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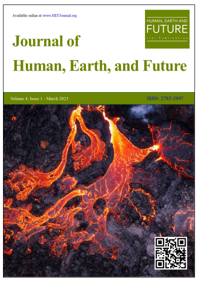

Post Occupancy Evaluation of Ventilation Coefficient Desired for Thermal Comfort in Educational Facilities

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Abstract

In tropical regions, one sustainable measure identified to attain thermal comfort and energy savings for interior spaces is natural ventilation. However, the ventilation coefficient as a factor for effective passive ventilation required for thermal comfort in educational facilities in warm, humid climates has not been adequately investigated. This study is a post-occupancy evaluation aimed at investigating the ventilation coefficient as a parameter for effective passive ventilation efficiency for good thermal comfort in the classrooms of public primary school buildings in Enugu Metropolis, Nigeria. Among the data collection instruments are two data logging devices (thermo-anemometers -AZ 9871) used to measure air velocity, humidity levels, and temperature outside and inside the classrooms of 60 government primary school buildings in the study area. This selection was based on stratified random sampling techniques. For data analysis, the global ventilation coefficient and linear regression analysis were used. The findings demonstrate that the average natural ventilation efficiency was 80%, which is higher than the global ventilation efficiency standard of 60%. The research results further highlight that colonial classroom prototype buildings have a lower temperature value and ventilation coefficient of 83%, which in turn influenced the thermal comfort conditions of the classrooms investigated. The significance of this study is that the findings contribute to the existing knowledge base that would advance strategic policy formation towards acceleration of the uptake of sustainable and energy-efficient building designs for educational facilities in warm, humid tropical environments.

Keywords: Educational Facilities; Passive Ventilation, Post-occupancy Evaluation; Ventilation Coefficient.

1. Introduction

Most metropolitan cities in the world are characterized by large populations and economic development, resulting in increased anthropological activity with high pollution levels [1], consequently adding to the global warming crisis and severely affecting the air quality in these cities. High temperatures are one example of the risk associated with climate change that can have a variety of repercussions, from immediate to long-term, and in some situations, they might be

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irreversible, especially if they result in the destruction of certain ecosystems [2]. The extent, peak, and duration of warming play a crucial role in determining the severity of these effects [3]. Among the effects observed are human psychological trauma, prolonged hot weather conditions [4], sick building syndrome [5], and an increase in energy demand, consumption, and associated expenses [6]. This, in turn, contributes to the deterioration of the air quality of the built environment due to the heightened heat emissions from HVAC systems used to maintain comfort in enclosed spaces [7].

The creation of a thermally conducive environment is necessary for optimum productivity in any confined space meant for living or working, but especially critical in educational settings where teaching and learning activities are conducted. One of the functional requirements of a classroom as a product of the architectural design process is ventilation [8–12]. Extensive educational research has highlighted that most educational facilities, particularly in Africa and parts of Asia, are designed to function independently of active cooling systems [13] and has emphasized the significance of the thermal conditions within a classroom as they have a direct impact on the teaching and learning environment. The effectiveness of natural ventilation plays a vital role in this regard, and it is influenced by various factors, including ventilation coefficients and the architectural characteristics of the classroom buildings, or learning areas. Natural ventilation requires little or no energy to function, resulting in inexpensive cooling costs, and in developing countries, its importance cannot be overemphasized [6].

The ventilation coefficient is a ventilation parameter and an atmospheric condition that indicates the air quality and pollution potential of a space (i.e., the capabilities of the surrounding air to disperse and dilute pollutants over any location/area). The coefficient is the ratio of the mean indoor velocity and the mean outdoor velocity at the same height. The characteristics of the site, the orientation of the building, the exterior characteristics of the building, and the interior architecture and aerodynamics of the building are factors that affect the ventilation coefficient [14]. The higher the coefficient, the better the atmosphere's ability to discharge pollutants and the better the indoor air quality (IAQ). The tropical warm-humid climate is characterized by high relative air humidity and high temperatures, making airflow in buildings crucial for achieving comfort levels [15, 16]. In these tropical locations, air flow ranges from 0.5 to 2.5 m/s, compared to 0.2 m/s in other temperate zones [17]. Thus, the design of classrooms for natural ventilation in such a climate will pose a challenge to architects and building engineers. To ensure that such designs, having been built, meet the objective of providing natural ventilation, there is a need to carry out post-occupancy evaluations on them [11, 18]. This is necessary to either validate such designs or review them and add to the existing knowledge base. It may also provoke retrofitting action on the built form.

