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An Assessment of Orientation on Effective Natural Ventilation for Thermal Comfort in Primary School Classrooms in Enugu City, Nigeria

By Emeka J. Mba[1], Chinwe G. Sam-amobi[1], Francis O. Okeke[1]*

Abstract

The current harsh climatic and high thermal conditions observed across the globe due to climate change is a challenge for indoor thermal comfort in buildings. In most developing nation, educational buildings where formal teaching and learning is conducted are designed to function without mechanical ventilation in an attempt to save energy costs hence relying solely on Natural ventilation. However, the effects of orientation on effective natural ventilation in educational buildings in the hot-humid tropical environments have not been adequately explored. The aim of this study was to investigate the effect of orientation of the classroom buildings with respect to cardinal and wind directions on effective natural ventilation desired for thermal comfort in buildings of public primary schools in the city of Enugu, Nigeria. It adopted a combination of experimental and descriptive survey research design. Instruments for data collection were two thermo-anemometer data logging device (AZ 9871) for determining both indoor and outdoor temperatures, wind velocities and relative humidity of classrooms of selected 60 public primary school building in the metropolis based on stratified sampling technique. Data analysis was done using linear regression analysis, the global coefficient of ventilation and building orientation standards. The research results showed that there was a correlation between classroom building orientations and effective natural ventilation coefficient and that the mean natural ventilation efficiency of 80% above the 60% global ventilation efficiency standard was achieved. In addition, orientation of classroom buildings in terms of inlet window planes to the dominant wind direction had positive significant effect on natural ventilation efficiency, invariably influencing the thermal comfort conditions of the investigated classrooms. The research concludes that adequate attention should be given to the orientation in classroom buildings especially in the hot humid tropical environments by architects and building designers to ensure thermal comfort is achieved for effective teaching and learning.

Keywords: Building orientation, Natural ventilation, Tropical environment, Classroom buildings, Thermal comfort

1. Introduction

Architecture establishes profound realities that once erected are not easily altered, and its product can help escalate public health issues (Okeke et al., 2019). In a formal educational environment, a conducive atmosphere is required for effective teaching and learning. The thermal condition, which is largely dependent on effective ventilation, is one facet of a conducive atmosphere that influences teaching and learning (Olygay, 1963; Okedele, 1988; Akinniyi, 2006; Chan et al., 2014). A well-ventilated classroom and also the removal of odour according to Nielsen (2001), are critical features of good designs for educational facilities and it entails a wide range of unique characteristics evidenced by the architectural design of the building. Also, air flow has been recognized to be vital in total

| [1]Department of Architecture, University of Nigeria, Enugu State, Nigeria.
*Corresponding Author.

indoor air quality, and this is strongly related to their capacity to maintain temperature regulation. Therefore, to achieve the desired thermal comfort level in the tropics, airflow is crucial because of the elevated temperature and high relative humidity of this region (Okeke et al., 2021). Consequently, one functional requirement of building design in this climate is effective cross ventilation.

Practically all notable building structures used passive means for ventilation until late 20th century when the technique was generally abandoned in larger buildings due to excess heat gains (Walker, 2016). As a means of compensating for the excess heat gains especially in the hot humid tropics, the use of mechanical cooling systems became rampant. However, with global climate change issues and the advent of advanced Building Energy Modeling (BEM) software, Leadership in Energy and Environmental Design (LEED) design requirements, improved Building Automation Systems (BAS), and improved window manufacturing techniques; natural ventilation is making a comeback in institutional buildings around the world (Walker, 2016). Available building stock have been identified as a major contributor to greenhouse gas emission and key consumer of energy, therefore to reduce energy usage, building structures are to be designed to maximize free natural air supply.

Architectural design strategies like orientation of buildings with respect to wind direction, ordering of building forms, openings and use of shading devices among other strategies can be used to achieve Natural ventilation. However, thermal comfort which is a condition of the mind depends on impacts of three factors (relative humidity, wind speed and temperature). According to Okedele (1988), ventilation that can remove heat, cool the body and the building without mechanical assistance is what he referred to as effective ventilation for thermal comfort. Sharma et al. (2011), believed that higher air flow rates of between 0.5m/s to 2.5m/s are necessary in the tropical climate, as opposed to 0.2m/s in temperate regions. As a result, designing classroom structures for natural ventilation in the tropics may be a difficult task. Therefore, to guarantee that such designs accomplish the goal of delivering effective natural ventilation, Quirix (2002), recommends that post-occupancy evaluation (POE) be performed on buildings to give the empirical foundation for either validating or revising such designs. This submission was buttressed by Baiyewu (2002), who stated that for continual improvement in all areas of architectural building design and construction, extensive studies of building performance versus objectives and principles are required. This is due to the fact that buildings do not always perform as-designed and expected, and such assessments will provide feedback for either improving or modifying the structure through re-design, retrofitting and renovation (Godwin, 1988, Baiyewu, 2002; Idowu, 2009).

In spite of this knowledge, only few empirical studies on effective natural ventilation in institutional buildings (public primary school classrooms) in Nigeria have been conducted. As a result, Idowu, 2009; Izomoh, 1988 and Godwin, 1988 reported replication of prototype designs of primary school classrooms in various micro-climatic settings all over the country. Evidence in literature reveals that most public primary schools in hot humid climates lack conducive thermal environment for teaching and learning due to poor natural ventilation. Furthermore, the current harsh climatic and high thermal conditions observed across warm-humid tropical environs, including Enugu city due to climate change is a source of challenge to designers and administrators of school building. This study therefore aims to examine the effects of orientations in classroom buildings for natural ventilation and desired thermal comfort of users in public primary school in Enugu Urban, Nigeria. The objectives of this study include: 1) Identify the desired natural ventilation coefficient for thermal comfort in the classrooms of selected Enugu city public primary schools, 2) investigate the influence of building orientation in relation to cardinal direction on effective natural ventilation necessary for thermal comfort in classrooms of selected Enugu urban primary schools and 3) Evaluate the orientation of the classrooms with respect to the inlet planes and predominant wind on natural ventilation for the required thermal comfort. Furthermore, the following hypotheses were tested in this study:

H1: There is no significant relationship between orientation of classroom buildings and effective natural ventilation in classrooms

H2: There is no significant relationship between natural ventilation and thermal comfort in the classrooms.

This research is predicated on the notion that orientation of buildings as a design strategy can have a considerable effect on natural ventilation and thermal comfort levels of building users, particularly in a hot- humid tropical environment of south-eastern Nigeria. Although, the findings of this study can be used to provide input on the utilization of natural ventilation systems in public schools in Enugu City and other warm humid tropical environments. The purpose of this information is to discourage high energy usage in heating, ventilation and air-conditioning (HVAC) system in primary school buildings in the study area, while maintaining the acceptable thermal comfort levels.

