POST CONSTRUCTION ASSESSMENT OF THE EFFICIENCY OF THERMAL COMFORT WITHIN SPACES IN RESIDENTIAL BUILDINGS: A CASE OF GOVERNMENT HOUSING ESTATES IN NIGERIA

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Abstract: Natural ventilation is created and generated by pressure differences between the outside and the inside of the building; this pressure difference may be wind-driven or due to air temperature difference. The study assesses the efficiency of thermal comfort within the living room and bedrooms in the residential buildings in South-West Nigeria. Givoni Mathematical model was used to calculate the indoor air velocity and data obtained were analysed using descriptive statistics. Givoni empirical model indicated that none of the spaces investigated (living room and bedroom) satisfied ventilation comfort standard of between 0.5-1.5m/s for warm humid climate. The highest Thermal comfort was obtained in buildings with casement window with indoor air velocity of 0.40m/s while the worst thermal comfort was found in buildings with sliding windows having 0.21m/s indoor air velocity. The study concluded that with the use of casement and louver window types placed on a sill height of 0.9m, thermal comfort can be improved in residential buildings.

Keywords: Living room, Bedroom, Casement, Louvre, Air Velocity, residential buildings, thermal comfort, South-West Nigeria.

Introduction: As important as housing is, the incidence of urban population increase has created severe housing problems, resulting in overcrowding and inadequate dwellings and in a situation in which 60% of Nigerians can be said to be homeless (Federal Government of Nigeria, 2004; Olotuah and Ajenifujah, 2009). Rapid population growth creates problems toward adequate and efficient supply and distribution of basic utilities and services for the city inhabitants. The situation has become so pathetic such that, overcrowding, slum and substandard housing as well as unhealthy and poor environmental conditions are expressions of this problem. Thus, access to decent housing has become a challenge worldwide, especially in developing countries (Abotutu, 2006). Housing provision in most nations of the world is made through a blend of public and private sector initiatives; Nigeria is not an exemption to this development. For instance, it has been observed that about 80% of the available housing stocks in Nigeria are provided by private sector initiatives, while only 20% of them are public sector housing (Ademuliyi, 2010). As a package of shelter and services, housing is a veritable tool for macro-economic development. Agbola and Olatubara (2007) noted that the performance of the housing sector is the barometer for measuring the health or ill - health of a nation. In other words, the derivable satisfaction of a housing unit by the occupier in terms of the serviceability such as lighting, ventilation, acoustics, vibration, aesthetics, comfort, and security, along with safety and ergonomic design factors among others cannot be downplayed in the attainment of a functional housing delivery system.

However in Nigeria, limited research has been done on the efficiency of windows in residential buildings. This study therefore looks at the efficiency of ventilation in order to achieve thermal comfort with minimum cost and sustainability in residential buildings which is primarily attainable through natural ventilation. In addressing the ventilation efficiency in the study area, the following research questions address the window conditions:

1. What are the types of windows in use in Government housing Estate of South-West Nigeria?
2. What area the present conditions of windows for ventilation comfort in the study area?
3. At what level are the windows in use in the study area?