According to research, there is a clear link between instructor and pupil performance and the indoor environmental quality of educational facilities [19]. Unfortunately, post-occupation evaluation (POE) has been largely neglected in the design, construction, and management of primary schools, which have adverse effects on the well-being of all categories of building users [20]. These effects may include issues such as dissatisfaction, stress, nervousness, and reduced academic performance. Regardless of its potential to identify building deficiencies and correct building design and construction faults to guarantee the satisfaction of occupants, there is currently no legal provision to enforce the implementation of post-occupancy evaluation in the building and construction industry [21]. This poses a significant challenge given the ongoing push from the governments of most 3rd world economies to cut back on recurrent budgets for educational facilities [22]. However, schools can save money by using POE, and those savings can then be redirected to improve the daily lives of those using the facilities [23].

A post-occupancy evaluation conducted by Ahmed et al. [24] on three schools in the West Midlands, UK, focused on the building HVAC systems. Their study utilized a philosophical approach, combining interpretivism and post-positivism, to apply inductive reasoning. Data was collected through a questionnaire from the school's end-users, and findings showed that building users expressed a desire for more control over their environment's interior, which contrasts with the trend towards mechanical methods. A case study on post-occupancy evaluation was carried out in the UK by Macintosh & Steemers [25]. The study aimed to address questions regarding how effectively occupants of the houses manage the balance between natural ventilation and active systems to attain thermal comfort in an energy-efficient manner. It provided useful findings but was more quantitative social research. Furthermore, still in the UK, various methods were employed in Morgenstern [26] post-occupancy evaluations, including interviews with the project team, surveys of occupants, and a technical walk-around that involved examining building management systems and analyzing energy data. Their research highlights and adds a construction perspective to the ongoing debate, which is usually focused on design considerations and the occupant’s view. In the investigation of Khamidi et al. [27], the authors examined building performance by assessing occupants' satisfaction and analyzing the indoor environmental quality using the Malaysian Standard MS1525 and Green Building Index. Their findings offered suggestions for corrective measures to enhance elements such as noise and illumination that did not meet the required standards but did not explore the ventilation parameters of tropical climates. Okafor et al. [28] provided insight on the indoor thermal comfort values of warm, humid tropics, although it was a comparative evaluation of the internal thermal comfort characteristics of traditional and contemporary Nigerian buildings.

Consequently, evidence in the literature indicates that there has been limited academic focus on conducting thorough Post-Occupancy Evaluations (POEs) for schools and educational facilities [24]. Often, building end users are disconnected from the design process, with the hired building consultants and local government agencies disengaging after the handover phase, and most POE in the literature is often based on the perceived occupant perspective and devoid of adequate empirical investigations like building physics. Although Ajibola [29] and the recent study of Ikechukwu [30] concentrated on passive ventilation in public primary school buildings within Nigeria's hot, dry environment, specifically in Ile-Ife and Yola, respectively, they examined the functionality of classroom designs for passive cooling; however, there has not been any known attempt at research in the warm, humid region. Hence, it is a necessity to explore and establish the applicability and limitations of existing generalized theories on natural ventilation in the unique climatic context of the tropical, warm, humid environment. Therefore, this study is a POE of the classroom designs for natural ventilation in the warm, humid tropical environments of Enugu Metropolis, in sub-Saharan Africa. It cannot be denied that the harsh climatic and high thermal conditions in Enugu Metropolis and some other tropical regions due to climate change are a source of concern for school building designers and administrators. As a result, the purpose of the study is to investigate the ventilation coefficient in classroom buildings as a parameter for effective passive ventilation efficiency for good thermal comfort in the classrooms of a public primary school in Enugu Metropolis, Nigeria. The specific objectives of the study are as follows: (1) To identify the natural ventilation coefficient for thermal comfort in the classrooms of public primary schools; and (2) To determine the natural ventilation coefficient for effective natural ventilation in the classrooms of selected primary schools in Enugu Metropolis. In addition, the hypothesis tested in this study is:

H1. There is no significant relationship between natural ventilation coefficient and thermal comfort in the classrooms.