2. Context of Study

This study was designed to assess the effectiveness of natural ventilation in public primary school buildings in Enugu's warm-humid climate, Nigeria's south-east. Known as the "top of the hill," Enugu is Nigeria's oldest urban center of the Igbo speaking region. Located approximately between latitudes 6^0 21'N & 6^0 30'N and longitudes 7^0 26'E & 7^0 37'E (Okeke et al., 2020); Enugu is a metropolitan city that covers roughly 73 square kilometers with about nineteen residential areas (see figure 1).

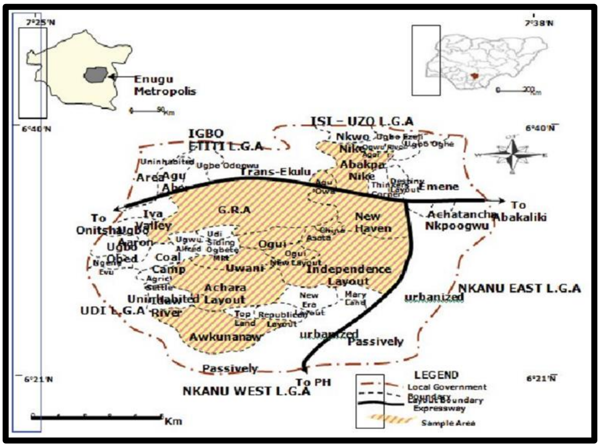

Figure 1: Map of Enugu Metropolis (City) in Enugu State, Nigeria.
Source: http://www.enugustate.gov.ng/ (2018).

3. Literature Review

Natural ventilation refers to the flow of external air to an indoor space as a result of pressure differences arising from natural forces. The control of natural ventilation is one of the most subtle and yet the most important of building design in a tropical environment (Roaf et al., 2004). It solves two fundamental needs: elimination of foul air to provide good indoor air quality and moisture, and the modification of interior overheating by boosting natural cooling for occupant thermal comfort, particularly in tropical environments (Rajapaksha, 2004; Aynsley, 2007). According to Chand (1976), Natural ventilation in a building is affected by velocity of wind outside, the orientation of building in relation to the outdoor wind, architectural features of the building and other external and man-made features. Building orientation is a significant design consideration, mainly with regard to solar radiation and wind. In predominantly humid and hot humid regions like Nigeria which receives sunlight all year around, buildings should be oriented to minimize solar gain and maximize natural ventilation (Munonye, 2020). Orientation of buildings is approximated either in relation to the outdoor wind direction or with respect to the cardinal points and the buildings' opened facades (Neufert, 1984). Buildings may not necessarily be oriented perpendicular to outdoor wind direction in order to maximize the benefit of natural wind. An angle between 90^0 and 60^0 to the face of the building was appropriate. An orientation as low as 20^0 to the face of building, was permissible for schools. Building orientation parallel to outdoor wind direction would benefit minimally from natural wind flow (Godwin, 1988; Boutet, 1987 and Idowu, 2009). Maximum air movement through the building is achieved by placing inlet openings in positive pressure zones and outlet openings in negative pressure zones. On the one hand when windows are located on opposite walls of a room, optimum air distribution is obtained when the wind is oblique at an angle of 45^0 to the inlet window. When windows are located on adjacent walls of a room, on the other hand optimum air distribution is obtained when the wind is incident perpendicular to the window (Aynsley, 2007). Ideally, naturally ventilated buildings should be oriented to maximize their exposure to the required wind direction, and designed with a relatively narrow plan form to facilitate the passage of air through the building (Boutet, 1987; Liman & Abadie, 1998).

In a study on natural ventilation performance of buildings with respect to their orientation and window location on walls, Olufowobi (1988) reported that optimum air distribution is obtained when the wind is oblique at an angle of 45^0 to the inlet window (for openings located on opposite walls of a room). On the other hand, optimum air distribution is obtained when the wind is incident perpendicular to the window for windows located on adjacent walls of a room. This report is in consonance with the findings of Givoni (1973) and Chand (1976). Uzuegbunam et al. (2012), in a study on evaluation of orientation as design strategy for effective passive ventilation in students' hostels in hot-humid tropical environment of Enugu campus, Nigeria, reported that orientation of buildings with respect to the cardinal points is no longer novel, but rather, that buildings be oriented in relation to the dominant outdoor wind directions and window inlet planes. The studies reveal that there is a correlation between effective ventilation coefficient (ventilation efficiency) and orientation of buildings. The authors recommended the need for proper investigation of wind paths which would provide orientation options for buildings to aide effective natural ventilation desired for thermal comfort in hot humid tropical environment.

4. Research Methodology

An experimental research design similar to the previous studies of Mba et al., (2021) was adopted because it is a sub-set of a broader research on building ventilation. Classrooms of public primary schools in Enugu Urban made up the study population, while sixty-seven (67) public primary schools obtained from Enugu State Universal Basic Education Board (ENSUBEB) in 2018 for Enugu City was sampling frame of the study. Employing Stratified sampling technique, sample size for this study was gotten. A pilot survey within the metropolis showed that three proto-type designs of classroom buildings exist in public primary schools with different design because of their educational era and systems. These are the colonial era classroom buildings (pre-independence era before 1960), the Universal Primary Education (UPE) era classroom buildings (built between 1960 & 1989) and the Universal Basic Education (UBE) era classroom buildings constructed from 1990 to 2018. The criteria utilized for identifying the study samples was generated through a design attributes study of the classroom buildings in the study area. These criteria defined building types (clusters) as models that share characteristics with others in the cluster. Only those primary schools with the three pro-type classroom designs (clusters) were selected for study. Twenty-one out of sixty-seven public primary schools were identified. The selected public primary schools were: Carter Street Primary Schools, Ekulu Primary Schools, and Independence Layout Primary Schools, Moore House Primary Schools, New Haven Primary Schools, Obiagu Primary Schools, Ogui-Nike Primary Schools, Ogui Primary Schools, and WTC Primary Schools in Enugu-North Local Government Area (L.G.A.), Achara Layout Primary School and Agbani Road Primary Schools. Others are Niger Close Primary Schools, Idaw River Primary Schools, Igbariam St. Primary Schools, Robinson St. Primary Schools and Zik Avenue Primary Schools in Enugu-South L.G.A.; Abakpa-Nike Primary Schools, Central Primary School Emene, Abakpa Housing Estate Primary Schools, and Trans-Ekulu Primary Schools in Enugu-East L.G.A.