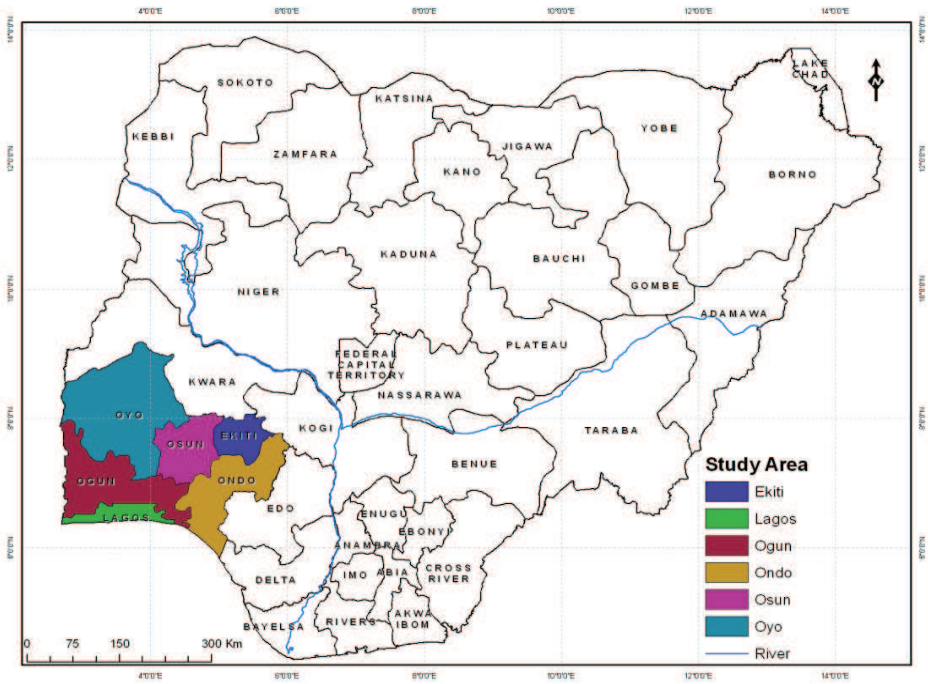

Figure 1: Map of Nigeria, showing South-West Nigeria

Literature Review:

Building Openings: There are a lot of literature 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.

In the 1960s Givoni conducted another thorough set of wind tunnel studies using a uniform wind tunnel. Many of the findings can be found in Givoni [1976]. But many more interesting findings regarding airspeeds in building groups and buildings with courtyards, methods to cross ventilate double-loaded corridors, and building layout for apartment buildings to enhance ventilation are only cited in the original research report by Givoni [1968]. Givoni demonstrated the usefulness of adjacent windows. He found that rooms with windows on adjacent walls ventilated better than traditional cross-ventilated rooms with windows on opposite walls when the incident wind angle was perpendicular to the inlet. At oblique wind incidences (45° incidence angle to inlet) traditional cross-ventilated rooms performed better than rooms with adjacent windows. The estimation of room air change rates, average room surface temperatures and room air temperatures enables one to predict the cooling or heat removal rate for natural ventilation. However, it is very important to note that the room air change rate may not be related to air flow rates through the openings. Consider normal wind incidence and windward and leeward openings directly in line with one another. Depending on the ratio of the areas of opening, the air can rush through without significantly mixing and entraining room air. As a result, little heat will be removed and circulation in many parts of the room will be poor. Staggered windward and leeward openings that force the air to turn are better for ventilation. For similar reasons, winds at an oblique rather than normal incidence provide better cooling if the apertures are not staggered [1980]. In the 1960s Sobin conducted another comprehensive wind tunnel study at the Architectural Association (London). Sobin was the first to use a boundary layer wind tunnel for natural ventilation studies. A boundary layer wind tunnel differs from the uniform speed wind tunnel used in aeronautical studies in that the former simulates both the variation of wind speed with height and the natural turbulence of the wind. Sobin published some of his findings in 1981. Sobin investigated many interesting window types and measured room airspeeds both in section and plan. One of his most interesting findings relates to window shape. He found horizontal windows (windows that are wider than their height) created greater wind speeds than vertical windows (windows that are higher than their width). This effect was more pronounced for oblique wind incidences. It is interesting to note that Givoni's apertures were also horizontal and he also found good performance at oblique wind incidences. Aynsley et al. [1977] continued airspeed measurements in a building with wind scoops. Insect screening is a necessary consideration in ventilation in many parts of the world. Givoni [1976] found that screening entire balconies produced greater airspeeds in rooms than did screening the windows. Van Straaten [1967] measured the decrease in airflow caused by screens and found that it was dependent on the incident wind speed. For a 1.5 mph (0.7 m/s) wind, the airflow was reduced by 60%, whereas in a 6 mph (2.7 m/s) wind the reduction was only 28%. This difference is possibly due to the reduction of the wake region behind a cylinder as the Reynolds number increases. Internal airspeeds can only be predicted by solving the three-dimensional turbulent flow equations, a difficult task that has been attempted by only a few [1974], [1984]. White of Texas A&M [1954] investigated airflow reductions caused by landscaping elements such as trees and hedges. He also discovered using solid paper and landscape moss models of trees and hedges, that certain landscaping schemes are advantageous for increasing ventilation in building [1979].

