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WINDOW TYPES AND INDOOR RATES AND PATTERNS OF AIR FLOWS FOR SUSTAINABLE BUILDING DESIGNS IN NATURALLY VENTILATED RESIDENTIAL BUILDINGS OF WARM-HUMID CLIMATE ZONES

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Abstract.
Air and moisture movements combine to influence energy consumption patterns and levels in warm humid climate zones. Windows create pathways for entries and exits of the elements of the climate in and out of buildings. However, windows come in varied types, configurations and designs, each behaving differently with regards to the provision of the pathway thereby, varying the indoor rates and patterns of air flows traceable to the various types of windows to achieve sustainable building designs. Therefore, this paper reports on the investigation done using physical measurements to determine the effects of different window types in wall panels on rates and patterns of air flows in naturally ventilated residential buildings in Asaba, Nigeria. Data on the indoor air flow speed of the five different window types: Casement window, casement with vent, sliding, projected, and louvre were obtained through data loggers (LUTRON Thermo-Anemometer AM4201A) mounted in the purposively selected residential buildings where the different window types were used. The Analysis of Variance (ANOVA) test conducted at 95% confidence level showed that there was significant statistical difference between the rates and patterns of air flows for the different window types thus: F=34.335; p=.000. The sliding window had a mean value of 0.39; projected 0.51; casement 0.69; louvre 0.93 and casement with vent 0.85. Recommendations were made for casement-with-vent windows to be used in the design of naturally ventilated residential buildings. This will aid the next generation of architecture and construction professionals in achieving effective ventilation, comfortable indoor environment, energy efficiency and sustainable future.

Keywords: *Natural Ventilation, Occupant Thermal Comfort, Rates and Pattern of Air Flow, Sustainable building design, and Window Types.*

1. Introduction

The discomfort of indoor environmental condition in occupied spaces in buildings due to window types has escalated the combined effect of high solar radiation and humidity levels in the warm-humid climate which is an impact from climate change (Szokolay, 2004; Adebamowo & Adeyemi, 2013). The discomfort faced by occupants of buildings are less effective air flow; which cannot remove foul air or ensure personal thermal comfort. As a result, these have contributed to use of artificial means to provide a comfortable thermal environment at high energy consumption in the warm-humid climate zone (Atolagbe, 2014; Olanipekun, 2014).

As part of energy conservation method, the understanding of performance of window types in naturally ventilated buildings is an important issue for building designers. The type of window fitted in the building could have a direct influence on the pattern of flow of air in the interior of the building. There are

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different window types in the study area and the promoters of building enterprise or architects use any of the window type without recourse to its implication on thermal comfort aspect of the building.

However, there are prevalent cases of where inhabitants changed from one type of window to another and vice versa due to social or aesthetics reasons (Anunobi, Adebayo, Oyetola, Siman & Audu, 2015). There is a wide range of possibilities with regard to selection of window type, size and location. In order to achieve a sustainable building design this research on window types and indoor rates and patterns of air flows is necessary for architects and engineers in selection of window types in the design of naturally ventilated residential buildings in the warm humid zone.

2. Literature Review

The control of air flow is one of the most subtle and yet an inexpensive concern of the building designer. The primary aim of effective air flow is to make air movement assume patterns in buildings that satisfies and even delights the occupant (Boutet, 1987; Heiselberg et al., 2002). Air flow merits a major consideration that control interactions among the physical elements of the building, its occupants, and the environment mainly because of its influence on heat and moisture content (Heiselberg et al., 2001). Air flow pattern within a building also affects its behaviour in the spread of smoke and other toxic gases, supply of oxygen in case of fire, indoor air quality, and thermal energy use (Gao & Lee, 2010; Anunobi et al., 2015).

However, the function of a building is to protect man against the weather and provide an environment that maintains his well-being (Anunobi et al., 2015). This emphasises the importance of building being both healthy as well as comfortable (Atolagbe, 2014; Olanipekun, 2014). The National Building Code (NBC, 2006) stated that the design of buildings accounts for both comfortable thermal indoor environment as well as obtaining the necessary air flow rate to secure a comfortable atmospheric indoor environment (NBC, 2006). Chartered Institute of Building Services Engineers (CIBSE, 2006) recorded that ventilation of occupied spaces in buildings has two primary purposes; to provide an acceptable indoor air quality (IAQ), which essentially is based on the supply of fresh air and the removal or dilution of indoor pollution concentration. The other is to provide thermal comfort by providing a direct cooling effect over the human body through convection and evaporation (CIBSE, 2006). Considering energy efficient buildings without mechanical cooling and ventilation, the air exchange rate provided by window ventilation is a crucial design variable (Heiselberg et al., 2001; NBC, 2006; Anunobi et al., 2015).