Furthermore, a sample size of public primary schools selected was determined using Cochran's formula for calculating sample size when population size is finite given as

Sample size (n) = $n_o / 1+ (n_o - 1) / N$. (Cochran, 1997) …. Equation 1

Where $n_o = z^2pq/e^2$, z = critical value of desired confidence level = 1.96; p = estimated proportion of population = 50%=0.5 = max variability, q = (1-p) = 0.5; e = desired level of precision at 95% confidence level = 0.005 and N = population size (21 public primary schools). The value for n_o was determined as shown in equation, which produced 384

$n_o = (1.96)\ 2\ (0.5)\ (0.5) / (.05)\ 2 = 384.16 = 384$ …………… Equation 2

Substituting the value of no in equation 1, the sample size was given as

$n = 384/ 1+ (384-1) / 21=20.21$…………………… Equation 3

This translated to 20 public primary schools in Enugu metropolis

In the selection, one classroom was sampled from each prototype building, representing an education era and was randomly selected from the calculated sample size. A total of sixty classrooms/and buildings were selected. This study was conducted in the months of March (hottest month), June, July, and August (coolest month) in 2018. The primary data were collected using two data logging instrument (thermo-anemometers -AZ 9871) to measure wind velocity, relative humidity, and temperature within and outside the selected classrooms. A magnetic compass was used to measure the wind directions while a digital still camera was utilized in taking photographs of the selected classroom buildings. A 30.6m fibre-glass and 3.6m metallic tapes were used to measure external dimensions and openings in buildings. The data logging instrument stores up to 12,000 readings for data analysis. One of the Anemometers labelled "Equipment X" was held outside at a point 1500 mm high above the ground and 4000mm wide from each of the classroom building selected for survey, and totally free from obstruction. The wind velocities, relative humidity and temperatures of the outdoor climate were measured. These measurements were repeated at ten minutes' interval, three times in the morning and three times in the afternoon, for five school days.

Indoor air speed, relative humidity and air temperature for each selected classroom were measured at 1500mm above ground floor level, with the other Anemometer "Equipment Y", at the Centre of the classrooms selected for the research. These measurements were also repeated after every 10 minutes three times in the morning and three times in the afternoon, for five school days. A minimum of 225 readings of average wind speed, relative humidity and temperature values for both the outdoor and indoor spaces were recorded for each of the classrooms studied. The outdoor and indoor climate measurements were taken simultaneously as shown in Table 1. The interior lengths, breadths and heights as well as the opening sizes and locations (doors and windows), corridor depths and window sill heights from the ground of the selected classrooms were also measured.

Simple linear regression analysis was used to analyze the data at 0.05 significant levels.

The thermal comfort was estimated using the following equation

$TC = a+b1NV+e$ ……………………………Equation 4

Where: TC = thermal comfort (dependent variable), NV = effective natural ventilation (independent variable) and a=constant of regression, b=regression coefficient and e=standard error. Effective natural ventilation (NV) of the classrooms was determined by the Ventilation coefficient (V.C.). This is a method of evaluating global ventilation coefficient (CG) and it is a product of design strategy, of a wind-induced indoor air motion proposed by Centre Scieitifique et Technique du Batiment (CSTB, 1992). The coefficient is defined as the ratio of the mean indoor velocity, Vi at a height of 1.5m to the mean outdoor velocity, V_0 at the same height and could vary due to the following: V.C. = mean wind velocity indoors divided by mean wind velocity outdoors, or mean maximum wind velocity indoors divided by mean maximum wind velocity outdoors; depending whether the result is an equality or inequality. This ratio when expressed as a percentage is the natural ventilation efficiency of a building (effective natural ventilation).

Orientation of classroom buildings was expressed in terms of North-South (N/S) and East-West (E/W) cardinal directions with respect to buildings' opened façades or Dominant wind direction in relation to the inlet (window) plane. Windward and leeward sides were determined from the dominant wind direction in a session of observation. The dominant wind direction was the most frequent classroom-outdoor wind direction in a session of observation of wind indoor/outdoor of a classroom. It was either SW or a combination of the following; East (E), West (W), North(N), South(S), north-west (NW), north west-west (NWW), north-north west (NNW), north-east (NE), north east-east (NEE), north-north east (NNE), south-east (SE), south south-east (SSE), south-west

(SW), south west-west (SWW), and south south-west (SSW). These were expressed in relation to inlet plane as: normal/perpendicular to inlet plane (coded NML), parallel to inlet (window) plane (coded PRL) and neither normal nor parallel to inlet plane (coded NNP). In analyzing the effect orientation of building openings on natural ventilation desired for thermal comfort, the mean ventilation coefficient (a measure of effective ventilation) of the classrooms studied was firstly determined and compared with the known global ventilation coefficient (CG), which is given as 0.6 and used to ascertain the performance of the buildings. In order to identify the significant effect of Orientation of openings on the natural ventilation efficiency, the corresponding opening parameters of the classrooms were also compared with the standard architectural models proposed by Centre Scieitifique et Technique du Batiment (CSTB, 1992). The ventilation coefficients of the classrooms under different orientation strategies were also compared to identify their effects on effective natural ventilation.

5. Results

5.1 Natural ventilation coefficient desired for thermal comfort in the selected classrooms

The results in Table 1 reveal that the mean natural ventilation coefficient of the classrooms in the study area as it relates to the known global ventilation coefficient models was found to be 0.8; 57 out of the 60 classrooms studied representing 95% of all subjects recorded mean ventilation coefficients ranging from 0.6 to 0.9 higher than the global ventilation coefficient of 0.6. This suggests that 80% of the available free wind outside was admissible into the classrooms (See Table 1). Although some of classroom buildings identified were not sited at standardized setback distances from each other leading to obstructions of the prevailing wind directions resulting in poor ventilations of the affected classrooms, the available high outdoor wind mean speeds of 1.6m/s (average) and 2.0m/s (max.) during the periods of investigation favored the classrooms. Furthermore, the mean indoor climate of the classrooms desirable for thermal comfort was 30^{0}C temperature, 55% relative humidity and wind speed of 1.3m/s. Details of the mean indoor climates of the various proto-type classrooms are presented in Table 1.

Table 1: Weekly Mean of Instantaneous Temperature, Relative humidity and Wind speed in the Study Area

Selected Classroom Typology		**Indoor Climate**				**Outdoor Climate**				**Ventilation Coefficient (V.C.)**
		Temp (^{0}C)	**R.H. (%)**	**Av Wind Speed (m/s)**	**Max Wind Speed (m/s)**	**Av Wind Speed (m/s)**	**Temp (^{0}C)**	**R.H.**	**Max Wind Speed (m/s)**	
Abakpa-Nike	COL	30.4	54.5	1.3	1.5	1.6	29.7	50.2	2.1	0.8
	UPE	29.4	56.7	1.1	1.3	1.4	29.7	53.7	1.8	0.8
	UBE	29.1	57.7	1.3	1.5	1.6	30.0	52.6	2.1	0.8
Achara layout	COL	31.9	49.4	1.2	1.3	1.9	30.9	47.4	2.4	0.6
	UPE	32.1	49.9	1.4	1.5	1.8	33.4	47.3	2.1	0.8
	UBE	30.7	52.4	1.3	1.5	2.2	33.6	44.5	2.5	0.8
Agbani Road	COL	29.9	56.4	1.3	1.5	1.7	28.3	60.8	2.0	0.8
	UPE	31.2	51.2	1.9	2.0	2.0	27.6	61.2	2.3	0.9
	UBE	31.3	53.1	1.2	1.3	1.6	28.3	61.8	1.8	0.8
Carter Street	COL	29.1	57.1	1.1	1.2	1.3	32.1	47.1	1.6	0.9
	UPE	29.1	55.9	1.3	1.4	1.4	32.2	47.0	1.7	0.9