The current study is premised on the supposition that ventilation coefficient has a substantial impact on the natural ventilation effectiveness and thermal comfort levels of building occupants and users, particularly in south-eastern Nigeria's warm, humid tropical environment. As a result, the findings of this study can provide feedback on how natural ventilation systems are utilized in government schools in Enugu and the tropics. Furthermore, its research findings will inform local authorities to adopt the appropriate attitudes regarding sustaining existing school buildings or enhancing them through re-design and renovation processes to improve performance. The current study encountered limitations due to the delayed authorization from the Education Board to study the selected school buildings, and the unavailability of layout and architectural working drawings for the schools under investigation was another major hindrance. The authors have to resort to measured drawings.

1.1. Study Area

The study was conducted in the city of Enugu, located between latitudes 6° 21'N and 6° 30'N and between longitudes 7° 26' E and 7° 37'E (see Figure 1), with an estimated land mass of 215 mi^2 equivalent to 556 km^2 [31]. It has three local government areas stretching outward and gradually engulfing other nearby towns [32]. The urban area used to be a small coal mining camp in the early 1900s with its indigenous people from the Igbo ethnic group, but is now fast growing with educational, industrial, commercial, economic, and transportation activities [33]. Enugu lies almost entirely in the deciduous vegetation of the rain forest belt, characterized by heavy rainfall, high humidity in the rainy season, and voluptuous interspaced hills and valleys. The city has good soil and climatic conditions all year round, sitting at 223 m (732ft) above sea level. In February, the lowest rainfall is about 0.16 cm^3, while the maximum is over 37 cm^3 in July. Enugu has a reasonably high annual temperature of 26°C [34].

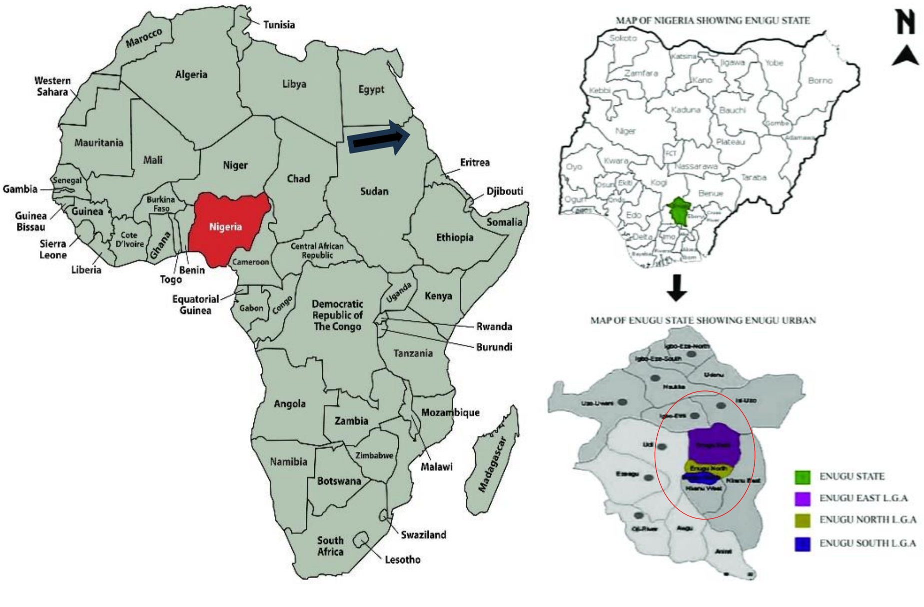


Figure 1. Map of Enugu city inscribed

2. Literature Review

Natural ventilation is an ancient design principle that is gaining popularity among architects because of its ability to create comfortable, healthy interiors. Fresh outside air can enter a large space through low-level inlet ventilators in a properly designed natural ventilation system [35]. Using natural ventilation promotes green practices, reduces mechanical dependence, and creates an environment that is more natural and environmentally friendly for occupants. The Central Building Research Institute of India did a quantitative analysis of air movement within buildings. It was noted that the stack-effect effect of wind speed indoors is insignificant in a humid climate and that the effect of motive forces is difficult to evaluate mathematically. Because of growing local and international issues regarding global warming, the demand for thermal comfort and good indoor air quality has occasioned a greater emphasis on environmental impact and building performance. Natural ventilation can provide building occupants with thermal comfort and a healthy indoor environment [36].

