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NATURAL VENTILATION PERFORMANCE AND WINDOW DESIGN OF RESIDENTIAL APARTMENTS IN ONITSHA

Chime[1], Charles C[2]
[1,2]Department of Architecture, Delta State University of Science and Technology, Ozoro, Nigeria.

ABSTRACT
The rise in global temperature due to climate change has increased the need for cooling to satisfy residents' comfort in buildings. Thus the residents' in Onitsha then use electro-mechanical devices for comfort provision with its high cost and climate change effects. Natural ventilation can help improve indoor air quality, and reduce the energy consumption of mechanical ventilation systems. Due to the pulsating characteristics of natural ventilation, it can provide a comfortable indoor environment, which is conducive to people's physical and mental health. One of the important methods of realising natural ventilation is through window design. Window design are usually categorised as cross-ventilation design, where openings are on opposite sides of a building; and single-sided ventilation design, where the openings are on only one side of a building. This paper reports on the investigation using physical measurement to determine the effects of window design on natural ventilation of buildings. Data on different window openings in purposively selected rooms were used. The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the natural ventilation performances for the different window design. The result shows that the natural ventilation performance in buildings is influenced by window design variables. It states that the use of natural ventilation potentially reduces the operational and the maintenance cost needed for mechanical system. Recommendations were made for the potential of cross ventilation through windows in buildings, and its effect on the indoor temperature, depends greatly on the position of the windows. Thus, it is important to promote the adoption of natural ventilation in buildings.

Keywords: Cross ventilation, Natural ventilation, Single-sided ventilation, Warm humid, and Window design.

1. INTRODUCTION

Natural ventilation can be defined as the movement of air through openings in a buildings envelope, due to wind or to static pressures created by the differences in temperature between the interior and exterior of the building (generally known as the stack effect), or to a combination of these acting together (British Standard; BS:5925:1991). Natural ventilation is subject to the variability of wind speed, wind direction, air temperature and window configuration. Not only do these factors affect the rate of fresh air supply but also determine whether openings will act as an inlet or outlet for the air in any space within a building (NBC, 2006; Heiselberg et al., 2001; Atolagbe, 2014; Anunobi et al., 2015).

Natural ventilation has been used throughout history to ventilate and passively cool structures in the study area. It is the increased heat load and concerns over occupant comfort that often restrict dependence on natural ventilation in residential buildings. The attainment of uniform internal temperatures for occupant comfort was thought to be possible only by controlling amount of air being supplied to an occupied space (Givoni, 1998; NBC, 2006; Adebamowo & Adeyemi, 2013).

Figure 1: Natural ventilation concept (Tommy, 2003).

Three essential aspects of natural ventilation can be used to describe and classify various natural ventilation concepts as shown in Figure 1. The first aspect is the natural force utilised to drive the ventilation. The driving force can be wind, temperature or a combination of both. The second aspect is the ventilation principle used to exploit the natural driving forces to ventilate a space. This can be done by single-sided ventilation, cross ventilation, or stack ventilation. The third aspect is the characteristic ventilation element used to realise natural ventilation. The most important characteristic elements are windows (Tommy, 2003; Hazim, 2010).

2. LITERATURE REVIEW

The major role of all ventilation's systems is to secure optimal indoor air quality. Air motion or air speed is vital to determine the evaporation rate. The higher the evaporation rate, the better is the thermal comfort (Olanipekun, 2014; Adebamowo & Adeyemi, 2013). Natural ventilation is a strategy for achieving acceptable indoor air quality, thermal comfort with reduced energy consumption (Blocken et al., 2011). It is essentially based on the supply of fresh air to a space and the dilution of the indoor pollution concentration (Liddament et al., 1990). Standard requirement for a minimum ventilation rate is required to dilute odours and concentration of CO_2 to an acceptable level, and to provide sufficient oxygen for occupant needs (Allard 1990). Thermal comfort is achieved when the air motion that passes the human skin enhances the sweat evaporation. This Natural ventilation is effective especially in warm humid climatic conditions.

