Innovations

Evaluation of Sustainable Design and Wind Induced Ventilation in Warm Humid Climate in Nigeria

Chime Charles C[1]., Oniovokukor Rukevwe R[2]

[1]Department of Architecture, Delta State University of Science and Technology, Ozoro, Nigeria
[2]Department of Building Maintenance, Delta State Ministry of Housing, Asaba

Abstract

The key aspect of sustainable design is to achieve natural ventilation through efficient utilization of wind, and maintain body heat balance in the house with little or no expenditure of energy in warm humid climate zone. One of the cardinal attributes of habitability in a house, and indeed any built form in the warm-humid climate zone is effective natural ventilation, or the ability to maintain a constant indoor air flow for residents' living comfort, even in the face of wind fluctuations. This paper describes and summarizes the results of a series of wind measurements that is performed on different window openings to determine the characteristics of the air flow in rooms.

The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the wind induced ventilation of different window openings in rooms. Therefore sound knowledge of performance of wind induced ventilation is necessary for efficient design of window opening in buildings. Recommendations were made for architects and designers to identify and use the effective window openings to improve wind induced ventilation and achieve sustainable building design.

Keywords: *Indoor Air flow, Sustainable design, Warm humid climate, Wind induced ventilation, and Window openings*

1. Introduction

The warm-humid climate zone in Nigeria is located in southern part of the country. The region has 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 southwest monsoon wind and then North-east trade wind. Annual rainfall in the area is up to 2500mm with double peak rainfall regime which takes place both in June and September. Annual average temperature is about 27^{0}C 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). This is the region in which 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 electric energy facilities by the use artificial ventilation (Diogu & Okwonkwo, 2005). Energy is now considered a serious economic and sustainability issue in the built environment (Dahiru, Abdulazeez & Muawiyya, 2010). Baker and Steemers (2000) stated that heat loss to the environment occurs predominantly by three mechanisms (radiation, convection and evaporation) and to a much lesser extent by conduction. Heat transfer between human body and its surrounding in a normal comfort condition can be influenced by breeze. Szokolay (2004) pointed out that most conventional windows provide some control of breeze. This is the simple opening that lets air come in but doesn't give it direction. With a simple opening, the direction of the incoming breeze is determined by the location of the inlet (window) in the windward fenestration. In the case of warm-humid climate zone location of the window to the prevailing breeze is paramount.

2. Literature Review

Natural ventilation is influenced by several environmental conditions, the most unpredictable being wind velocity, both its speed and its direction. Both of these factors are difficult to control and analyse, especially in a building. In the actual environment, instantaneous wind speed varies with time, and the pressure difference varies with building geometry and location on the building surface. In most wind-driven natural ventilation experiments a constant, uniform wind speed is used. These design wind speeds are often the mean wind speeds for a given location over a specific period, often years or decades (NBC, 2006; Anunobi et al., 2015, Allard, 2002).

Wind induced ventilation

Ventilation can be induced solely by the action of the wind on the surface of the building, around the location of any openings in the building envelope as shown in Figure 1 (Evans, 2010).

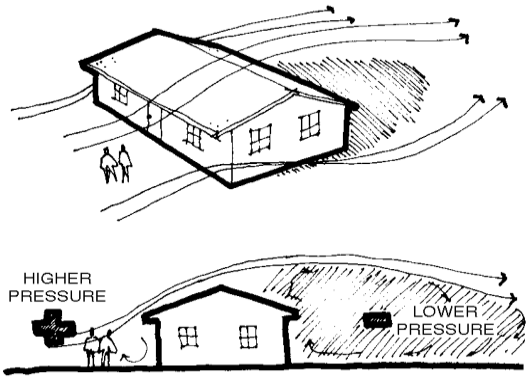


Figure 1: Aerodynamics around building (Evans, 2010)

The nature of the pressure distribution and the momentum of the incoming wind around the structure drive this form of ventilation. Assuming no fluctuations in the incoming wind, flow is induced by the difference in mean pressures between the building faces containing openings. From the pressure distributions for a simple structure, air flows in through the openings located on the windward face and out of those on the leeward face. Vickery and Karakatsanis (1987), state that for free wind speeds exceeding (approximately) 1.8 ms-1, thermal buoyancy can be neglected. Hence the assumption that temperature effects are negligible here is valid in many cases (this include greenhouses located in warm humid climates). There are several equations that have been developed to describe pressure difference due to wind-driven flow. The equations below describe a case with a constant wind speed creating a situation where wind pressure does not fluctuate with time.