Selected Classroom Typology		**Indoor Climate**				**Outdoor Climate**				**Ventilation Coefficient (V.C.)**
		Temp (^{0}C)	**R.H. (%)**	**Av Wind Speed (m/s)**	**Max Wind Speed (m/s)**	**Av Wind Speed (m/s)**	**Temp (^{0}C)**	**R.H.**	**Max Wind Speed (m/s)**	
	UBE	28.9	58.0	1.1	1.2	1.3	32.5	46.0	1.6	0.9
Central Emene	COL	31.8	49.8	1.4	1.4	1.6	34.5	42.7	2.1	0.9
	UPE	29.8	57.7	1.4	1.6	1.6	27.5	57.6	2.0	0.9
	UBE	31.9	50.2	1.4	1.5	1.7	32.2	46.4	2.2	0.8
Ekulu	COL	31.7	50.6	1.3	1.5	1.5	33.5	39.6	1.9	0.9
	UPE	31.4	50.8	1.4	1.6	1.6	32.4	42.9	2.4	0.9
	UBE	31.7	50.2	1.4	1.5	1.6	32.2	42.6	2.4	0.9
Hse Estate Abakpa	COL	30.2	54.9	1.2	1.4	1.4	31.1	49.0	1.7	0.8
	UPE	30.7	53.7	1.1	1.2	1.4	31.6	46.6	1.8	0.8
	UBE	30.4	55.5	1.1	1.2	1.4	30.9	49.2	1.7	0.8
Idaw River	COL	30.6	52.8	1.4	1.5	1.6	30.0	55.0	1.9	0.8
	UPE	31.7	50.2	1.3	1.4	1.4	30.0	55.2	1.6	0.9
	UBE	30.1	55.7	1.5	1.6	1.8	30.1	55.7	2.1	0.8
Igbariam Street	COL	30.3	52.6	1.5	1.6	1.8	29.9	55.5	2.1	0.8
	UPE	30.0	53.7	1.6	1.8	1.8	30.3	54.7	2.0	0.9
	UBE	30.4	52.8	1.4	1.5	1.8	29.8	55.0	2.0	0.8
Independence	COL	28.3	58.8	1.3	1.4	1.6	28.7	60.2	1.9	0.8
	UPE	28.5	58.0	1.2	1.3	1.5	30.1	56.2	1.8	0.8
	UBE	29.2	57.5	1.2	1.3	1.5	28.8	59.1	1.8	0.8
Moore House	COL	29.0	57.0	1.2	1.3	1.6	31.0	48.6	2.2	0.7
	UPE	28.6	58.2	1.3	1.5	1.4	30.5	50.7	2.0	0.9
	UBE	29.2	57.7	1.1	1.3	1.3	31.5	49.2	2.0	0.8
New Heaven	COL	31.9	50.2	0.7	1.0	1.4	32.2	46.4	2.2	0.5
	UPE	31.8	49.8	0.8	1.1	1.4	34.5	42.7	2.1	0.5
	UBE	31.8	50.6	0.7	1.3	1.5	33.0	45.0	1.7	0.5
Niger Close	COL	30.1	53.5	1.4	1.5	1.5	32.3	48.4	1.8	0.9
	UPE	30.0	55.1	1.3	1.4	1.6	31.0	51.2	1.8	0.9
	UBE	30.5	52.5	1.3	1.4	1.5	31.4	48.5	1.8	0.8
Obiagu	COL	28.4	58.8	1.3	1.5	1.5	30.8	49.5	1.9	0.9
	UPE	28.6	57.8	1.3	1.5	1.5	30.5	59.3	2.1	0.8
	UBE	28.2	59.9	1.5	1.7	1.8	30.5	59.8	2.2	0.8
Ogui-Nike	COL	28.5	59.8	1.7	1.9	1.9	29.7	52.8	2.3	0.9
	UPE	27.7	60.4	1.6	1.8	1.9	29.5	51.7	2.5	0.8
	UBE	27.8	61.2	1.9	2.1	2.1	29.0	50.3	2.6	0.9
Ogui	COL	28.7	59.3	1.4	1.5	1.6	30.1	52.8	1.9	0.8
	UPE	28.7	58.5	1.1	1.2	1.4	30.8	51.7	2.0	0.9
	UBE	28.6	59.0	1.3	1.5	1.5	30.7	50.3	1.8	0.8
Robinson Street	COL	30.1	56.0	1.0	1.1	1.1	27.4	58.8	1.5	0.8
	UPE	32.6	46.0	1.5	1.6	2.1	30.7	48.5	2.4	0.7
	UBE	31.2	53.3	1.3	1.4	1.8	32.7	48.3	1.9	0.8
Trans-Ekulu	COL	32.6	48.3	1.7	1.9	1.8	33.4	39.6	2.2	0.9
	UPE	30.9	53.2	1.4	1.5	1.7	33.5	43.3	2.2	0.8
	UBE	32.3	49.8	1.3	1.4	1.5	32.5	44.7	1.9	0.9
WTC	COL	29.4	57.5	1.2	1.5	1.4	27.4	61.4	1.8	0.9
	UPE	29.7	57.3	1.3	1.5	1.5	28.1	59.0	2.0	0.9
	UBE	29.5	57.6	1.3	1.6	1.6	27.0	59.9	2.2	0.8
Zik-Avenue	COL	29.4	57.5	1.3	1.4	1.5	31.0	49.4	1.8	0.9
	UPE	30.9	50.8	1.6	1.7	1.7	30.5	52.4	2.0	0.9
	UBE	30.9	50.9	1.4	1.5	1.9	30.1	52.9	2.1	0.9
Mean of Proto-Types	COL	**30.1**	**54.7**	**1.3**	**1.4**	**1.6**	**30.7**	**50.8**	**2.0**	**0.8**
	UPE	**30.2**	**54.2**	**1.3**	**1.5**	**1.6**	**30.7**	**51.8**	**2.0**	**0.8**
	UBE	**30.2**	**54.8**	**1.3**	**1.5**	**1.6**	**30.8**	**51.4**	**2.0**	**0.8**
Mean of Study Area	**30**		**55**	**1.3**	**1.5**	**1.6**	**30.8**	**51.3**	**2.0**	**0.8**

Source: Analysis of Authors' Field Survey (2018)

5.2 Effect of orientation on natural ventilation for the desired thermal comfort in the classrooms

The effect of orientation on natural ventilation desired for thermal comfort in the classrooms of selected primary schools in the study area was expressed either in terms of orientation with respect to buildings' opened façades and dominant wind direction in relation to the inlet (window) plane. The study found that 40 out of 60 classrooms studied, which is around 67% of the sample recorded N/S orientation. The Universal Primary Education (UPE) classrooms typology recorded the highest number classrooms of 16 and best ventilation coefficient of 0.9 followed by the Colonial (COL) era typology which recorded 15 classrooms. The Universal Basic Education (UBE) era classrooms proto-type recorded 11 classrooms. The mean ventilation coefficient of the classrooms was 0.9 (Table 2). 11 of these classrooms openings were normal (NML) to dominant wind direction while 28 of them window planes neither normal nor parallel (NNP) to dominant wind direction. Ogui-Nike primary schools recorded the best ratio of outdoor to indoor wind speeds (Ventilation Coefficient), greater than the global Ventilation standard (G0.6) desired for thermal comfort. The details of natural ventilation coefficient performances and orientation of the individual proto-type classrooms in the various schools studied are presented in Table 2.