Based on a study for office buildings, Gratia et al. [37] concluded that natural ventilation may be sufficient to ensure user thermal comfort, though some strategies to reduce internal heat gains may be required. According to Rajapaksha [38], infiltration and natural ventilation can be used to improve thermal comfort in some buildings, but their effectiveness is dependent on climate conditions. They also stated that manual opening control is an option for reaching comfortable building temperatures. In addition, natural ventilation has been used in buildings to reduce internal heat gains and energy consumption associated with air conditioning systems. According to ECG [39], the final energy cost of a naturally ventilated building is 40% less than that of a conditioned building.

The ventilation coefficient is an atmospheric condition and an indicator of air quality and effective natural ventilation efficiency; it is a product of mixing depth and the average wind speed. A higher ventilation coefficient is a better indicator of natural ventilation efficiency. The Scientific and Technical Building Center (CSTB) [14] defined and proposed a method for calculating the global ventilation coefficient (CG) of wind-induced indoor air movement. The coefficient (V.C.) is the ratio of the mean indoor velocity, V_i, at a height of 1.5m to the mean outdoor velocity, V_0, at the same height and could vary due to the following: characteristics of the site, orientation of the building and of the wind, exterior characteristics of the building, sizes and positions of wall openings, and other interior architecture and aerodynamics of the building. The amount of airflow within a building depends on the available outdoor wind speeds, sizes and positions of wall openings, the building's orientation relative to the outside wind, architectural features, and other external and artificial characteristics. Wall openings affect air movement by altering the inertia pressure differentials and buoyancy characteristics of airflow [40].

Melaragno [41], using wind tunnels, carried out a more detailed study of indoor wind speed for naturally ventilated interiors under varying wind directions and varying number sizes and locations of openings, and reported that an increase in the ratio of outlet to inlet area can increase airflow. Research has also shown that average wind speed increases exponentially with an increase in window width until it reaches two-thirds of the wall width, and that wind speed indoors also increases with an increase in the ratio of window area to floor area to attain a maximum of forty percent of the available outdoor speed [41]. The importance of thermal comfort in classrooms and indeed any architectural space will always be relevant.

3. Research Methodology

This paper is part of a broader study on the effectiveness of passive ventilation on thermal comfort in educational facilities. An experimental research approach was employed for the study. This is because, according to Groat and Wang [42], it is assumed to be a reliable and most efficient type of research technique used to determine causality. The experiment procedure adopted is referenced to previous studies by Mba et al. [15], hence a similar research method is utilized, and a detailed description of the research procedure is contained. Enugu Metropolis public primary school classrooms make up the research population. Data for Enugu City's 67 public primary schools in 2018 was gathered from the Enugu State Universal Basic Education Board (ENSUBEB) and used as a sampling frame. The sample for this investigation was obtained using a stratified sampling strategy.

According to a pilot survey of public primary schools, there are three prototype classroom building designs with unique features related to their pedagogical epoch and methods. These are the colonial era classroom buildings (pre-independence era before 1960), the Universal Primary Education (UPE) era classroom buildings (built between 1960 and 1989), and the Universal Basic Education (UBE) era classroom buildings constructed from 1990 to 2018. The study samples were identified based on an analysis of the design attributes of classroom buildings in the study area. The building clusters were defined by these criteria as models that shared similar qualities with others in the cluster. Table 1 contains details of the prototypes.

