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EFFECT OF WINDOWS CONFIGURATION IN WALL PANELS ON ROOM TEMPERATURE IN NATURALLY VENTILATED RESIDENTIAL BUILDINGS IN ASABA, NIGERIA

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***Abstract*—The type of windows configuration in residential building influences the amount of radiation that enters into the interior occupied spaces. The level of comfort or discomfort experienced within the buildings is thus hinged on the type of window configuration in the building facade. There are different window configurations in the study area, and the environmental designers or architects use any of the window type in spite to its implication on thermal comfort aspect of the building. Physical measurements and questionnaire were conducted in naturally ventilated residential buildings, to investigate the effect of window configuration in wall panels on room temperature in naturally ventilated residential buildings in Asaba, Nigeria. The effect of indoor room temperature on occupant thermal comfort was examined. Different window configurations commonly used in residential buildings in the study area are sliding, projected, casement, casement-with-vent, and louvre window. The results show that appropriate window configuration in wall panels can provide comfort level on room temperature. Recommendations were made to improve thermal comfort in residential buildings using window configuration with PMV value of 4.5 or less which are casement with vent, louvre and casement windows in naturally ventilated residential buildings.**

***Keywords*— Natural Ventilation, Occupant Thermal Comfort, Room Temperature, Warm-humid climate, Window Configuration, Asaba, Nigeria.**

I. INTRODUCTION

The cardinal attributes of habitability in a house, and indeed any built form in the warm-humid climate is effective natural ventilation, or the ability to maintain a constant indoor temperature for residents' living comfort, even in the face of fluctuations in outdoor temperature [8]. Windows play significant role in the admittance of radiation into residential buildings thereby influencing thermal comfort of the indoor space [10]. Besides this, the issues that often arose and complained about by residents of naturally ventilated buildings in the study area were terrible health conditions due to room temperature effect emanating from window configuration [12]. Residents' then use electro-mechanical devices for comfort provision with its high cost and climate change effects. The aim of this study is to achieve comfort level on room temperature through efficient utilization of window configuration in naturally ventilated residential buildings in Asaba, Nigeria. The research question is; to what extent do windows configuration in wall panels affect room temperature in naturally ventilated residential buildings? Room temperature could be influenced by the configuration of window thereby making its study imperative in residential buildings. The sound knowledge of effect of window configuration in wall panels on room temperature is necessary for efficient design of window opening types in buildings.

II. LITERATURE REVIEW

In naturally ventilated buildings purpose-provided openings allow fresh outside air to enter and exhaust air to exit a building through a window [14]. Windows can provide the needed amount of good air quality through a natural process of allowing air, in and out of buildings, in order to achieve thermal comfort if appropriately used [9]. However, the American Society of Heating, Refrigerating and Air-Conditioning Engineers [1] define thermal comfort as that condition of mind which expresses satisfaction with the thermal environment. Nevertheless, thermal discomfort can lead to heat stress. Heat stress is defined as the combination of air temperature, radiation, moisture content of the air, air movement, clothing and behaviour that induces a physiological inability of the body to maintain its temperature within limits that permit normal physiological performance [2]. Thermal comfort level can be defined in term of range of operative temperature and also by Predicted Mean Vote (PMV) index and Predicted Percentage of Dissatisfied (PPD) index. The model named Predicted Mean Vote model was developed by Fanger [4] which combines the six thermal comfort parameters into an index that can be used to predict thermal comfort level. PMV index is derived on the basis of experimental conditions which are near thermal neutrality or slightly discomfort. The index provides a score that corresponds to ASHRAE thermal sensation scale and represents the average thermal sensation felt by a group of people in a space. Fanger [4] proposed the Predicted Percentage of Dissatisfied (PPD) to predicate the percentage of people‘s dissatisfaction degree. The quality of the thermal environment may be expressed by the PPD index, which is related to the PMV index. When calculating the indoor thermal climate, operative temperature (T_o) can be used as a simple measure for the heat loss from an occupant and also used to determine the temperature limit of the comfort zone [2]. A range of operative temperature provides an acceptable thermal environmental condition. In determining operative temperature, mean radiant temperature is seems to be a significant factor, especially in buildings [13].