Table 2: Classrooms with North - South Opening Orientation

Name of School	Class Typology	Opening Orientation	Relative angle: dominant wind to Inlet plane	Av outdoor wind Speed	Av Indoor Wind Speed	Outlet/ Inlet Area Ratio	Ventilation Coefficient
Abakpa-Nike Primary Schools	UPE	N-S	NNP	1.4	1.1	1.4	0.8
	COL	N-S	NNP	1.6	1.3	1.3	0.8
Achara layout P/S	UPE	N-S	NNP	1.8	1.4	1.8	0.8
Agbani Road P/S	UPE	N-S	NML	2.0	1.9	1.6	0.9
Carter Street Primary School	UPE	N-S	NML	1.4	1.3	2.5	0.9
	COL	N-S	NNP	1.2	1.1	1.6	0.9
Central Primary Schools Emene	UPE	N-S	NNP	1.6	1.4	1.4	0.9
	COL	N-S	NNP	1.6	1.4	1.4	0.9
Ekulu Primary Schools	UPE	N-S	NML	1.6	1.4	2.5	0.9
	COL	N-S	NML	1.5	1.4	1.8	0.9
	UBE	N-S	NNP	1.6	1.3	1.6	0.9
Housing Estate Primary Schools	COL	N-S	NML	1.4	1.2	2.0	0.8
	UBE	N-S	NNP	1.4	1.1	1.9	0.8
Idaw River Primary Schools	UPE	N-S	NML	1.4	1.3	1.7	0.9
	COL	N-S	NML	1.6	1.4	1.5	0.8
	UBE	N-S	NML	1.8	1.5	1.9	0.8
Igbariam Street Primary Schools	UPE	N-S	NNP	1.8	1.5	1.6	0.8
	COL	N-S	NNP	1.8	1.4	1.2	0.8
Indep. Layout Primary Schools	UPE	N-S	NML	1.6	1.3	1.6	0.8
	COL	N-S	NML	1.5	1.2	1.2	0.8
Moore Hse P/Sch	UPE	N-S	NNP	1.4	1.3	1.5	0.9
New Haven P/Sch	UBE	N-S	NNP	1.3	0.7	1.7	0.5
Niger close Primary Schools	UPE	N-S	NNP	1.5	1.4	1.7	0.9
	COL	N-S	NNP	1.6	1.3	1.4	0.9
Obiagu Primary Schools	COL	N-S	NNP	1.4	1.3	1.5	0.9
	UBE	N-S	NML	1.8	1.5	1.5	0.8
Ogui-Nike Primary Schools	UPE	N-S	NNP	1.9	1.6	2.0	0.8
	COL	N-S	NNP	1.9	1.7	2.1	0.9
	UBE	N-S	NNP	2.1	1.9	1.5	0.9

Name of School	Class Typology	Opening Orientation	Relative angle: dominant wind to Inlet plane	Av outdoor wind Speed	Av Indoor Wind Speed	Outlet/ Inlet Area Ratio	Ventilation Coefficient
Ogui Primary Sch	UPE	N-S	NNP	1.6	1.4	1.3	0.9
Robinson Street Primary Schools	COL	N-S	NNP	1.1	1.0	1.3	0.8
	UBE	N-S	NNP	1.6	1.3	1.7	0.8
Trans-Ekulu Primary Schools	UPE	N-S	NNP	1.7	1.4	1.6	0.9
	COL	N-S	NNP	18	1.8	1.5	0.8
	UBE	N-S	NNP	1.5	1.3	1.7	0.9
WTC Primary Schools	UPE	N-S	NNP	1.5	1.3	0.8	0.9
	COL	N-S	NNP	1.4	1.2	1.3	0.9
Zik Avenue Primary Schools	UPE	N-S	NNP	1.7	1.6	1.1	0.9
	COL	N-S	NNP	1.5	1.4	1.9	0.9
Mean				**1.6**	**1.4**	**1.6**	**0.9**

Source: Analysis of Authors' Field Survey (2018)

The study also found that 20 classrooms representing 33% out of the sample studied recorded E/W orientation. The Universal Basic Education (UBE) era classrooms prototype recorded 12 classrooms, followed by the Colonial (COL) era typology which recorded 5 classrooms. The Universal Primary Education (UPE) classrooms typology recorded 3. The mean ventilation coefficient of the classrooms was 0.8. This orientation type recorded classrooms (such as New Haven primary schools) with the least ventilation coefficients of 0.5 below the acceptable global ventilation coefficient (G0.6) desired for thermal comfort in tropical climate by the standard architectural model proposed by Centre Scieitifique et Technique du Batiment (CSTB, 1992). The classrooms admitted only 50% indoor ventilation from the available average outdoor wind speeds. The details of the ventilation coefficients and orientations of the individual proto-type classrooms in the sample studied are presented in Table 3.

Table 3: Classrooms with East - West Opening Orientation

Name of School	Class Typology	Opening Orientation	Relative angle: dominant wind to Inlet plane	Av outdoor wind speed	Av indoor wind speed	Outlet/inlet area ratio	Ventilation Coefficient
Abakpa-Nike P/S	UBE	E - W	NNP	1.6	1.3	1.7	0.8
Achara layout Primary Schools	COL	E - W	NNP	2.2	1.3	1.8	0.8
	UBE	E - W	PRL	1.9	1.2	1.2	0.6
Agbani Road Primary Schools	UBE	E - W	NNP	1.6	1.2	1.3	0.8
	COL	E - W	NNP	1.7	1.4	1.4	0.8
Carter Street P/S	UBE	E - W	NNP	1.3	1.1	1.6	0.9
Central P/S emene	UBE	E - W	NNP	1.7	1.4	1.5	0.8
Igbariam Str P/S	UBE	E - W	NNP	1.8	1.4	2.0	0.8
Indep. Layout P/S	UBE	E - W	NNP	1.5	1.2	1.5	0.8
Moore House Primary Schools	COL	E - W	NNP	1.6	1.4	0.8	0.7
	UBE	E - W	NNP	1.3	1.2	2.0	0.8
New Haven Primary Schools	COL	E - W	PRL	1.4	0.7	1.4	0.5
	UPE	E - W	PRL	1.4	0.8	1.1	0.5
Niger close P/Sch	UBE	E - W	NNP	1.5	1.3	1.3	0.8
Obiagu P/ Schools	UPE	E - W	NNP	1.5	1.3	1.7	0.8
Ogui Primary	UBE	E - W	NNP	1.5	1.3	0.8	0.8