Wind pressure, $P^{w} = ½\ P\ V^{2}$ ……………………… (1)

Where P = air density,

V = wind velocity in ms $^{-1}$.

However, for single-sided ventilation fluctuations in wind speed may be important. A diagram portraying wind-driven ventilation, the airflow direction and resulting pressure versus height is presented in Figure 2(a). If the openings on opposite sides are identical, the pressure differences across the openings are equal to half the pressure difference across the building when it is assumed that there is negligible pressure differential through the interior of the building. The Bernoulli equation applied between a point at some distance from the face of the building containing the window and the facade then reduces to the ideal equation (Straw, 2000).

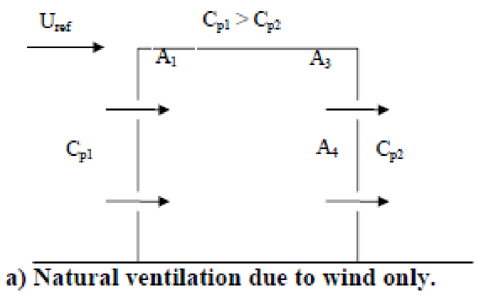


Figure 2: natural ventilation of a building by the dominant driving forces (Straw, 2000)

Where:

A_1 = inlet opening area (m^2)

A_2 =outlet opening area (m^2)

$Cp1$ = windward pressure coefficient

$Cp2$ = leeward pressure coefficient

θ = wind angle (°)

U_{ref} =reference wind speed (velocity at building height – m/s)

Geometry of window opening

Window size and shape are important factors that determine the air flow pattern within buildings. Shape and size of window also influence the internal wind speed. For a given window size, horizontally, square and vertically shaped inlet window openings yield different internal air motions. The ratio of the inlet to outlet determines the speed of the airflow Figure 3, (Heiselberg, Bjorn, & Jensen, 2002a; Elvans, 1999). Window-to-Wall ratio (WWR) also known as window area is considered as a very important parameter affecting window performance in a building (NBC, 2006). WWR is usually measured as the percentage area determined by dividing the building's total glazed area by its exterior envelope wall area. A proper selection for the optimal area of the glass and applying natural ventilation system can increase the effect of window air flow rate in reducing the indoor air temperature (Hazim 2010; Anunobi et al., 2015; NBC, 2006; CIBSE, 2006).

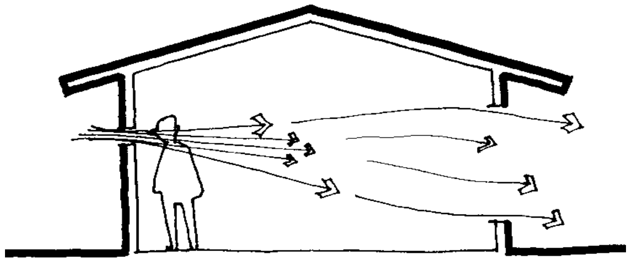


Figure 3: The effect window shape and size (Evans, 1999).

Position of window

In considering the selection of window types for a building, the main issue is the position of the windows. The potential of the air flow penetration through windows in buildings, and its effect on the indoor temperature, depends greatly on the location of the windows as shown in Figure 4.

