observation were employed to obtain information on the types of window, sizes and location of windows in the Selection Senate Buildings in the study area. Frequency counts inform of Cross Tabulation was used to examine variation in the Window characteristics of the selected Senate Building in the Study Area. This was done by physical observation of the size, types, orientation and location of windows. Frequency table was for analysis to determine the suitable window characteristics for office building.

Analysis and Discussion of Results: Data collected were analyzed using Statistical Package for Social Sciences (SPSS version 26). This analysis includes descriptive and inferential analysis to explain the information that suits the objectives. Descriptive analysis adopted in the study include, the use of cross tabulation, frequency count and percentage tables as well as graph presentation. All these were used to analyze the socio-economic characteristics of respondents such as gender, age marital status, and educational status among others. There are several Offices in the selected Senate buildings. This represents the sampling frame. The study purposefully selected typical offices, Registrar Office and Vice-Chancellors office. The typical office was selected because it constitutes the largest number in the selected senate building. The Registrar office and Vice-Chancellor's office was selected because they have another type of orientation unlike other offices; in terms of location of windows, number of windows, sizes of windows, floor area and wall area.

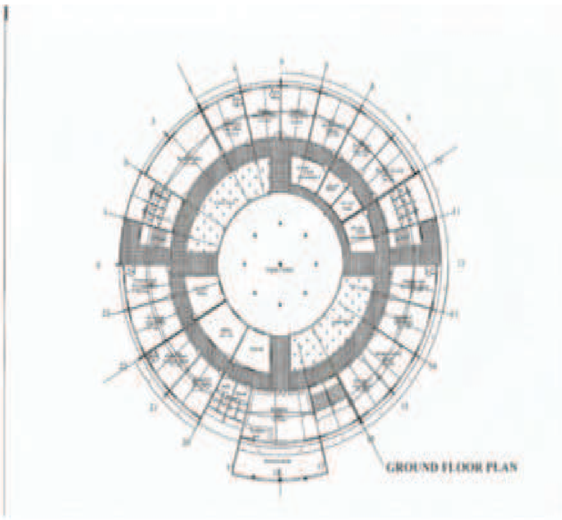
Definition of Variables:
1. Typical Office – Typ. Off.
2. Registrar's Office- Reg. Off.
3. Vice- Chancellor's Office- V.C's Off.
4. Sectary to Vice- Chancellor's Office - Sec. to V.C's Off.

Observed Senate Buildings:

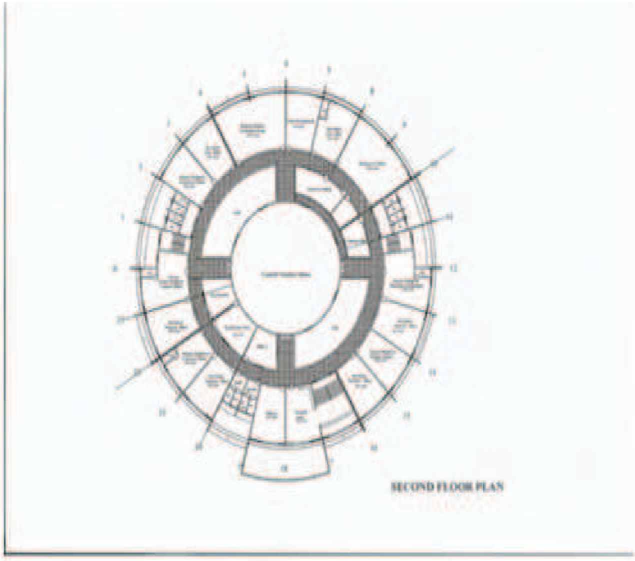
Picture showing the UNILAG Senate Building
Source: Author's Field Survey, 2017

Approach Elevation of the OAU Senate Building.
Source: Author's Field Survey, 2017

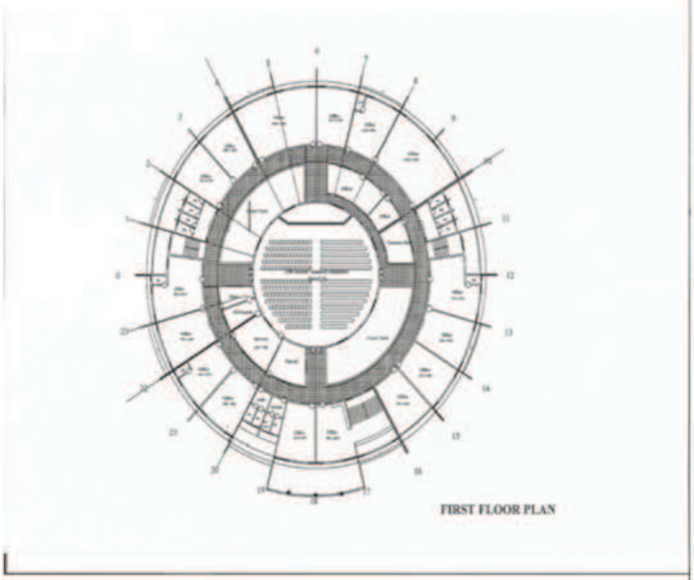
Approach view of LAUTECH Senate Building
Source: Author's Field Survey, 2017