Table 1. Classroom Building Typologies in Enugu Metropolis

Characteristics	Type 'A' (Colonial)	Type 'B' (UPE)	Type 'C' (UBE)*
Building Volume	Usually a floor (bungalow)	Usually, two floors	Usually, one floor
Foundation Height (DPC)	Usually low with one or two steps	Usually high with many steps	Usually low with few steps
Room Height	2.7 -3.0 m; usually with no ceiling covering	Between 3 m and 3.6 m with a ceiling cover	B/w 2.85 m and 3.2 m with a ceiling cover
Plan Shape	Usually, Rectangular	Usually, Rectangular	Usually, Square shape
Plan Form (L/W)	Between 1.1 and 1.3	Between 1.0 and 1.2	Between 1.0 and 1.1
Roof Form	Usually hip or double pitched (Gable)	Usually double pitched (Gable)	Double pitched /Hip
Roof Covering	Zinc or Asbestos cement	Zinc or long span Al. sheets	Long span Aluminium
Roof Eave	0.9 m to 1.2metres	0.6m to 0.9 metres	Usually, 0.6metres
Roof Slope	Between 30 and 40 degrees	Between 20 and 25 degrees	Between 20 and 25 degrees
Partition Wall	Usually non-existent; low rare	Usually to deck or Ceiling	Usually to Ceiling level
Cor. depth /Col. Type	B/w 0.6-1.2 m; no Col	B/w 2-2.7 m; Rectangle Col	B/w 1.5 – 2 m; Square Col
Wall Openings	40%– 45% porosity, high sill height.	45-50% porosity, low sill hgt	25-40% porosity, high Window sill height
Window materials &Type	Wood/metal casement, mesh	Wood Casement, Louvre, pivoted	Sliding window; sometimes metal casement
Orientation of Bldg.	Usually good (E-W)	Usually very good (E-W)	Usually good (E-W)

* Type 'C' (UBE) includes also those Colonial and 'UPE classroom buildings renovated to enhance natural ventilation effectiveness and appearance

The study was limited to primary schools with the three prototype classroom configurations (clusters). Twenty-one public primary schools were identified out of a total of sixty-seven. They include: Carter Street, Ekulu, Independence Layout, Moore House, New Haven, Obiagu, Ogui-Nike, Ogui, and WTC Primary Schools in Enugu-North Local Government Area; Achara Layout, Agbani Road, Niger Close, Idaw River, Igbariam Street, Robinson Street, and Zik Avenue Primary Schools in Enugu-South Local Government Area; Abakpa-Nike, Central Primary Emene, Abakpa Housing Estate, and Trans-Ekulu Primary Schools in Enugu-East Local Government Area.

Figure 2 reveals the workflow that briefly shows the process of the study methodology. Cochran's formula $(n) = n_o/1+ (n_o - 1)/N$. [43] for a finite sample population was used to obtain a sample size of 20. In total, 60 classroom buildings were included in the selection process; one classroom was randomly chosen from each prototype building, representing different educational eras. March (the hottest month of the year 2018), June, July, and August (the coolest month of 2018) were used as the sampling months for this study. Indoor and outdoor temperatures, wind velocity, and humidity level were collected using two thermo-anemometers (-AZ 9871). External dimensions and openings in the buildings were measured using 30.6 m and 3.6 m of fiberglass and metallic tape, respectively. The wind direction was determined with the use of a magnetic compass, and photographic images were captured as evidence of the study. The two data logging devices were labeled A & B and used to measure environmental parameters (temperature, humidity, and wind velocity) for the interior and exterior of the building spaces, held 4m apart and 1.5m above the ground, free of any obstruction. The measurement was done simultaneously by two research assistants for both inside and outside climates. Over the span of five school days, the readings were collected at intervals of 10 minutes each in the morning hours and repeated three times at noon. Each of the classrooms under investigation received a minimum total of 225 observations of relative humidity, air velocity, and temperature values for both the interior and outdoor building regions. For analysis, a mean ventilation coefficient was determined by dividing mean or maximum wind velocity indoor by mean or maximum wind velocity outdoor and compared with the known global ventilation coefficient (CG), which is estimated by CSTB to be 0.6, to ascertain the natural ventilation efficiency necessary for the classroom's thermal comfort. This coefficient was then used to assess the performance of the studied classrooms/buildings. The data was also analyzed using simple linear regression analysis at a significance level of 0.05 to test the hypothesis and results presented in charts, texts, and tables.