The effect of window types and locations in wall panels on rates and pattern of air flow is essential to provide reliable design data for exploring natural ventilation air flow through window opening types. Whilst window type can improve natural ventilation in warm humid climates, there is still a knowledge gap on the effect of window types. Nevertheless the location, geometry and composition of window types can effect either positively or negatively on the air flow rates and patterns. This gap motivated this study on window types and indoor rates and patterns of air flows for sustainable building designs in naturally ventilated residential buildings of warm humid climate zones.

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

3. Research Methodology

This study will apply questionnaire survey research and physical measurement in the sense that it will partly be concerned with identifying, describing, recording, analysing, and interpreting conditions that either exist or existed. The researcher does not manipulate the variable or arrange for events to happen. The study is only concerned with conditions or relationships that exist, opinions that are held, processes that are going on, effects that are evident or trends that are developing. They are primarily concerned with the present but at times do consider past events and influences as they relate to current conditions. Thus, in survey research, variables that exist or have already occurred are selected and observed (Groat & Wang, 2013). 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 temperatures, relative humidity, and air velocity which will be used to identify the frequency of indoor comfort temperature range by different window types location in wall panels with respect to orientation and opening sizes. 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 access the effect of window types on thermal comfort of the occupants in naturally ventilated buildings.

3.1 Method and Apparatus:

The indoor climate LUTRON Thermo-Anemometer (AM4201A): multi-purpose pocket and hand held indoor climate tracker was utilized to measure the indoor climate conditions during the observation survey and this took place alongside questionnaire survey. The multi-purpose LUTRON Thermo-Anemometer (AM4201A) was ideal because it measures air velocity, air flow, and air temperature, with sensory accuracy of ±(3%+0.20m/s). 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. Mean radiant temperatures were calculated based on the equation provided by the ASHRAE standard 55.

While the instruments recorded the surrounding environmental conditions, the researcher observed and kept track of the respondents` clothing levels as well as the utilization of environmental controls. The measuring

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apparatus for field study and data documentation is shown in table 1.

Table 1: Measuring apparatus

Apparatus	Specification
	**LUTRON Thermo-Anemometer (AM4201A):** it measures air velocity, air flow and air temperature respectively. Air velocity range is 0.40-45m/s, resolution of 0.001m/s and recording accuracy of ±(3%+0.20m/s). Air flow range is 0 to 9999m^3/min, resolution of 1, and recording area of (0 to 9.999m^2). Air temperature range is -10^{o}C–60^{o}C, resolution of 0.1^{o}C and recording accuracy of 2.0^{o}C respectively.

Source: field work (2022).

3.2 Characteristics of monitored building:

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. In determining a suitable sample, the sample size must be a near representative of the entire population as possible for the generalization of findings (Osuala, 2001). In order to have adequate sample size required in addressing the research questions, sampling was focused on the residential buildings and the five window types as well as the occupants of the naturally ventilated buildings.

The buildings and window types are casement Plate 1, casement-with-vent Plate 2, sliding window Plate 3, projected window Plate 4, and Louvre window Plate 5.

Plate 1: Two storey building with casement window: Type A. (field work, 2022).

Plate 2: One storey building with casement / vent window: Type B. (field work, 2022).

Plate 3: Two storey building with sliding window: Type C. (field work, 2022).

Plate 4: One storey building with sliding window: Type D. (field work, 2022).

Plate 5: One storey building with Louvre window: Type D. (field work, 2022).

In these five buildings, the average air flow rate on the window was recorded and locations of apparatus are shown in Figure 1.

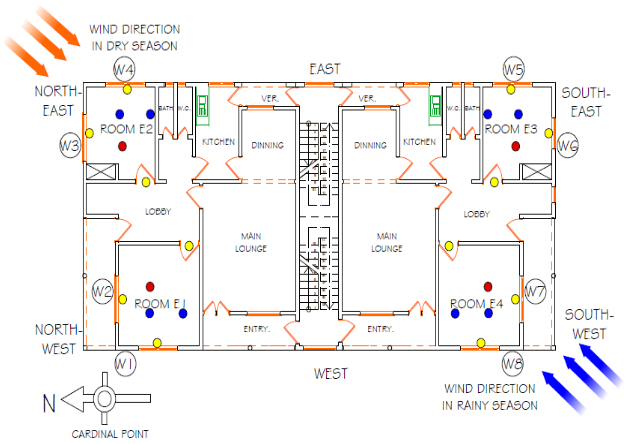
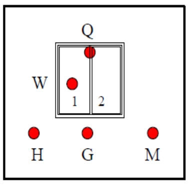


Figure 1: First floor plan shewing apparatus location
Sorce:Field work, 2022.

3.3 Data Presentation and Analysis:

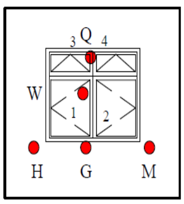
This section present the data generated from the field work. The data generated from the various sources will be sorted and arranged a way that is adequately fit for statistical analysis and interpretation using tables, bar charts, graphs, frequency distributions and percentages.