Conversely, glazing ratio also known as window-to-wall ratio (WWR) is considered as a very important parameter affecting the thermal performance of window configuration [7]. WWR is usually measured as the percentage area determined by dividing the building’s total window area by its exterior envelope wall area, and multiplies by one hundred. In this context, Atolagbe [4] carried out a study on natural ventilation and body heat comfort: an evaluation of residents’ satisfaction in Ogbomoso, Nigeria. This study evaluates the variations in the level of natural ventilation in houses across the three main residential density zones of Ogbomoso. The study employs two approaches. First, it surveys the perception of residents with respect to the body heat comfort in their houses. Second, it examines the window opening sizes for compliance with floor areas considered desirable for effective natural ventilation in a warm humid climate like Nigeria. The main objective is to validate residents’ perception of body heat comfort through the assessment of window opening to floor areas ratio. The methodology employed is the multi-stage sampling procedure where houses are sampled from sampled streets, and a household head sampled from each house, such that the perception of residents and evaluation of window and floor areas ratio are both carried out on the same household and house, respectively. The result shows that residents’ satisfaction as well as window to floor areas decreases with residential density zones.

Gao and Lee [5] evaluated the influence of opening configuration on natural ventilation performance of residential unit at Honk Kong. On-site tracer-gas experiments and measurements were carried out in a representative residential unit with side-hung window. Based on the measured data, CFD software Airpak was used to simulate the natural ventilation performance for the use of different window types. The result stated that relative position of the two window opening in bedroom windows and living room windows were the most affecting parameter. Also better natural ventilation performance can be achieved when the two openings are positioned in opposite direction or perpendicular to each other [6]. None of these previous researches in this area addressed the effect of window configuration in wall panel on room temperature in naturally ventilated buildings in Asaba, Nigeria. Therefore there is need to study the effect of the varieties of configuration of window types in the design of buildings to meet the residents’ requirements or aesthetic demand of buildings in order to ascertain the effect(s) they exert on room temperature in naturally ventilated buildings in the study area.

III. RESEARCH METHODOLOGY

This section presents the study area, the data collection method and characteristics of the monitored buildings.

Study area

The study area is Asaba, capital city of Delta state. Nigeria lies within 4^0N to 14^0N Latitudes and 2^0E to 14.5^0E Longitudes. Asaba lies in Latitudes 6.2^0N of the Equator and Longitude 6.73^0E of the Greenwich Meridian located within the warm humid climate zone. The annual mean temperature usually varies between 25^0C and 27^0C. The monthly mean and daily temperatures vary and often range between 20^0C and 33^0C, while throughout the year, temperature hardly falls below 20^0C at any instance and little variation exists between day and night temperatures [11].

Data collection instrument

The data for this research were collected through physical measurement and questionnaire. In the field work, the data were collected from the three easily recognisable residential zones in Asaba, which are Nnebisi Road Axis, Okpanam Road Axis, Asaba-Benin Express axis. The sampling was focused on the residential buildings and the five most popularly used window types which are casement, casement-with-vent, sliding, projected, and louvre window in the study area. Data were collected through a multi-stage sampling procedure from each zone. Fifteen naturally ventilated residential buildings were randomly sampled from the Nnebisi Road Axis, Okpanam Road Axis, Asaba-Benin Express residential zones. A randomly systematic sampling procedure was adopted in picking five buildings with different window configuration in each of the three residential zones in the study area.

The primary sources of data were collected through physical measurements using sensors (data logger) to monitor the indoor air temperature in the naturally ventilated buildings. The indoor climate Data logger (TA298) and Air Flow digital anemometer (AM-4812-2-2) were utilized to measure the indoor climate conditions during the physical measurement. The data loggers were ideal because the accuracy of temperature reading is between ±1^oC and record temperature from 0^oC to 50^oC. The accuracy for relative humidity is ±5%RH and the reading resolution is 0.1^oC for temperature and 0.3% for relative humidity. The instruments were placed at 0.6m, 0.9m, and 2.1m from the floor to record the thermal

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comfort variables simultaneously, as the subjects filled in the thermal comfort questionnaire. 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. Equation 1.1 shows the mean radiant temperature:

$$T_{mrt} = T_g + 2.35\,(v)^{0.5}\,(T_g - T_a) \qquad \text{...............Equation (1.1)}$$