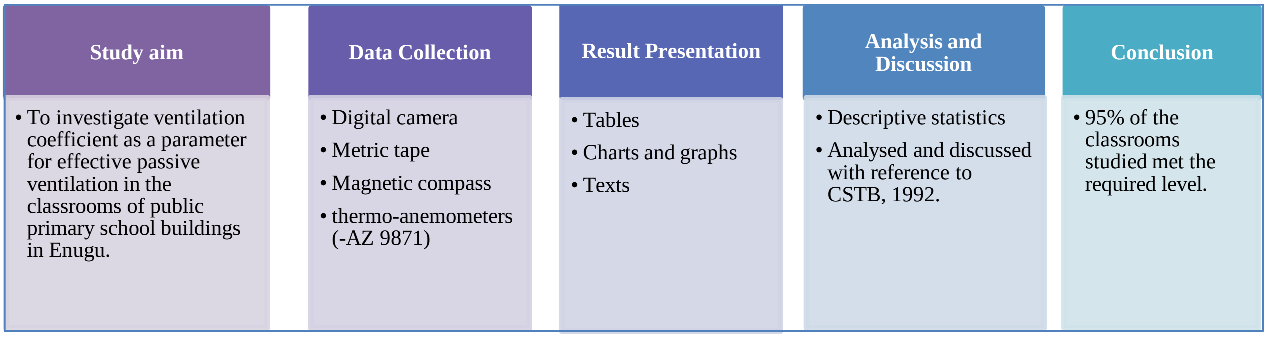


Figure 2. Research methodology flowchart

4. Results

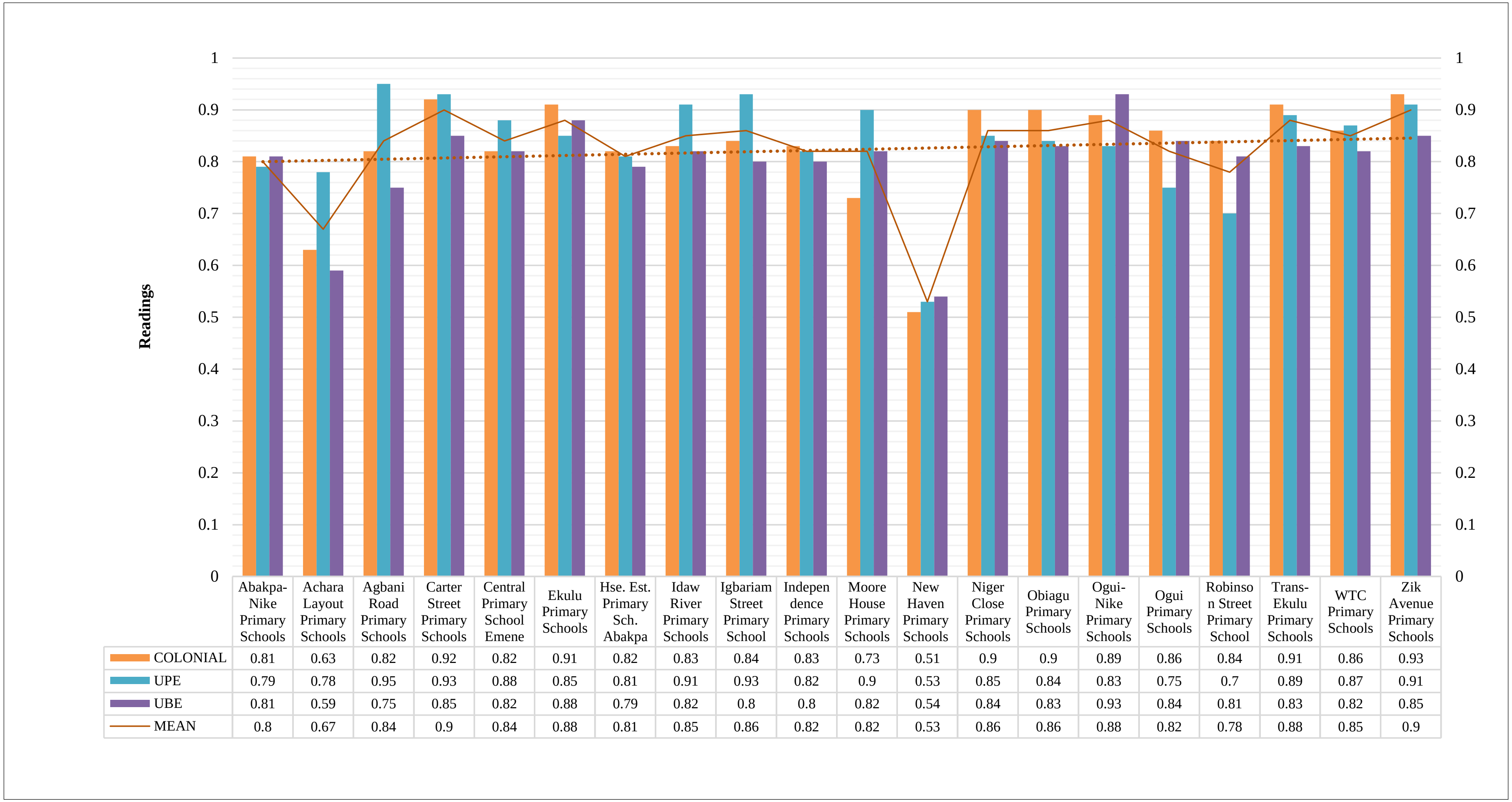
The ventilation coefficient, a measure of effective natural ventilation efficiency, is a ratio of mean wind velocity indoors and mean wind velocity outdoors. The ventilation performance of the standard architectural model according to the CSTB [14] is given as CG = 0.6. Fifty-seven out of the sixty classrooms studied, representing 95%, had ventilation coefficients (0.8) greater than the global ventilation coefficient, CG (0.6). The mean ventilation coefficients within schools' range between 0.5 and 0.9, while the mean between schools was 0.82 with a variance of 0.00 and a standard deviation of 0.00.