Research Methodology: Givoni, (1976) Mathematical model was used to calculate the indoor air velocity of the spaces investigated. The data required are window characteristics and the wall area as well as the floor area. The data collected are both primary and secondary. The primary data is informed by physical observations to get the floor area and the window area. The secondary data is in form of chart, gotten for journals to get the indoor air velocity. Givoni, (1976) Mathematical model was used to compute the corresponding indoor velocity of the spaces under consideration; window sizes as well as the area of both the floor and the wall were considered. There are several spaces in the selected residential buildings. This represents the sampling frame. The study purposefully selected living rooms and bedrooms in the selected residential buildings. The spaces were selected because they constitute the largest number in the selected residential buildings.

Objective: To analyze ventilation Efficiency of openings in the Study Area.

Data Analysis: The data obtained from the study were analysed with frequency counts and percentages. Givoni mathematical model was used to measure the efficiency of ventilation in relation to window openings and floor area of the building. The mathematical model is an empirical one that is based on simplified methods for the estimating of air velocity inside naturally ventilated buildings. Thus, the method was chosen because it is used to measure the efficiency of natural ventilation in warm humid climate. The model established the relationship between average indoor and outdoor air velocity with the window placed perpendicularly to each other and the formula is $\mathbf{V_i = 0.45\ (1\text{-}exp^{-384x})\ V_o}$

Where: V_i average indoor velocity

x is the ratio of window area to wall area

V_o is the outdoor wind velocity.

Note: For Ventilation comfort in warm Humid Climate Indoor air velocity should be within the range of 0.5-1.5m/s (Ayinla,2011)

Case Study 1: The Nest, Organic City.

PARROT as 2 bedroom bungalow with the followings:

Lounge -19sqm

Dinning -9sqm

kitchen -7sqm

bedroom(ensuite) -12sqm

toilet -2.7sqm.

Source: Author's Fieldwork, (2014).

Figure 2.4: 3 Bedroom Floor Plan

DUCK as 3 bedroom bungalow with the followings:

Lounge / Dinning -22sqm,

kitchen/Store-10sqm,

Master's bedroom & Toilet-16sqm, bedroom & toilet-14 sqm.

Source: Author's Fieldwork, (2018).

Figure 2.5: 4 Bedroom Floor Plan.

HAWK as 4 bedroom bungalow with the followings:
Ante Room -6.5sqm
Lounge & Dinning-34sqm
kitchen & Store-11sqm
Master's bedroom & Toilet -24sqm
bedroom & toilet (average) -18sqm
Car port -15sqm,

Source: Author's Fieldwork, (2018).

Figure 2.6: Ground & First floor Plan of 3 Bedroom Terrace apartment.

Source: Author's Fieldwork, (2018).

Figure 2.7: Ground & First floor Plan of 4 Bedroom duplex.

Source: Author's Fieldwork, (2014).

Window Types Used in the Study Area:

Casement Window Type

Projected Window Type

Louvered Window Type

Assessment of the Ventilation with Givoni Empirical Model:

a) Window Sill.

Table 3.14: Window sill of Living room and Bedroom

Living room and bedroom's sill height (m)	Frequency (N)	Percentage (%)
0.0 -0.9	25	15.3
0.9	63	38.7
0.9 above	75	46.0
Total	**163**	**100**

Source: Author's Fieldwork, (2018).