There are two fundamental principles of natural ventilation; namely stack effect and wind driven ventilation (Givoni, 1998). The stack effects are caused by temperature differences between indoor and outdoor of buildings. This phenomena occurs when the inside building temperature is higher than the outside and the warm indoor air will rises and exit replacing the cooler and denser air from below. Wind driven natural ventilation is based on pressure differences created by wind. These pressure differences between the two opposite points on the building geometry are the driven force of the wind induced natural ventilation strategy. Givoni (1998). suggested that wind-induced natural ventilation design has a great potential and can be used to achieve the desirable air speed in the indoor building environment to improve the evaporation rates and cooling effect for the building occupants especially in warm humid climatic conditions. Naghman K. et al. (2008), observed that the stack effect reduces when the temperature differences between the indoor and outdoor of buildings are small. Because of the relatively lower difference between the indoor and outdoor temperature especially in hot and humid conditions, stack ventilation alone is rendered insufficient to create desirable air flow to achieve thermal comfort for the building occupants. The shape of a building together with the location of the ventilation openings dictates the natural ventilation's manner of operation. One usually differentiates between three different ventilation principles for natural ventilation (Andersen, 2002; CIBSE, 2005; NBC, 2006; Atolagbe et al., 2014).

In the case of warm-humid climate zone, position of the window to the prevailing breeze is paramount. Szokolay et al., (2013) 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 position 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).

When evaluating ventilation effectiveness, the path of the air from entry to exit point must be 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 may also be 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 thermal performance of window types (Evans, 1999).

The method in which the air is introduced, travels through, and is exhausted from individual spaces and the building contribute to the window performance and effectiveness of the building. 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 (Allard, 1998; Atologbe, 2011; Anunobi et al., 2015). On the other end of the spectrum, stagnant air is also undesirable, as fresh air is important to the occupants' health and productivity. Allard (1998) 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 natural ventilation performance.

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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 thermal performance of window types (Evans, 1999). The method in which the air is introduced, travels through, and is exhausted from individual spaces and the building contribute to the natural ventilation performance and effectiveness of the window. 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 (Allard, 1998; Atologbe, 2011; Anunobi et al., 2015). The design of the window 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. Givoni (1998), in considering the natural ventilation performance for a building, the main issue is the position of the windows as shown in Figure 2.

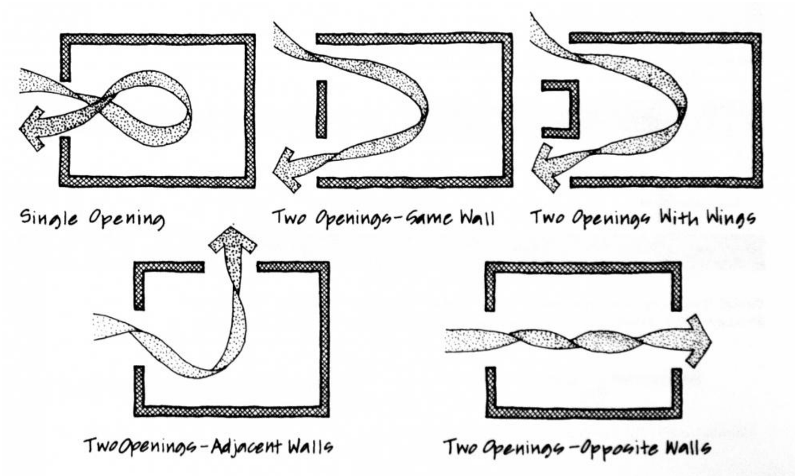

Figure 2: Natural ventilation principles and window position (Allard, 1998).

- Single-sided ventilation
- Cross-ventilation
- Stack ventilation

Single sided ventilation relies on opening(s) on only one side of the ventilated enclosure. Fresh air enters the room through the same side as used air is exhausted. A typical example is the rooms of a cellular building with operable windows on one side and closed internal doors on the other side. With a single ventilation opening in the room, the main driving force is wind turbulence. In cases where ventilation openings are provided at different heights within the facade, the ventilation rate can be enhanced by the buoyancy effect (NBC, 2006; Gao and Lee 2010; Anunobi et al., 2015). Cross-ventilation is the case when air flows between two sides of a building envelope by means of wind-induced pressure differentials between the two sides. The ventilation air enters and leaves commonly through windows, hatches or grills integrated in the facades. The ventilation air moves from the windward side to the leeward side. A typical example is an open-plan room landscape where the space stretches across the whole depth of the building. The airflow can also pass through several rooms through open doors or overflow grills. The term cross ventilation is also referred to when considering a single space where air enters one side of the space and leaves from the opposite side. In this case the ventilation principle on the system level can be either cross- or stack ventilation. As the air moves across an occupied space, it picks up heat and pollutants. Consequently, there is a limit to the depth of a space that can be effectively cross-ventilated. In cross ventilation, the airflow will be driven by wind if there is no significant height differential between inlet and outlet window openings and no vertical connection between floors (Awbi, 2003; NBC, 2006; Gao and Lee 2010; Anunobi et al., 2015). Stack ventilation occurs where the driving forces promote an outflow from the building, thereby drawing fresh air in via ventilation openings at a lower level. Fresh air typically enters through ventilation openings at a low level, while used and contaminated air is exhausted through high level ventilation openings (a reversed flow can occur during certain conditions). Designing the outlet to be in a region of wind-induced under pressure can enhance the effectiveness of stack ventilation. A typical example is a building with an elevated central part, in which warm and contaminated air from the surrounding spaces rises to be exhausted through wind towers located on the roof. Due to its physical nature, the stack effect requires a certain height between the inlet and the outlet (Straw, 2000; NBC, 2006; Gao and Lee, 2010; Anunobi et al., 2015). However, care must be taken when designing natural ventilation openings, since the position of the opening can reduce or even reverse the impact of the air flow This gap motivated this study on natural ventilation performance and window design in residential buildings in Onitsha.