Where;

T_{mrt} = mean radiant temperature
T_a = air temperature (dry bulb temperature)
T_g = globe temperature
V = relative air velocity

Operative temperatures were obtained from the average of mean radiant temperature and dry bulb temperature weighted by their respective transfer coefficients (Aynsley, Harkness, & Szokolay, 1996).Hence, Equation 1.2 shows the operative temperature:

$$T_o = \frac{h_c T_a + h_r T_{mrt}}{h_c + h_r} \qquad \text{.................Equation (1.2)}$$

Where;
h_c=convection coefficient
h_r = radiation coefficient
T_{mrt} = air temperature
T_a = mean radiant temperature

This index integrates the effect of air temperature and radiation, but ignores humidity and air movement.

3.3 Characteristics of monitored building:

The first residential building measured in the field work was a semi-detached three bedrooms flat with sliding, louvre and casement windows on each floor respectively. The building character can be seen from the floor plan as shown in Figure 1.1.

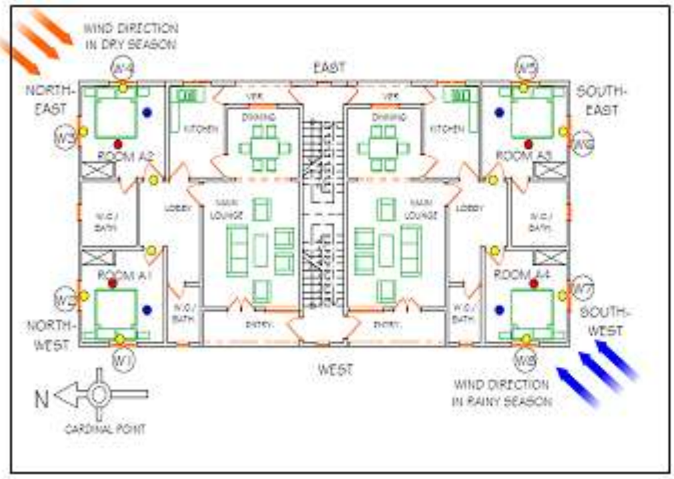

Fig.1. Floor plan showing Characteristics of monitored building
Source: Field work (2022).

The Table 1.2 above shows window size in rooms A, B and C were the same, and there were two windows in each room. The maximum operable area varies in percentage. In room A, we have sliding window 3 panes (13.2%), room B louvre 3 panes (20%) and Casement 3 panes (18%). The windows were 1800mm width and 1200mm height respectively as shown in Plate 1.1.

Floor level		Ground floor	First floor	Second floor
Room		Room A	Room B	Room C
Orientation		North-west 345°	North-west 345°	North-west 345°
Number of panes		3	3	3
Dimensions of room	Width (m)	3300	3600	3600
	Depth (m)	3300	3600	3600
	Height (m)	2700	2700	2700
Window characteristics	Width (m)	1800	1800	1800
	Height (m)	1200	1200	1200
	Glazing ratio [WWR] (%)	20%	20%	20%
Window type		Sliding	Louvre	Casement
Maximum openable area		13.2%	20%	18%

Table 1.1: Characteristics of typical rooms and windows in the monitored building

Plate 1.1: Semi-detached three bedrooms flat building, with sliding in ground floor, louvres in first floor and casement in second floor (Field work, 2022).

IV. DATA PRESENTATION AND ANALYSIS

This section presents the data generated from the field work. Thermal environment measurements and questionnaire were carried out in 15 buildings. Environmental parameters relating to body thermal balance, such as air temperature, relative humidity, and air velocity, were recorded. Mean radiant temperature calculated based on ASHRAE standard 55.