Table 2: window type A: Casement window

Windows in the Room	Room	Point W (m/s)	Point Q (m/s)	Point G (m/s)	Point H (m/s)	Point M (m/s)
	A1	0.08	0.06	0.07	0.05	0.05
	A2	1.23	0.49	0.62	0.67	0.69
Average		0.65	0.27	0.34	0.34	0.36

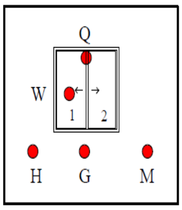
Source: field work (2022).

Table 3: window type B: Casement -with- window

Windows in the Room	Room	Point W (m/s)	Point Q (m/s)	Point G (m/s)	Point H (m/s)	Point M (m/s)
	B1	1.12	0.52	0.91	0.73	0.67
	B2	0.57	0.31	0.54	0.48	0.48
	B3	1.13	0.52	0.73	0.84	0.86
Average		0.94	0.45	0.72	0.68	0.67

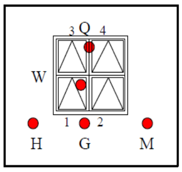
Source: field work (2022).

Table 4: window type C: Sliding window

Windows in the Room	Room	Point W (m/s)	Point Q (m/s)	Point G (m/s)	Point H (m/s)	Point M (m/s)
	C1	0.22	0.09	0.10	0.12	0.12
	C2	1.07	0.52	0.54	0.63	0.71
	C3	1.11	0.53	0.55	0.71	0.71
Average		0.80	0.38	0.39	0.48	0.51

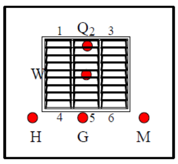
Source: field work (2022).

Table 5: window type D: Projected window

Windows in the Room	Room	Point W (m/s)	Point Q (m/s)	Point G (m/s)	Point H (m/s)	Point M (m/s)
	D1	2.72	0.95	0.17	0.17	0.17
	D2	1.52	0.75	0.93	0.93	0.93
	D3	2.15	0.92	0.16	0.16	0.16
Average		2.13	0.87	0.42	0.42	0.42

Source: field work (2022).

Table 6: window type E: Louvre window

Windows in the Room	Room	Point W (m/s)	Point Q (m/s)	Point G (m/s)	Point H (m/s)	Point M (m/s)
	E1	1.15	1.15	0.57	0.57	0.57
	E2	1.18	1.18	0.94	0.94	0.94
	E3	1.15	1.15	0.83	0.83	0.83
Average		1.16	1.16	0.78	0.78	0.78

Source: field work (2022).

Table 4.25 shows the result of the average air flow rate and pattern. It seemed that the indoor conditions were acceptable. And in the cross-ventilated room, as the indoor air flow rate was positive, occupants used windows to control indoor air flow pattern and air flow rate which may improve their comfort perception. The measured data at different points on different opening and closing combinations were unified as shown in

Figure 4.28, Figure 4.39, Figure 4.30, and Figure 4.31 respectively.

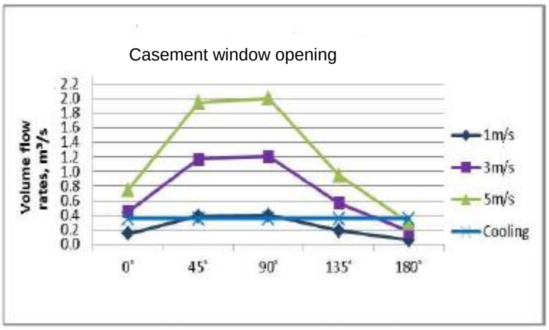


Figure 2: The effect of Casement window on air flow rate and pattern
Sorce:Field work, 2022.

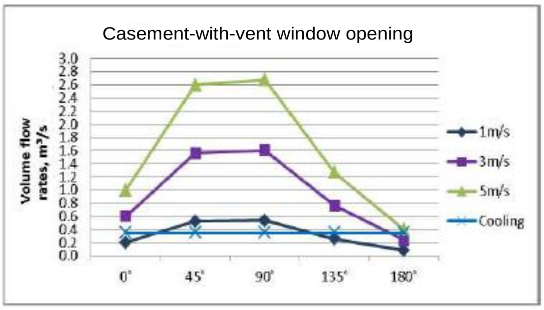


Figure 3: The effect of Casement-with-vent window on air flow rate and pattern
Sorce:Field work, 2022.