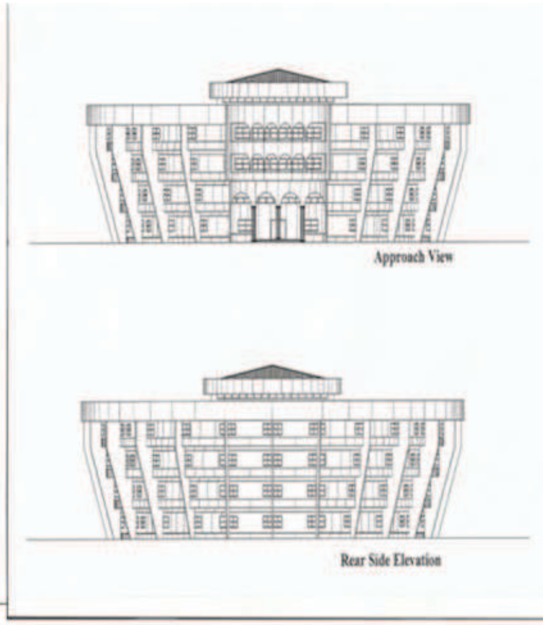
Showing the Ground floorplan of LAUTECH Senate Building
Source: Author's Field Survey, 2017



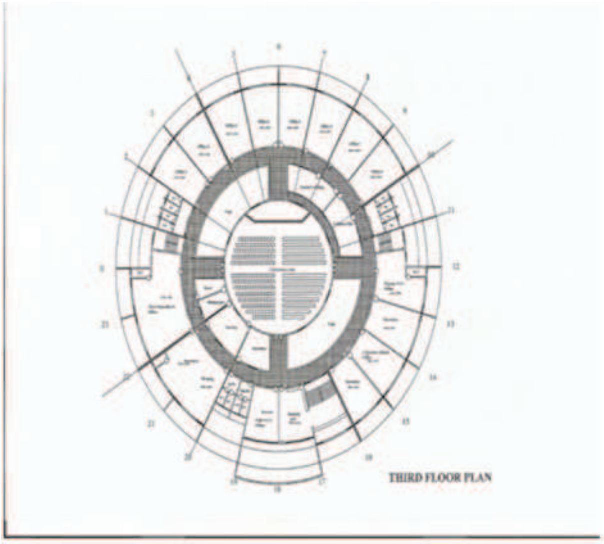
First Floor Plan of LAUTECH Senate Building
Source: Author's Field Survey, 2017



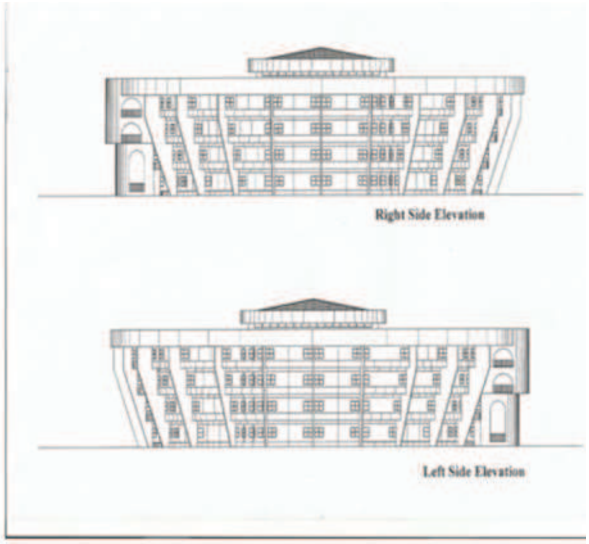
Second Floor Plan of LAUTECH Senate Building
Source: Author's Field Survey, 2017



Approach and Rear Elevation of LAUTECH Senate Building
Source: Author's Field Survey, 2017



Third Floor Plan of LAUTECH Senate Building
Source: Author's Field Survey, 2017



Right and Left side Elevation of LAUTECH Senate Building
Source: Author's Field Survey, 2017