Type "B" (UPE) classrooms recorded the highest mean ventilation coefficient of 0.84 and a standard deviation of 0.00, while Type "A" (COL) classrooms were next with a mean ventilation coefficient of 0.83, and proto-Type "C" (UBE) classrooms recorded a mean ventilation coefficient of 0.80. Although Carter Street Primary Schools and Zik Avenue Primary Schools performed better with a 0.9 mean ventilation coefficient, the classroom prototype in New Haven Primary School has the lowest mean ventilation coefficient of 0.53 (see Figure 3). The mean ventilation coefficient of the schools in Enugu-North L.G.A. was 0.82. Carter Street, Ekulu, Obiagu, and Ogui-Nike primary schools recorded the highest mean ventilation coefficients (V.C.) of 0.9, while Independence Layout, Moore House, Ogui, and WTC primary schools recorded a mean ventilation coefficient of 0.8. New-Haven primary schools recorded the least mean coefficient of 0.5.

On individual classroom performances, the UPE (proto-type 'B') classroom recorded the highest individual classroom mean coefficient of 0.93 in Carter-Steet primary schools, followed by the COL (proto-type 'A') classroom at 0.92, while the UBE (proto-type 'C') was last with a mean value of 0.85. In Ekulu primary schools, the highest individual classroom ventilation coefficients of 0.88 were recorded by UPE and UBE classrooms, while COL classrooms recorded a V.C. of 0.87. However, in Obiagu primary schools, the COL classroom recorded the highest individual classroom ventilation coefficient of 0.93, while the UPE and UBE recorded 0.87 and 0.83, respectively. In WTC primary schools, the highest individual classroom mean ventilation coefficient of 0.87 was recorded by the UPE classroom, while the COL and UBE classrooms recorded mean ventilation coefficients of 0.86 and 0.81, respectively (see Table 2).

Table 2. Mean Ventilation Coefficient for Enugu North L. G. A

Name of School	Classroom Typology	Outdoor mean wind Speed	Indoor mean wind Speed	Mean Ventilation Coefficient (classroom)	Mean Ventilation Coefficient (School)	Remarks: V.C. Greater or les than Global V.C. (0.6)
Carter Street Primary Schools	COL	1.2	1.1	0.92	**0.9**	Greater than (G.)
	UPE	1.4	1.3	0.93		
	UBE	1.3	1.1	0.85		
Ekulu Primary Schools	COL	1.5	1.3	0.87	**0.9**	Greater than (G.)
	UPE	1.6	1.4	0.88		
	UBE	1.6	1.4	0.88		
Indep. L/out Primary Schools	COL	1.6	1.3	0.81	**0.8**	Greater than (G.)
	UPE	1.5	1.2	0.80		
	UBE	1.5	1.2	0.80		
Moore House Primary Schools	COL	1.6	1.2	0.75	**0.8**	Greater than (G.)
	UPE	1.4	1.3	0.93		
	UBE	1.3	1.1	0.85		
New Haven Primary Schools	COL	1.4	0.7	0.50	**0.5**	Less than (G.)
	UPE	1.4	0.8	0.57		
	UBE	1.3	0.7	0.54		
Obiagu Primary Schools	COL	1.4	1.3	0.93	**0.9**	Greater than (G.)
	UPE	1.5	1.3	0.87		
	UBE	1.8	1.5	0.83		
Ogui-Nike Primary Schools	COL	1.9	1.7	0.89	**0.9**	Greater than (G.)
	UPE	1.9	1.6	0.84		
	UBE	2.1	1.9	0.90		
Ogui Primary Schools	COL	1.6	1.4	0.88	**0.8**	Greater than (G.)
	UPE	1.4	1.1	0.79		
	UBE	1.5	1.3	0.87		
WTC Primary Schools	COL	1.4	1.2	0.86	**0.8**	Greater than (G.)
	UPE	1.5	1.3	0.87		
	UBE	1.6	1.3	0.81		
MEAN (SCH.)		**1.5**	**1.3**	**0.82**	**0.8**	Greater than (G.)
MEAN (COL)		1.5	1.2	0.82		Greater than (G.)
MEAN (UPE)		1.5	1.3	0.83		Greater than (G.)
MEAN (UBE)		1.6	1.3	0.81		Greater than (G.)