3. RESEARCH METHODOLOGY

The study area is Onitsha in Anambra State, Nigeria. It is located in warm-humid climate zone in Nigeria. The window configurations were investigated based on the natural ventilation principles within a case study building. Hence the study was carried out through direct physical measurements, to investigate the window configuration which indicates the number of window panes, dimension per pane, overall window opening size, percentage of window to wall area and ventilation area percent. The characterizations of the monitored buildings were based on the type of window openings in the building. The natural ventilation types in each room are also defined and the results of single-side ventilation and cross-ventilation type were compared. The percentage of window-to-wall area was calculated for each window type, based on the window arrangements and size of openings in naturally ventilated residential buildings in the study area. The monitored buildings are shown in Plate 1, Plate 2, Plate 3, Plate 4, Plate 5, Plate 6, and Plate 7.

Plate 1: Onitsha City View (Field work, 2023).

Plate 2: Four storey building at Awada , Onitsha (Field work, 2023). **Plate 3:** Five storey building at Nkpor, Onitsha (Field work, 2023).

Plate 4: Four storey building at Obosi, Onitsha (Field work, 2023). **Plate 5:** Four storey building at Fegge Onitsha(Field work, 2023).

Plate 6: Four storey building at Iweka, Onitsha (Field work, 2023). **Plate 7:** Four storey building at Akpaka, Onitsha (Field work, 2023).

Data Presentation:

The data generated from the various sources were sorted and arranged in a way that is adequately fit for statistical analysis and interpretation using tables, bar charts, graphs, frequency distributions and percentages. The variables measured comprise dimension per pane (height and width), opening size, sill height, window to wall ratio, geometry, and position of window. The data collected on casement window with 1200mm height are presented in Table 1. Based on the field work the data on casement-with-vent with 1200mm height are shown in Table 2. Then data on sliding window with 1200mm height are shown in Table 3. Table 4 shows data on projected windows with 1200mm height. However, data on louvre windows with 1200mm height are shown in Table 5.

Table 1: Window configuration and ventilation performance of casement windows (1200mm height) in naturally ventilated buildings in the study area

Table 1: Window configuration and ventilation performance of casement windows (1200mm height) in naturally ventilated buildings in the study area.

		W WA%	Vent.%	W WA%	Vent.%	W WA%	Vent.%
Width (600mm) W1	Pane(1)	6	5.7	6	5.7	3.3	2.8
Width (750mm) W2	Pane(1)	8.3	7.4	8.3	7.4	4.1	3.7
Width (900mm) W3	Pane(1)	10	9	10	9	4.1	3.7
Width (1200mm) W4	Pane(2)	13.3	11.9	13.3	11.9	6.6	5.9
Width (1500mm) W5	Pane(2)	16.6	14.9	16.6	14.9	8.3	7.4
Width (1500mm) W6	Pane(3)	16.6	15.9	16.6	15.9	8.3	7.9

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Table 2: Window configuration and ventilation performance of casement windows with vent (1200mm height) in naturally ventilated buildings in the study area.