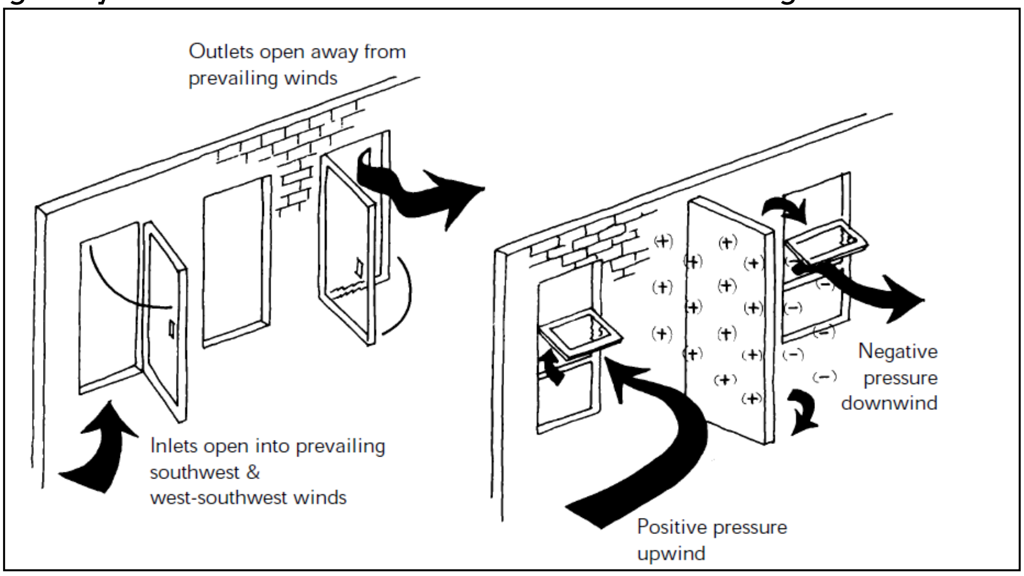


Figure 4: Orientation of Window to Prevailing Breeze (GBD, 1999)

In the case of warm-humid climate zone the location of the window to the prevailing breeze is paramount. Szokolay, (2004) pointed out that most conventional windows provide some control of breeze. This is the simple opening that lets air come in but doesn't give it direction. With a simple opening, the direction of the incoming breeze is determined by the location of the inlet (window) in the windward fenestration. With a horizontal vane window, the air will follow the direction of the window vane-up or down. The sideways direction of the breeze is still a function of the position of the inlet in the windward wall. With a vertical vane window, the air can be directed right or left. Again, the up or down pattern will be determined by the position of the inlet in the windward wall. To allow the occupant to direct the incoming breeze, the designer should provide for the appropriate choices in the aperture type. Cross-ventilation is optimum in rooms with window openings in three different facade but such configuration is not common (Hazim, 2010; Anunobi et al 2015). The position of the openings in the building has an indirect influence on the air flow rate due to the variation of the pressure distribution across the building surface.

3. Research Methodology

Five types of window detectors were configured and evaluated based on the detection of a set of windows within a case study building, which will help seek the most accurate detection and recognition of window opening status. Hence the study is divided into two parts: the first part was carried out through direct physical measurements by using sensors (data logger) to monitor indoor air flow and air velocity which will be used to identify the frequency of wind-induced ventilation by different window openings. The essence of physical measurement is to represent, and predict causal effects. The second part will be carried out through obtaining data from the questionnaire survey to evaluate the effect of sustainable design in buildings.

3.1 Method and Apparatus:

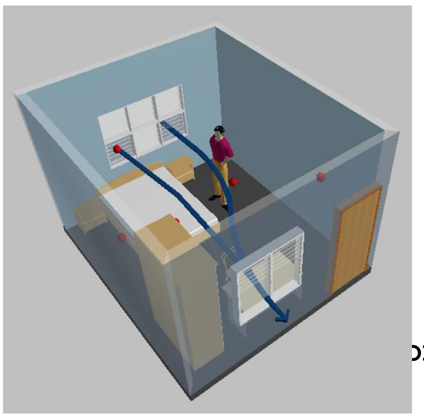
The multi-purpose Air Flow Digital anemometer (AM-4812-2-2) was used to measures air velocity, air flow, and Data logger (HTC-1) air temperature & humidity. The system collected concurrent physical data: air temperature, air flow and air velocity. The instruments were placed at 0.6m, 0.9m, and 2.1m from the floor to record the thermal comfort variables simultaneously, as the subjects filled in the thermal comfort questionnaire. The data logger was set to acquire data at 60-min intervals. The readings were recorded in separate data sheets. All the completed questionnaires and data sheet entries were given serial numbers for easy identification and synchronization. The readings were transferred onto the corresponding questionnaires at the end of every survey day. The measuring apparatus for field study and data documentation is shown in Table 1.

Table 1: measuring apparatus

Apparatus	Description
	**Air Flow Digital anemometer (AM-4812-2-2):** velocity range is between 0.4m/s- 30m/s, 1.4km/h-108.0km/h, 0.8knots- 58.3knots with accuracy of ±2% +1d at 0^oC-50^oC and less than 90%RH.
	**Data logger (HTC-1):** recording air temperature from -10^oC to +50^oC and relative humidity from 10% to 99%. The reading resolution for temperature and relative humidity are 0.1^oC and 1%.