Name of School	**Class Typology**	**Opening Orientation**	**Relative angle: dominant wind to Inlet plane**	**Av outdoor wind speed**	**Av indoor wind speed**	**Outlet/inlet area ratio**	**Ventilation Coefficient**
Schools	COL	E - W	NNP	1.4	1.1	1.6	0.8
Robinson Str. P/S	UPE	E - W	PRL	2.1	1.5	1.7	0.7
WTC Primary Sch.	UBE	E - W	NNP	1.6	1.3	1.7	0.8
Zik Avenue P/Sch	UBE	E - W	NNP	1.9	1.4	3.3	0.9
Mean				**1.6**	**1.2**	**1.6**	**0.8**

Source: Analysis of Authors' Field Survey (2018)

5.3 Evaluation of the orientation of the classrooms with respect to the inlet planes and predominant wind

The study on Orientation of classrooms on natural ventilation with respect to inlet planes and dominant wind directions showed that 21 out of 60 classrooms studied, which is about 35% of the sample, recorded Normal (NML) inlet planes to the dominant wind directions. The Universal Primary Education (UPE) era classrooms typology recorded 8 classrooms, followed by the Colonial (COL) era typology which recorded 7. The Universal Basic Education (UBE) era classrooms proto-type recorded 6 classrooms. However, the mean ventilation coefficient of the classrooms in this cluster was 0.8, and the ratio of outlet area to inlet area was 1.6, higher than G 0.6 and 1.2 recommended by the standard architectural models proposed by Centre Scieitifique et Technique du Batiment (CSTB, 1992). This orientation strategy also recorded the second best average outdoor wind speed of 1.9m/s and the best indoor speed of 1.5m/s of the entire classrooms studied (Table 4).

Table 6: Classrooms with inlet planes Normal (NML) to dominant wind Direction

Name of School	**Class Typology**	**Opening Orientation**	**Dominant wind direction**	**Av outdoor wind speed**	**Av indoor wind speed**	**Outlet/ Inlet Area Ratio**	**Ventilation Coefficient**
Housing Est. P/S	COL	N - S	S	1.4	1.2	2.0	0.8
Achara layout P/S	UBE	E - W	W	1.9	1.2	1.2	0.6
Agbani Road P/S	UPE	N - S	S	2.0	1.9	1.6	0.9
Carter Street P/S	UPE	N - S	S	1.6	1.4	2.5	0.9
Ekulu Primary Schools	UPE	N - S	S	1.7	1.4	1.5	0.8
	COL	N - S	S	1.8	1.4	2.0	0.8
Idaw River Primary Schools	COL	N - S	S	1.6	1.4	1.5	0.8
	UPE	N - S	S	1.4	1.3	1.7	0.9
	UBE	N - S	S	1.8	1.5	1.9	0.8
Indep. Layout Primary Schools	UPE	N - S	S	1.6	1.3	1.6	0.8
	COL	N - S	S	1.5	1.2	1.2	0.8
Moore House	COL	E - W	W	1.6	1.4	0.8	0.7
Obiagu P/ Schools	UBE	N - S	S	1.8	1.5	1.5	0.8
Ogui-Nike P/S	UBE	N - S	S	2.1	1.9	1.5	0.9
Ogui Primary Sch	UPE	N - S	S	1.6	1.4	1.3	0.9
Robinson Street P/S	UBE	N - S	S	1.6	1.3	1.7	0.8
Trans-Ekulu Primary Schools	UPE	N - S	S	1.7	1.4	1.6	0.8
	UBE	N - S	S	1.5	1.3	1.7	0.9
WTC Primary Sch.	UPE	N - S	S	1.5	1.3	0.8	0.9
Zik Avenue Primary Schools	UPE	N - S	S	1.7	1.6	1.1	0.9
	COL	N - S	S	1.5	1.4	1.9	0.9
Mean				**1.9**	**1.5**	**1.6**	**0.8**

Source: Analysis of Authors' Field Survey (2018)

The study also found that 35 out of 60 classrooms studied, which is around 58% of the sample recorded window planes which were neither normal nor parallel (NNP) to dominant wind direction. The Universal Basic Education (UBE) era classrooms typology recorded 13 classrooms, while the Colonial (COL) era classrooms typology was 12. The Universal Education (UPE) era classroom proto- types recorded 10. The mean ventilation coefficient of the classrooms in this cluster was 0.8 and the ratio of outlet area to inlet area was 1.3 (Table 5). These coefficients, again were higher than the standard architectural models proposed by Centre Scieitifique et Technique du Batiment (CSTB). The details of orientation performances of the individual proto-type classrooms in the various schools studied are presented in Table 5.

Table 5: Classrooms with inlet planes neither Normal nor Parallel to dominant wind

Name of School	**Class Typology**	**Opening Orientation**	**Dominant wind direction**	**Av outdoor wind speed**	**Av indoor wind speed**	**Outlet/ Inlet Area Ratio**	**Ventilation Coefficient**
Abakpa-Nike Primary Schools	UPE	N - S	S	1.4	1.1	1.4	0.8
	COL	N - S	S	1.6	1.3	1.3	0.8
	UBE	N - S	S	1.6	1.3	1.7	0.8
Achara layout P/S	UPE	N - S	S	1.8	1.4	1.8	0.8
Agbani Road Primary Schools	UBE	E - W	W	1.6	1.2	1.3	0.8
	COL	E - W	W	1.7	1.4	1.4	0.8
Carter Street Primary Schools	UBE	E - W	W	1.3	1.1	1.6	0.9
	COL	N - S	S	1.2	1.1	1.6	0.9
Central Primary Schools Emene	UPE	N - S	S	1.6	1.4	1.4	0.9
	UBE	E - W	S	1.7	1.4	1.5	0.8
Ekulu	UBE	N - S	S	1.7	1.3	1.6	0.9
Housing Estate Primary Schools	UPE	N - S	S	1.4	1.1	1.0	0.8
	UBE	N - S	S	1.4	1.1	1.9	0.8
Igbariam Street Primary Schools	UPE	N - S	S	1.8	1.5	1.6	0.8
	COL	N - S	S	1.8	1.4	1.2	0.8
	UBE	E - W	W	1.8	1.4	2.0	0.8
Indep. Layout P /S	UBE	E - W	W	1.5	1.2	1.5	0.8
Moore House	UPE	N - S	S	1.4	1.3	1.5	0.9
New Haven P /S	UBE	N - S	S	1.3	0.7	1.7	0.5
Niger Close Primary Schools	UPE	N - S	S	1.5	1.4	1.7	0.9
	COL	N - S	S	1.6	1.3	1.4	0.9
	UBE	E - W	W	1.5	1.3	1.3	0.8
Obiagu Primary Schools	UPE	E - W	W	1.5	1.3	1.7	0.8
	COL	N - S	S	1.4	1.3	1.5	0.9
Ogui - Nike Primary Schools	COL	N - S	S	1.9	1.7	2.1	0.9
	UPE	N - S	S	1.9	1.6	2.0	0.8
Ogui Primary Schools	UBE	E - W	W	1.5	1.3	0.8	0.8
	COL	E - W	W	1.4	1.1	1.6	0.8
Robinson Street Primary Schools	COL	N - S	S	1.1	1.0	1.3	0.8
	UPE	E - W	S	2.1	1.5	1.7	0.7
Trans-Ekulu P / S	COL	N - S	S	1.8	1.8	1.5	0.9
WTC Primary Schools	UBE	E - W	W	1.6	1.3	1.7	0.8
	COL	N - S	S	1.4	1.2	1.3	0.9
Zik Avenue P / S	UPE	N - S	S	1.7	1.6	1.1	0.9
Mean				**1.6**	**1.3**	**1.6**	**0.8**