CASEMENT WITH VENT	Height(1200mm)	TYPICAL ROOM WINDOW LOCATION (P1) WWA%	TYPICAL ROOM WINDOW LOCATION (P1) Vent.%	TYPICAL ROOM WINDOW LOCATION (P2) WWA%	TYPICAL ROOM WINDOW LOCATION (P2) Vent.%	TYPICAL ROOM WINDOW LOCATION (P3) WWA%	TYPICAL ROOM WINDOW LOCATION (P3) Vent.%
Width (600mm) W1	Pane(1)	6.6	6.2	6.6	6.2	3.3	3.1
Width (750mm) W2	Pane(1)	8.2	7.2	8.2	7.2	4.2	3.8
Width (900mm) W3	Pane(1)	10	9.4	10	9.4	5	4.7
Width (1200mm) W4	Pane(2)	13.2	12.4	13.2	12.4	6.6	6.2
Width (1500mm) W5	Pane(2)	16.6	15.6	16.6	15.6	8.3	7.8
Width (1500mm) W6	Pane(3)	16.6	16.2	16.6	16.2	8.3	8.2

Table 3: Window configuration and ventilation performance of sliding windows (1200mm height) in naturally ventilated buildings in the study area.

SLIDING WINDOW	Height(1200mm)	TYPICAL ROOM WINDOW LOCATION (P1) WWA%	TYPICAL ROOM WINDOW LOCATION (P1) Vent.%	TYPICAL ROOM WINDOW LOCATION (P2) WWA%	TYPICAL ROOM WINDOW LOCATION (P2) Vent.%	TYPICAL ROOM WINDOW LOCATION (P3) WWA%	TYPICAL ROOM WINDOW LOCATION (P3) Vent.%
Width (900mm) W1	Pane(2)	10	5	10	5	5	2.5
Width (1200mm) W2	Pane(2)	13.2	6.6	13.2	6.6	6.6	3.3
Width (1500mm) W3	Pane(2)	16.6	8.3	16.6	8.3	8.3	4.2
Width (1800mm) W4	Pane(2)	20	10	20	10	10	5
Width (1500mm) W5	Pane(3)	16.6	11	16.6	11	8.3	5.5
Width (1800mm) W6	Pane(3)	20	13.2	20	13.2	10	6.6

Source: field work (2023).

Table 4: Window configuration and ventilation performance of louvre windows (1200mm height) in naturally ventilated buildings in the study area.

LOUVRE WINDOW	Height(1200mm)	TYPICAL ROOM WINDOW LOCATION (P1) WWA%	TYPICAL ROOM WINDOW LOCATION (P1) Vent.%	TYPICAL ROOM WINDOW LOCATION (P2) WWA%	TYPICAL ROOM WINDOW LOCATION (P2) Vent.%	TYPICAL ROOM WINDOW LOCATION (P3) WWA%	TYPICAL ROOM WINDOW LOCATION (P3) Vent.%
Width (600mm) W1	Pane(1)	6	6	6	6	3.3	3.3
Width (750mm) W2	Pane(1)	8.3	8.3	8.3	8.3	4.1	4.1
Width (900mm) W3	Pane(1)	10	10	10	10	5	5
Width (1200mm) W4	Pane(2)	13.3	13.3	13.3	13.3	6.6	6.6
Width (1500mm) W5	Pane(2)	16.6	16.6	16.6	16.6	8.3	8.3
Width (1800mm) W6	Pane(3)	20	20	20	20	10	10

Source: field work (2023).

Table 6: Window configuration and ventilation performance of projected windows with vent (1200mm height) in naturally ventilated buildings in the study area.

PROJECTED WINDOW	Height(1200mm)	TYPICAL ROOM WINDOW LOCATION (P1) WWA%	TYPICAL ROOM WINDOW LOCATION (P1) Vent.%	TYPICAL ROOM WINDOW LOCATION (P2) WWA%	TYPICAL ROOM WINDOW LOCATION (P2) Vent.%	TYPICAL ROOM WINDOW LOCATION (P3) WWA%	TYPICAL ROOM WINDOW LOCATION (P3) Vent.%
Width (600mm) W1	Pane(1)	6	4.2	6	4.2	3.3	2.1
Width (750mm) W2	Pane(1)	8.3	5.8	8.3	5.8	4.1	2.9
Width (900mm) W3	Pane(1)	10	7	10	7	5	3.5
Width (1200mm) W4	Pane(2)	13.3	9.3	13.3	9.3	6.6	4.6
Width (1500mm) W5	Pane(2)	16.6	11.6	16.6	11.6	8.3	5.8
Width (1500mm) W6	Pane(3)	16.6	12.1	16.6	12.1	8.3	6

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Source: field work (2023).