4. Data Presentation and Analysis

The characterizations of the monitored buildings was based on the type of windows in the building which are casement window, casement with vent, sliding window, projected window and louvre windows respectively. Understanding the characteristic of naturally ventilated residential buildings can help to identify the natural ventilation type. The natural ventilation types in each room are also defined and the results of single-side ventilation and cross-ventilation type were compared. While the instruments recorded the surrounding environmental conditions, the researcher observed and kept track of the occupancy behavior or activities, such as the opening and closing of windows. The monitored rooms are shown in Plate 1, Plate 2 and Plate 3.



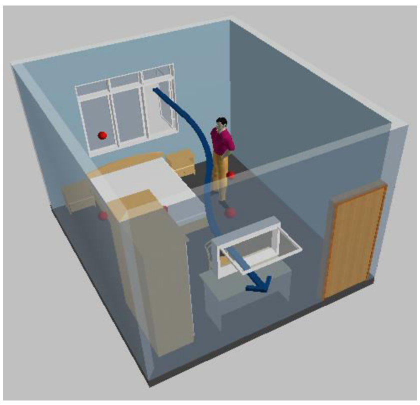


Plate 1: Louvre Window

Source: Field work (2024)

Plate 2: Casement-with-vent Window

Source: Field work (2024)

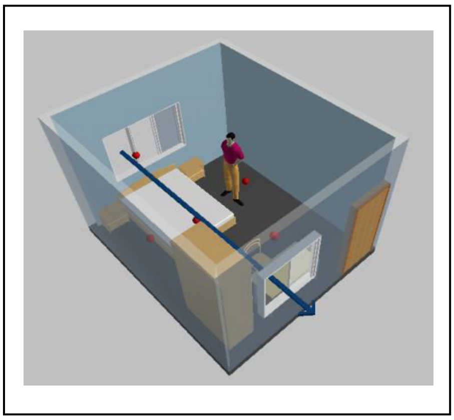


Plate 3: Sliding Window

Source: Field work (2024)

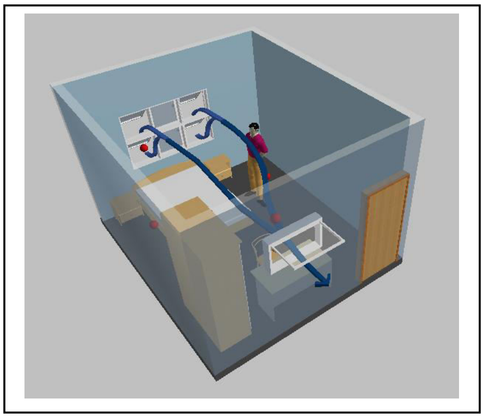


Plate 4: Projected Window

Source: Field work (2024)

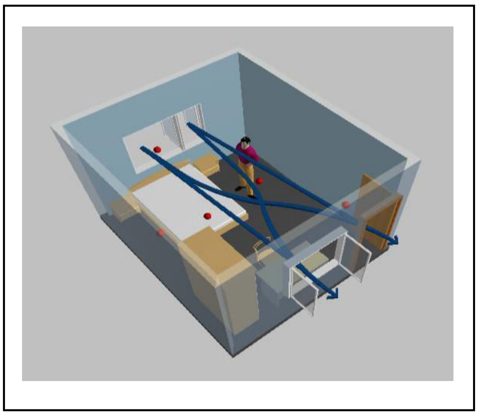


Plate 5: Casement Window

Source: Field work (2024)

Table 2: Characteristics of typical rooms and windows in the five buildings

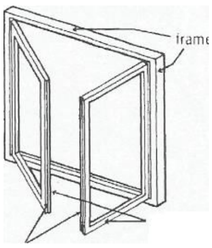
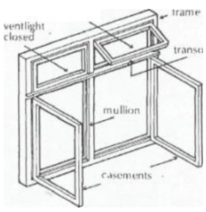
		Room A1	Room B1	Room C1	Room D1	Room F1
Dimensions	Width (m)	3.6	3.6	3.6	3.6	3.6
	Depth (m)	3.6	3.6	3.6	3.6	3.6
	Height (m)	2.7	3.0	2.7	3.0	3.0
Window area	Size (m^2)	1.5	2.2	1.4	1.4	2.7
	Glazing ratio [WWR] (%)	16.6	20.8	13.3	13.3	20.0
Window type		Casement	Casement /vent	Sliding	Projected	Louvre
Maximum openable area (m^2)		14.9	19.6	0.7	9.3	20.0