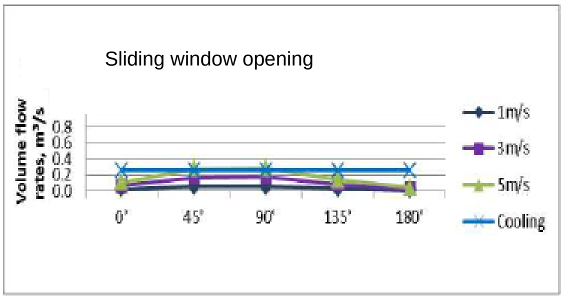


Figure 4: The effect of Sliding window on air flow rate and pattern
Sorce:Field work, 2022.

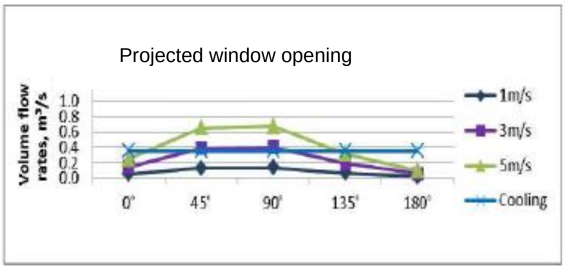


Figure 5: The effect of Projected window on air flow rate and pattern
Sorce:Field work, 2022.

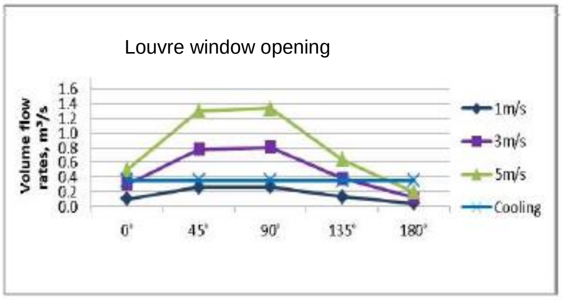


Figure 6: The effect of Louvre window on air flow rate and pattern
Sorce:Field work, 2022.

3.4 Result analysis:

The result in table 4.53 above has reported the p-value result for the ANOVA analysis the rate and pattern of air flow in window types in naturally ventilated buildings in study area. The result is said to be significant if p-value is less than 0.05 significant level. The result reports a p-value of 0.000 with an F-value of 34.335. We therefore reject the null hypothesis and accept the alternate hypothesis stating that the rate and pattern of air flow in window types significantly differ in naturally ventilated buildings in the study area.

Table 7: The ANOVA analysis result on the rate and patt of air flow between window types

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.027	4	.257	34.335	.000
Within Groups	2.693	20	.135		
Total	3.720	24			

Source: ANOVA analysis output, SPSS 25

The Duncan result in table 4.54: shows the comparative analysis of the rate and pattern of air flow in window types. The sliding windows have lower rate and pattern of air flow and casement with vent window have higher rate and pattern of air flow, but projected, casement and louvre windows are between.

Table 7: The Pos Hoc Duncan alpha analysis result on the rate and pattern of air flow between window types

		Subset for alpha = 0.05	
GPR	N	1	2
Sliding	5	.3900	
Projected	5	.5120	.5120
Casement	5	.6920	.6920
Louvre	5	.8520	.8520
Casement/ vent	5		.9320
Sig.		.081	.111

Means for groups in homogeneous subsets are displayed.
a. Uses Harmonic Mean Sample Size = 5.000.
Source: ANOVA analysis output, SPSS 25

4. Discussion of Results

This research shows the need to understand the window types to be used in naturally ventilated residential designs for occupant thermal comfort, low energy consumption and sustainable building design. The actual design of windows to collect and direct breezes within and through the home is the most important design criteria in natural ventilation, because breeze can be deflected or diverted, whether the windows provide single-sided or cross-ventilation to interior spaces, the amount of air that flows through a window (volume flow rate) depends on the window design. From this study a new set of strategies are identified to select the window types that improve indoor air flow rate in naturally ventilated residential buildings in warm humid climate zone. However stagnant air is also undesirable, as fresh air is important to the occupants' health and productivity. This research pointed out that increasing the indoor air flow rate (within occupants' acceptable limit of course) can improve occupant thermal comfort level. When the speed value is less than 0.25m^3/s, it is low, but if it is moderate at 0.3m^3/s to 0.9m^3/s, and high at 1.0m^3/s. Sliding windows were mostly used in the study area because it is considerably cheaper, and not because it is good for ventilation.

5. Conclusions

The most effective window types 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 rates and patterns of air flows for the different window types thus: F=34.335; *p*=.000. The sliding window had a mean value of 0.39; projected 0.51; casement 0.69; louvre 0.93 and casement with vent 0.85. 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 worst performance.

The research recommendations are to improve the sustainable design of residential buildings by applying casement-with-vent window which renders optimal ventilation in single side ventilation and cross ventilation. Recommendations were made for casement-with-vent windows to be used in the design of naturally ventilated residential buildings. This will aid the next generation of architecture and construction professionals in achieving effective ventilation, comfortable indoor environment, energy efficiency and sustainable future.

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