Table 4.14 revealed that (15.3%) of building assessed have their window sill level below 0.9m,while (38.7%) have theirs to be exactly 0.9m from DPC. The implication is that, the required air expected at the occupied zone would be effective for ventilation comfort but table 4.9 shows that most of them were wrongly placed on the wall. Also 46.0% of buildings have their window sill level above 0.9m and the implication is that the required air for effective ventilation within the occupied zone not visible.

(b) Window Types

Table 3.7: Window Type

Type	Frequency (N)	Percentage (%)
Louver	51	31.0
sliding	17	10.5
Casement	59	36.5
Projected	36	22.0
Total	**163**	**100**

Source: Author's Fieldwork, (2015).

Out of the respondents that utilised window, casement window constituted (36.5%) while louver blade was (31.0%). Also, projected window type was (22.0%), with sliding window being (10.5%) as shown in table 3.7.

c) Average value of indoor air velocity in the living room (LR) and bedroom (BR) spaces during afternoon period.

$$V_i = 0.45\ (1\text{-}exp^{-384x})\ V_o$$

Where: V_i average indoor velocity,
x is the ratio of window area to wall area,
V_o is the outdoor wind velocity
Where V_o = 0.52 m/s (Average of Five years data(2000-2004) of outdoor wind velocity of Ibadan

Table 1: Yearly mean wind speed, standard deviation and wind power in Ibadan between 1995 and 2004 (IITA)

Year	V_m	σ	P (kW)
1995	0.95	0.24	0.65
1996	1.21	0.23	1.35
1997	1.10	0.26	1.01
1998	0.92	0.42	0.59
1999	0.83	0.42	0.43
2000	0.81	0.36	0.40
2001	0.46	0.26	0.07
2002	0.40	0.26	0.05
2003	0.41	0.27	0.05
2004	0.53	0.23	0.11
Yearly	0.76	0.30	0.33

where V_m is mean wind speed and σ is the standard deviation.

Source: K.O Rauff and E.f Nymphas,2016

Average Indoor Air Velocity:

Window type	Reference window area (m^2)		Reference wall area (m^2)		Window / wall area ratio (x)		Average indoor air velocity V_i (*m/s.*)	
	LR	BR	LR	BR	LR	BR	LR	BR
Louver	1.62	1.44	8.10	7.20	0.20	0.20	0.33	0.33
Sliding	1.80	1.44	20.0	6.86	0.09	0.21	0.21	0.35
Casement	2.16	1.44	10.30	7.20	0.21	0.20	0.40	0.33
Projected	2.16	1.44	9.53	7.20	0.17	0.20	0.35	0.33

Source: Author's Fieldwork, (2018).

Table 3.15 explains average indoor velocity of the assessed buildings using the Givoni empirical model in reference to the window type respectively. Average ventilation obtained in buildings with louver, casement and projected window type is 0.33m/s, 0.40m/s and 0.35m/s respectively while the least gotten in the living room is 0.21m/s with sliding window type. Considering both living room and bedroom spaces the implication of those values according to Givoni empirical model shows that none of the spaces satisfied ventilation comfort standard of between 0.5-1.5m/s for the warm humid climate.

Conclusion: Physical observation of the windows types and location in the selected residential buildings revealed that 59 (36.5%) of the windows used were casement type; 51(31.0%) were louvered type; 36(22.0%) were projected type while 17(10.5%) were louvered type. The study further showed that the highest indoor air velocity occurred in bedrooms where casement window type was largely adopted with indoor air velocity of 0.40m/s and the lowest occurred in living rooms where sliding windows were used with an indoor air velocity of 0.21m/s. However, this research has gone ahead in solving more that the persisting problems of ventilation and space in residential buildings. Location and placement of windows problems were also solved.

Recommendations: The study hereby recommends that with adequate location and sizes, casement window type is the best for residential building designs and for thermal comfort. This study also informs the policies makers about orientation and location of windows of residential buildings to enhance the natural ventilation.

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