Table 1: Types of Window Used

	Windows types											
	Louvre Window			**Projected Window**			**Sliding Window**			**Casement**		
Selected Senate Building	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**
OAU				96	2	2						
LAUTECH							101	2	2			
UI				23	2	2				36	2	2
UNILAG	35	2	2							96	2	2
TOTAL	35	2	2	119	4	4	101	2		132	4	4
GROUND TOTAL	39 (9.5%)			127 (30.0%)			105 (25.5%)			140 (34.0%)		

Source: Author's fieldwork, April 2017

Table1 reveals the distribution of window types in the study area. Most of the windows in the study area are projected window. The table revealed that One hundred and Forty (34.0%) of the windows were casement type, One hundred and twenty seven (30.0 %) were projected, one hundred and five (25.5%) were sliding; while thirty nine (9.5%) were louvered type. Each university has their peculiar usage of window type. The result shows that when proposing for window type, projected and casement should be considered in constructing senate building. Thus, the result analysis shows that casement is highly acceptable because of it is open to strong blast of wind (Table 1). However, this result supported the outcome of the research done by Iannone and Adebamowo in 1999 and 2004 respectively.

Table 2: Orientation of Window

	OAU (%)	LAUTECH (%)	UI (%)	UNILAG (%)	TOTAL	TOTAL AVERAGE (%)
WEST	20	20	53.3	0	93.3	23.32
NORTH	20	0	16.7	0	36.7	9.17
SOUTH	20	0	23.3	83.3	126.6	31.65
N-E	20	20	0	3.3	43.3	10.82
N-W	20	0	0	0	30	7.5
EAST	0	20	3.3	6.7	30	7.5
S-W	0	0	3.3	3.3	26.6	6.65
S-E	0	0	0	3.3	13.3	3.32
TOTAL					400	100

Source: Author's fieldwork, April, 2017

Another area to look at in this research work is the location of window in different universities selected in the study areas. Climatic analysis of Abeokuta reveals that the openings should be in the north and the south walls to take advantage of the prevailing winds and also to exclude solar penetration of the indoor spaces. However, orientation of building in the study area (Table 2) reveals that out of the four (4) senate buildings surveyed, 127 windows representing 31.65% were oriented on South axis, while 94 windows representing 23.32% were oriented on west axis, 44 windows representing 10.82% were oriented on North-east axis, 37 windows representing 9.17% are oriented on the North axis, 30 windows representing 7.5% were oriented on North-West axis, 30 windows representing 7.5% were oriented on East axis, 27 windows representing 6.65% were oriented on South-West axis and 14 windows representing 3.32% were oriented on South-East axis. In all the windows physically observed in the study area, 59.18% were badly orientated. The Implication of this is that only 40.82% of the spaces examined adequately offered ventilation comfort. This result is related to the recommendation of Ayinla, 2011 and 2013.

Table 3: Window Location (Sill Height)

	Window Location (Sill Height)											
	0.00-0.90			**0.91-1.20**			**1.21-1.50**			**1.51-1.80**		
Selected Senate Building	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**	**Typ. Off.**	**Reg. Off.**	**V.C's Off.**
OAU	21	2	2									
LAUTECH	21	2	2									
UI	21	2	2									
UNILAG	21	2	2									
TOTAL	21	2	2									
GROUND TOTAL	100 (100%)											

Source: Author's fieldwork, April 2017

The location of opening along the height of the wall is defined by the height of the window sill. However the air passing through a window of a given size of wall depends largely on the location of that window on the height of the wall. The effectiveness of the window location on the wall depends on the task expected of the indoor space in which the wall encloses. Table 3 reveals that the all the windows in the selected Senate Building satisfy the window location (sill height) requirement of 0.90m height. The implication of this is that the required air movement expected at the occupied zone would be effective ventilation comfort if other factors are considered.

Conclusion: The study identifies the types, sizes and locations of windows of the purposive randomly selected buildings. Based on the survey results, it was found that 31.65% were oriented on South axis, while 23.32% were oriented on west axis, 10.82% were oriented on North-east axis, 9.17% are oriented on the North axis, 7.5% were oriented on North-West axis, 7.5% were oriented on East axis, 6.65% were oriented on South-West axis and 3.32% were oriented on South-East axis. In all the windows physically observed in the study area, 59.18% were poorly orientated. The study shows that only 40.82% of the spaces examined adequately took advantage of the prevailing wind and ventilation comfort in the study area, which is having their openings positioned on north and south walls. The study also showed that window height with respect to floor (sill height) of all the selected buildings were at the normal (0.9m).

Recommendations: The study concluded that with adequate location (orientation, positioning and sizes of windows, casement type of window is best used to enhance natural ventilation in office buildings like Senate building. This study also informs the policies makers about orientation and shape of the office buildings to enhance the natural ventilation.

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