Source: Analysis of Authors' Field Survey (2018)

4 out of 60 classrooms studied, which is around 7% of the sample recorded window planes which were parallel (PRL) to dominant wind direction. The orientation of the classrooms

was E/W. The Colonial (COL) era classrooms typology recorded two classrooms while the Universal Education (UPE) era and the Universal Basic Education (UBE) era classrooms typologies recorded one classroom each. The mean ventilation coefficient of the classrooms was 0.6 and the mean ratio of outlet area to inlet area was 1.6. This cluster of classrooms recorded the lowest mean ventilation coefficient (0.6) and mean indoor speed of 1.2 even with the best mean outdoor wind speed of 2.2m/s (Table 6).

Table 6: Classrooms with Inlet Planes Parallel to Dominant Wind Direction

Name of School	**Class Typology**	**Opening Orientation**	**Dominant wind direction**	**Av Outdoor wind speed**	**Av indoor wind speed**	**Outlet/ Inlet area Ratio**	**Ventilation Coefficient**
Achara layout P/S	COL	E - W	W	2.2	1.3	1.8	0.6
Moore House P/S	UBE	E - W	W	3.6	1.8	2.0	0.7
New Haven Primary Schools	COL	E - W	W	1.4	0.7	1.4	0.5
	UPE	E - W	W	1.4	0.8	1.1	0.5
Mean				**2.2**	**1.2**	**1.6**	**0.6**

5.4 Hypotheses testing

The first hypothesis was formulated to test whether there is a significant relationship between Orientation (an architectural design strategy) and effective natural ventilation in classrooms sampled. The multiple linear regression model produced R= 0.918, R^2 = 0.842, the Adjusted R^2 = 0.824, P = 0.00 (Table 7).

Table 7: Classroom Orientation and effective natural ventilation

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	0.918[a]	0.842	0.824	.03996	0.842	47.066	6	53	0.000
a. Predictors:(Constant) Classroom Orientation b. Dependent Variable: Effective Natural Ventilation									

This result means that there is a significant relationship between orientation (an architectural design strategy) and effective natural ventilation in classrooms sampled. Therefore, the null hypothesis was rejected. The second hypothesis was stated to investigate whether there is significant relationship between effective natural ventilation and thermal comfort in the classrooms studied. In the simple regression model produced R = 0.327, R^2 = 0.107, Adjusted R^2 = 0.092, P = 0.011 (Table 8).

Table 8: The effect of Effective Natural Ventilation on Thermal Comfort Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.327[a]	0.107	0.092	1.25380	0.107	6.966	1	58	0.011
a. Predictors: (Constant), NA b. Dependent Variable: T									

Since p-value is less than 0.05 ($p<0.05$), there is a significant relationship between effective natural ventilation and thermal comfort in the classrooms studied. Consequent upon this, the null hypothesis was also rejected.

The hypothesis established a significant relationship between natural ventilation and thermal comfort in the classrooms of the study area at 0.05 levels. In the simple regression model: $R = 0.327$, $R^2 = 0.107$, Adjusted $R^2 = 0.092$, $P = 0.011$ and $P < 0.05$ sig.

6. Discussion

From the research results presented in the previous section, it was discovered that the mean indoor room climate of the whole classrooms in the study area was: temperature, 30.0^0C; relative humidity, 55% and average wind speed, 1.3m/s. Ninety-five percent of the classrooms met the required level of effectiveness desired for thermal comfort. The result is in consonance with thermal comfort studies of Arens, (2016); Chan et al., (2014); Uzuegbunam et al., (2012); and Kwok, (1998) to the fact that there was a correlation between thermal comfort and effective natural ventilation. This also agrees with the works of Tantasavasdi et al., (2001) and Sharma et al., (2011) who postulated that higher air flow rates are required in the tropical areas compared to temperate zones. It also seems to be in agreement with the previous studies by Watson, (1982); Godwin, (1988); Szokolay, (1990); Okeke et al., (2017); Nnaemeka-Okeke et al., (2019); Okeke et al., (2019) and Nwalusi & Okeke (2021), to the effect that a functional design for natural ventilation requires micro-climatic analysis of a location. However, this finding contradicts the study of Idowu (2009) on adequate natural ventilation for thermal comfort in 60 classroom buildings within 9 public primary schools in hot dry climate Yola, Nigeria, where the author observed that 52 classrooms were thermally uncomfortable at an outside air temperature value of 34^0 C. Also, this work contradicts the study of Ajibola (1997), on thermal and visual comfort in 10 selected primary school classrooms in the warm humid climate of Ile-Ife, Nigeria. He observed that the classrooms were thermally uncomfortable at an outside air temperature value of 32^0 C and internal temperature variations from 33^0C to 40^0C. This result is also in line with the works of Komolafe (1988) and Malaragno (1982) on ventilation performance of windows with respect to their orientation and location on walls. Again, in support of previous study by Uzuegbunam et al., (2012) on significant correlation between design strategies and passive ventilation, the current study also revealed that a significant relationship exists between wall opening orientations and natural ventilation as well as between natural ventilation and thermal comfort in the classrooms. This means that there is a strong link between orientation of wall openings, natural ventilation and thermal comfort in buildings in the hot-humid tropical environment.

The research also found that the mean ventilation coefficient of the studied classrooms of primary schools in Enugu City, Nigeria; with respect to known global ventilation coefficient models was 0.8. This suggests that around 80% of the available free wind outside was admissible by the classroom designs. This mean ventilation coefficient of the classrooms studied is greater than the global ventilation coefficient of 0.6 reported by the Centre Scientifique et Technique du Batiment (CSTB). The availability of high outdoor wind mean speeds of 1.6m/s (average) and 2.0m/s (maximum) during the periods of the investigations contributed to this positive results in the classrooms. This finding appears to be greater than the 60% global ventilation efficiency recommended by CSTB Model. This is in line with the of work Tanabe and Kimura (1994) which suggested that air velocities up to 1.6m/s were still acceptable at temperature up to 31^{0}C. It seems to disagree with the earlier study by Ajibola (1997) in Ile-Ife, Nigeria where about 40% of the classrooms were reportedly effective in terms of natural ventilation, in a hot-humid climate. It also seems to contradict the finding of another earlier work by Chand (1976) in Roorkee, India, which reported a maximum attainable ventilation coefficient of 0.4.