Table 1.2: Result of indoor thermal measurement

Window type	Building location	Te AIR (ºC)	Te WET BULB (ºC)	Te WET BULB (ºC)	Te GLOBE (ºC)	Re HUM (%)	AIR Vel (m/s)	MRT (ºC)
Casement	Nnebisi axis	25.67	23.45	27.21	25.74	83.61	1.16	25.33
	Okpanam axis	24.89	21.63	28.93	24.95	75.75	1.12	25.28
	Express axis	26.46	22.47	31.47	26.73	65.35	1.11	26.97
Average		25.67	22.51	29.20	25.80	74.90	1.13	25.86
Casement /Vent.	Nnebisi axis	27.03	24.68	29.73	27.41	82.49	1.19	27.20
	Okpanam axis	24.51	21.76	32.84	24.62	58.97	1.23	27.30
	Express axis	26.23	25.01	30.01	26.71	81.25	1.17	27.51
Average		26.00	23.81	30.86	26.24	72.23	1.19	27.15
Sliding	Nnebisi axis	27.42	22.53	32.11	27.76	84.05	0.19	27.32
	Okpanam axis	24.81	25.63	26.97	24.63	75.95	0.20	26.30
	Express axis	25.65	21.95	31.95	25.73	80.74	0.15	26.95
Average		25.96	23.37	30.34	26.04	80.24	0.18	26.85
Projected	Nnebisi axis	24.76	23.83	29.83	24.82	82.50	0.20	26.83
	Okpanam axis	27.29	25.72	29.21	27.32	75.35	0.25	27.46
	Express axis	27.31	24.36	28.35	27.45	69.98	0.19	26.35
Average		26.45	24.63	29.13	26.53	75.94	0.23	27.04
Louvre	Nnebisi axis	24.52	21.58	29.53	24.72	85.03	1.25	25.55
	Okpanam axis	25.84	22.42	31.41	25.93	85.25	1.19	26.91
	Express axis	27.91	23.74	30.81	28.04	75.45	1.23	27.27
Average		26.09	22.58	30.58	26.23	65.91	1.22	26.57

Source: field work (2022).

Legend: Te AIR – Air temperature
Te WET BULB – Wet Bulb temperature
Te DRY BULB – Dry Bulb temperature
Te GLOBE – Globe temperature
Re HUM – Relative humidity
AIR Vel. – Air velocity
MRT – Mean radiant temperature

Thermal measurements indicate that indoor air temperatures range was 24–27ºC. The distributions of the globe temperature were within the range of 24.0-27.0°C. Values of mean radiant temperature were typically slightly higher than those of air temperature, with differences of 0.2–1.0ºC. The humidity varies from 58% to 85% and the air velocity range was 0.20 – 1.25 m/s as shown in Table 1.2.

Thermal perceptions are different among people, even though they are in the same environment. To reduce the individual differences, De Dear (2002) suggested that the bins' mean thermal sensation votes (MTSV), rather than the individual actual votes, be used in the analysis. The sensitivity of the occupant's thermal perception to operative temperature will be assessed by examining MTSV responses for each half-degree interval. The fitted regression lines for occupants' perception versus operative temperature are:

MTSV = 0.315 x T_0 - 8.068, R_2 = 0.805 ....Equation (1.3)

Again, the linear regression was applied to PMV model's prediction and operative temperature. A regression line for average binned predicted mean votes (PMV) was also superimposed in Figure 1.2. The regression equation fitted to PMV index values is:

PMV = 0.274 x T_0 - 6.732, R2 = 0.985 ....Equation (1.4)

The coefficient of determinant (R_2) between MTSV/PMV and the operative temperature is 0.805 for Eq. (1.3) and 0.985 for Eq. (1.4). The values of R_2 indicate high significance between the observed /predicted thermal perception and the indoor operative temperature

Table 1.3: Result of operative temperature, PMV and PPD values

Window type	Building location	PMV	PPD
Casement	Nnebisi axis	4.8	5.8
Casement	Okpanam axis	4.5	6.9
Casement	Express axis	4.5	5.8
Casement /Vent.	Nnebisi axis	3.8	5.2
Casement /Vent.	Okpanam axis	3.8	5.0
Casement /Vent.	Express axis	3.8	5.2
Sliding	Nnebisi axis	6.0	5.0
Sliding	Okpanam axis	6.5	5.0
Sliding	Express axis	6.2	5.0
Projected	Nnebisi axis	5.5	5.8
Projected	Okpanam axis	5.0	5.8
Projected	Express axis	4.8	5.8
Louvre	Nnebisi axis	3.8	5.2
Louvre	Okpanam axis	3.5	5.2
Louvre	Express axis	4.4	5.8

Source: field work (2022).

Based on the field work the parameters measured were dry bulb, wet bulb, globe temperature, relative humidity, and air velocity which were the main parameters needed in calculating the thermal comforts PMV and PPD values. Table 1.3 shows the results of the PMV and PPD values.