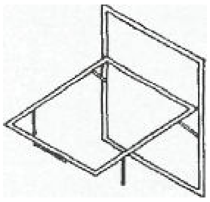
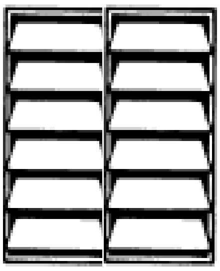
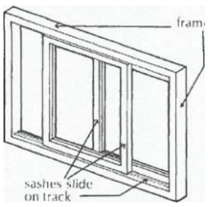
Source: Field Work (2024).

5. Discussion of results

When evaluating ventilation effectiveness, the path of the air from entry to exit point was considered. Air flow characteristics also play an important role in how effectively the fresh air is introduced to the occupied area. Air speed is important in cooling occupants. The faster the air moves the more moisture and heat it will take away from occupant body by evaporation. Air speed was also important in cooling the building itself when the outside air is cooler than the inside surfaces of the building. While air speed is important, the quantity of air moved through the interior (air change) is the most important factor in the wind induced ventilation of windows.

Table 1: The window types and the air flow characteristics

NAME	WINDOW TYPES	CHARACTERISTICS
Casement Window		These windows can be hinged left or hinged right (as viewed from the outside) and are operated with a roto-gear and crank. The sashes of casement windows can only minimally reduce air flow when the window is opened with the sash in a perpendicular position. Casement windows can have single leaf and be hung on one side. The leaves can open 90-180 degrees, allowing maximum air flow in the room. Casement windows provide almost 100% ventilation area, because they can be fully opened and the out-swinging sash can direct plenty of air into the building.
Casement with vent Window		These windows are more flexible for automatic control. The top hung window is better for day time ventilation, because the down part opening can modify the air flow pattern through to the occupant. The inward opening is good for night ventilation. . Maximum open area (50-80) percent.

Projected Window		Projected windows pivot at the top and may have outward or inward-swinging sash, the most common is the outward swinging sash. Projected windows are usually operated with a roto-gear or push-out lever so that the window can be adjusted to keep out rain but let in fresh air. This window type can open at different angles up to 90 degrees, depending on the amount of air that is to be allowed in. It provides up to 50% ventilation area, as the hardware does not allow them to be fully opened and this could affect its thermal performance of naturally ventilated residential buildings in the study area, with high indoor temperature.
Louvre Window		The vertical or horizontal pivot and Louvre windows seem to be an interesting window type in use, because they allow air flow into buildings. The sashes may be either horizontally or vertically pivoted to open. Horizontally-pivoted sashes are usually pivoted at the centre of the height of the window. Close control of ventilation with these windows is not possible as they have to open both top and bottom or both sides and they may act like a sail and catch and direct gusts of wind into the building. The blades to an extent impede the air flow, but a great amount of air still gets into the room. Louvre window is a type of window that for a long time now, its usage has seriously declined in the study area, but can offer 75% ventilation.
Sliding Window		These windows have sash that slide horizontally. Sliding windows can reduce air flow by as much as 50 percent. However, these sliding windows seem to be the most used window type, especially on naturally ventilated residential building in Asaba. It is notable that the window type, in the most cases, does not take advantage of natural ventilation potential. Single sliders have one fixed sash, while double sliders have two movable sashes. Most horizontal sliders have at least one removable sash. Sliding window is the prevalent type of window that is in use at study area, but can offer 50% ventilation.

6. Conclusions

The speed at which air enters a space is part of what determines its impact on the thermal conditions within the space. Air velocity must be controlled within a space to avoid draft conditions, which can cause not only occupant discomfort due to increased evaporative cooling if the skin is exposed, but also disruption of objects in the occupied space. The various air flow characteristics of window and their impact on natural ventilation design of buildings are essential in sustainable design. The method in which the air is introduced, travels through, and is exhausted from individual spaces and the building contribute to the wind induced ventilation and effectiveness of sustainable building design. Generally this research will be useful to the academia in inculcating knowledge to architects, and professionals in the built environment.

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