Regarding the effect of orientation on effective natural ventilation desired for thermal comfort in the classrooms of selected primary schools in the study areas, it was found that Orientation of classroom openings with respect to the cardinal direction affected the ventilation coefficients of the classrooms positively, though not very significantly. Forty classroom-buildings (67%) orientated N/S, recorded a high mean ventilation coefficient of 0.9 and least of 0.8. Twenty classroom buildings (33%) orientated E/W, recorded a mean ventilation coefficient of 0.8 and the lowest ventilation coefficient of 0.5. The more adopted N/S orientation, recommended for solar radiation minimization had more positive impact on effective natural ventilation than the E/W orientation. Furthermore, the mean ratio of Outlet to Inlet Area Ratio of the studied classrooms was 1.6 against 1.3 range established by the CSTB architectural standard models. This high porosity ratio contributed positively to the high mean natural ventilation efficiency recorded in 80% of the classrooms in the study area as shown in the data in Table 2.

In view of these results, it can be said that the current study provides support to the previous findings by Mohannad (2021), indicating that the orientation of openings can significantly affect the ventilation coefficient of the classrooms when they were oriented with their longer axis (north–south) aligned perpendicular to the prevailing winds to facilitate maximum air-flow and cross ventilation. Furthermore, it was also found out that the area of wall openings seems to have a significant positive effect on natural ventilation for the desired thermal comfort in the classrooms sampled in the study area. This is because there was significant difference in the mean ventilation coefficients of classrooms with ratio of outlet to inlet area less than 1.3 and those of classrooms with ratio of outlet to inlet area greater than 1.3. This contradicts the earlier works on the varying effects of openings in terms of distribution on windward and leeward facades by previous authors (e.g., Chand 1976; Malaragno, 1982; Idowu, 2009).

Furthermore, it was also found out that orientation of buildings in relation to dominant wind direction, seems to have a significant positive effect on natural ventilation for the desired thermal comfort in the classrooms sampled. This is because there was significant difference in the mean ventilation coefficients of classrooms with window planes normal (NML), neither normal nor parallel (NNP) and window planes parallel (PRL) to dominant wind direction. 56 classrooms representing 94.3% of all the subjects investigated, recorded mean natural ventilation coefficients of 0.9 and 0.8. They were classrooms with window planes either normal (NML) or neither normal nor parallel (NNP) to dominant wind direction. 21 classrooms (35.0%) with window planes normal (NML) to dominant wind direction recorded a mean natural ventilation coefficient of 0.9, while 35 classrooms (58.3%) with window planes neither normal nor parallel (NNP) to dominant wind direction recorded a mean natural ventilation coefficient of 0.8. 4 classrooms (7%) with window planes parallel (PRL) to dominant wind direction out of the sample recorded window planes which were parallel (PRL) to dominant wind direction and orientated E/W, recorded a mean natural ventilation coefficient of 0.6. 3 classrooms out of the 4 classrooms in this category recorded the lowest mean natural ventilation coefficient of 0.5. This suggests that there is a correlation between orientation of classrooms (angle of incidence of wind to window inlet plane) and mean ventilation coefficient. This is in line with the works of Chand (1976), Boutet (1987), Lechner (1991), Idowu (2009) and Uzuegbunam et al., (2012).

The hypothesis established a significant relationship between natural ventilation and thermal comfort in the classrooms. The Regression model had one predictor, the independent variable which is the Effective natural ventilation (Ventilation coefficient). The dependent variable was the thermal comfort of the studied classrooms. In the simple regression model: $R = 0.327$, $R^2 = 0.107$, Adjusted $R^2 = 0.092$, $P = 0.011$ and $P < 0.05$ sig (See table 8).

7. Conclusions

This research aimed to investigate the effect of building orientation (a design strategy) on natural ventilation and desired thermal comfort of users in public primary school in Enugu City, Nigeria. The conclusions and recommendations arrived at from the findings include. First, the required natural ventilation coefficient for thermal comfort in Enugu Metropolis classrooms was 0.8, which was higher than the global ventilation coefficient of 0.6, implying that approximately 80% of the available free wind outside was admissible into the classrooms. Second, classrooms oriented with their longer axis (north–south, the more adopted N/S orientation) and window planes aligned perpendicular (NML) or neither normal nor parallel (NNP) to prevailing winds were more effective in facilitating maximum air-flow and cross ventilation (resulting in higher ventilation coefficient) than classroom orientation with window planes parallel (PRL) to dominant wind direction. As a result, there was a high mean natural ventilation efficiency of 0.9 (90%) and 0.8 (80%) recorded by these orientation categories of classrooms in the study area, which is a clear indication of the fact that the proper orientation has positive effect on effective natural ventilation desired for thermal comfort in the classrooms sampled. Third, it can also be concluded that the ratio of outlet to inlet window openings also had significant positive effect on effective natural ventilation for the desired thermal comfort in the classrooms sampled in the study area. The recorded mean outlet/inlet ratio of 1.6 of the sampled classrooms was greater than the global outlet/inlet ratio of 1.3 recommended by the Centre Scientifique et Technique du Batiment (CSTB) model for effective natural ventilation. Although the findings of this study suggest that there was a positive significant effect of orientation of the wall openings in the classrooms on effective natural ventilation for the desired thermal comfort in geographical area of study, there is still need for improvements on this for a better result. Based on this, the following recommendations are put forward. To achieve enhanced performance, buildings should be oriented with their longer axis (north–south) aligned perpendicular to the prevailing winds to facilitate maximum air-flow and cross ventilation through the building. Buildings can be oriented at an angle between 0° to 30° with respect to the prevailing wind direction. It is suggested that equal or greater number of openings should be on the leeward side walls. This will ensure higher outlet areas to inlet areas ratios for improved effective ventilation. In addition, alternate arrangements of windows on opposite walls are also recommended for greater air content and movement in the classroom spaces rather than the direct opposite arrangements that characterized the study classrooms. Furthermore, to achieve effective natural ventilation, there is also a need for classroom-buildings to be sited at a distance not less than 12 times the height of obstruction or fence if such obstruction is parallel to wind direction and at a distance not less than four times height of obstruction if such obstruction is perpendicular to wind direction as recommended by Centre Scientifique et technique Du Batiment (CSTB). The buildings should also be provided corridors and shading devices to encourage opening all windows even during windy and rainy conditions. It is also suggested that partitions and high-level window openings (awning windows) may be introduced in some of the Colonial proto-type classroom buildings with long, large and open interior spaces with high head rooms to generate natural ventilation by both wind and stack effect. This will ensure individual room climate of each classroom with the building, providing the conducive environment for teaching and learning instead of the previous ware house, noisy state of the classrooms.

8. Areas of Further Studies

Despite the insights provided by this study, further climatological and natural ventilation studies of the micro-climate be conducted for optimum wind harvest of the prevailing unpredictable wind path, as climatic data from meteorological stations may not reveal much about the local microclimatic conditions due to the effects of local topography, vegetation, and other factors man-made or natural.

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