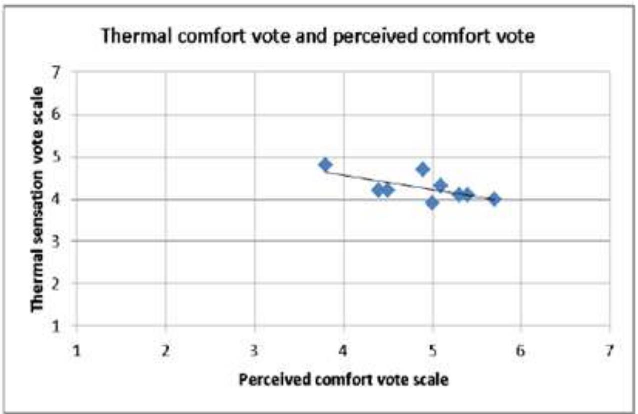

Figure 1.2: Result of PMV and PPD values (field work 2022).

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The result of occupant perception of thermal comfort emanating from naturally ventilated residential buildings with respect to the window types in the study area are shown in Figure 1.3.

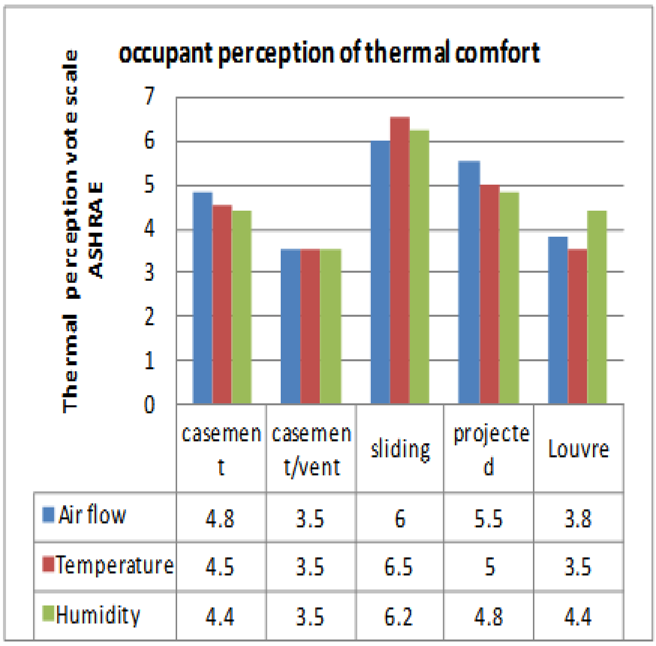

Figure 1.3: Result of occupant perception of thermal comfort emanating from buildings with casement (C), casement-with-vent (CV), sliding (S), projected (P), and louvre (L) (field work 2022).

V. DISCUSSION OF RESULTS

This research shows the need to understand the window configuration to be used in naturally ventilated residential designs so as to achieve a comfortable room temperature. The occupant perception of thermal comfort emanating from the monitored building shows the effect of window configuration in wall panel on room temperature. The ASHRAE scale was adopted in the analysis of the effect of casement window, casement with vent, sliding, projected and louvre window on room temperature. The result shows that the PMV of casement is 4.5 (which indicates neither cool nor warm), casement with vent 3.5 (comfortably cool), sliding 6.5 (too warm), projected 5.3 (comfortably warm), louvre 3.5 (comfortably cool). Atolagbe [3] carried out a study on natural ventilation and body heat comfort and the result stated that the comfort of users in regards to indoor heat or temperature is influence by windows in buildings. However, the result of this research shows that different window configuration have significant effect on room temperature in naturally ventilated residential buildings in Asaba, Nigeria.

VI. CONCLUSIONS

Window configurations in wall panel have effect in providing comfortable room temperature in naturally ventilated residential buildings. Sliding windows were mostly used because it is considerably cheaper and the prevailing type that is in use, despite that its PMV 6.5 (too warm). The most effective window configuration should be used in naturally ventilated residential buildings in Asaba, Nigeria. Therefore window configurations with PMV value of 4.5 or less which are casement with vent, louvre and casement is recommended to improve thermal comfort in residential buildings in the study area.

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