3.2 Result Analysis:

Table 6: Frequency and percentage of window sizes in the study area

Window sizes (mm)	Frequency	Percentage
600mm x1200mm	190	1.15%
750mm x 1200mm	352	2.13%
900mm x1200mm	1038	6.29%
1200mm x1200mm	6223	37.68%
1500mm x1200mm	3518	21.30%
1800mm x1200mm	1029	6.23%
2100mm x1200mm	527	3.19%
2400mm x1200mm	420	2.54%
600mm x 1500mm	84	0.50%
750mm x 1500mm	62	0.37%
900mm x 1500mm	884	5.35%
1200mm x1500mm	1007	6.09%
1500mm x1500mm	509	3.06%
1800mm x1500mm	392	2.37%
2100mm x1500mm	180	1.08%
2400mm x1500mm	120	0.73%
Total	**16514 windows**	**100%**

Source: field work (2023).

From the Table 6 it could be seen that 16514 windows were surveyed from the 650 buildings sampled for assessment. The window sizes in the study area has varied width ranging from 600mm-2400mm with two different heights 1200mm, 1500mm sill heights of 900mm and 600mm respectively as shown in Figure 3.

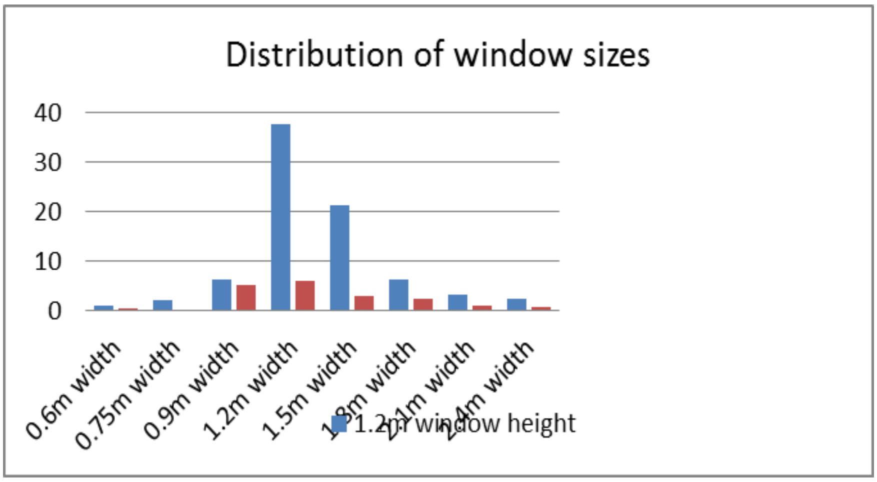

Figure 3: Distribution of window sizes in the study area (Field work, 2023).

The result in Table 7 has reported the p-value result for the ANOVA analysis between window design and natural ventilation performance. The result is said to be significant if p-value is less than 0.05 significant level. The result reports a p-value of 0.010 with an F-value of 3.509. We therefore reject the null hypothesis and accept the alternate hypothesis stating that the window configuration significantly differ natural ventilation performance of residential buildings in Onitsha, Nigeria.

Table 7: The ANOVA result between various window configuration and natural ventilation performance

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	609.715	4	152.429	3.509	.010
Within Groups	4561.239	105	43.440		
Total	5170.954	109			

Source: ANOVA analysis output, SPSS 25

4. RESULTS AND DISCUSSION

The investigation was carried out by physical measurement. The variables measured comprise the number of window panes, dimensions per panes, opening size, sill height, percentage of window-to-wall area, geometry and location of window types. The windows investigated are casement, casement with vent, sliding, projected and louvre windows. The effect of dimension per pane (height and width), opening size, sill height, window to wall ratio, geometry, and position of window on the ventilation varies. This implies that window design differs natural ventilation performance of residential buildings. Reducing opening area can decrease the indoor air flow speed and reduce the convective cooling effect on body and indoor temperatures. Atolagbe (2014) found out that opening size of window in natural ventilated residential building can result to poor natural ventilation, higher room heat-trap and poor body heat comfort. However, this study shows that natural ventilation can achieve a cooling purpose and remedy the risk of residents' discomfort in buildings within the study area and warm humid climatic zone.

5. CONCLUSIONS

The most effective window configuration should be used in naturally ventilated residential buildings in warm humid climate zone. The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the natural ventilation performance of different window configuration thus: $F=65.555$; $p=.000$. The performance of window types in providing comfortable air flow rate is now in this order; casement-with-vent window having optimal performance, followed by louvre window, casement window, projected window, and sliding window having the lowest performance. The research recommendations are to improve natural ventilation design of residential buildings in Onitsha and environs by applying casement-with-vent window which renders optimal ventilation in single side ventilation and cross ventilation.

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