	Abakpa-Nike Primary Schools	Achara Layout Primary Schools	Agbani Road Primary Schools	Carter Street Primary Schools	Central Primary School Emene	Ekulu Primary Schools	Hse. Est. Primary Sch. Abakpa	Idaw River Primary Schools	Igbariam Street Primary School	Independence Primary Schools	Moore House Primary Schools	New Haven Primary Schools	Niger Close Primary Schools	Obiagu Primary Schools	Ogui-Nike Primary Schools	Ogui Primary Schools	Robinson Street Primary School	Trans-Ekulu Primary Schools	WTC Primary Schools	Zik Avenue Primary Schools
COLONIAL	0.81	0.63	0.82	0.92	0.82	0.91	0.82	0.83	0.84	0.83	0.73	0.51	0.9	0.9	0.89	0.86	0.84	0.91	0.86	0.93
UPE	0.79	0.78	0.95	0.93	0.88	0.85	0.81	0.91	0.93	0.82	0.9	0.53	0.85	0.84	0.83	0.75	0.7	0.89	0.87	0.91
UBE	0.81	0.59	0.75	0.85	0.82	0.88	0.79	0.82	0.8	0.8	0.82	0.54	0.84	0.83	0.93	0.84	0.81	0.83	0.82	0.85
MEAN	0.8	0.67	0.84	0.9	0.84	0.88	0.81	0.85	0.86	0.82	0.82	0.53	0.86	0.86	0.88	0.82	0.78	0.88	0.85	0.9

Figure 3. Mean Ventilation Coefficients of the Studied Classrooms/Buildings

The mean ventilation coefficient of the schools in Enugu-South L.G.A. was also 0.82. Niger Close and Idaw River primary schools recorded the highest mean ventilation coefficients (V.C.) of 0.9, while Agbani Road, Igbariam Street, Robinson Close, and Zik-Avenue primary schools recorded a mean ventilation coefficient of 0.8. Achara Layout primary schools recorded the least mean coefficient of 0.7.

On individual classroom performances, UPE (Prototype 'B') classrooms recorded the highest individual classroom mean coefficient of 0.78 in Achara Layout primary schools, 0.95 in Agbani Road primary schools, 0.93 in Idaw River primary schools, 0.89 in Igbariam Street primary schools, and 0.94 in Zik Avenue primary schools. COL (Prototype 'A') classrooms also recorded the highest individual classroom mean coefficient of 0.93 in Niger Close primary schools and 0.91 in Robinson Close primary schools. This classroom type recorded second-best mean ventilation coefficients of 0.63 in Achara Layout primary schools, 0.82 in Agbani Road primary schools, 0.88 in Idaw River primary schools, 0.83 in Igbariam-Street primary schools, and 0.87 in Zik-Avenue primary schools. UBE (proto-type 'C') classrooms recorded second-best mean ventilation coefficients of 0.87 in Niger-Close primary schools and 0.81 in Robinson-Street primary schools. They had the least mean ventilation coefficients: 0.59 in Achara Layout, 0.75 in Agbani-Road, 0.83 in Idaw-River, 0.78 in Igbariam-Street, and 0.74 in Zik-Avenue primary schools, respectively (see Table 3).

Table 3.Mean Ventilation Coefficient for Enugu South L. G. A

Name of School	Classroom Typology	Outdoor mean wind speed	Indoor mean wind speed	Mean Ventilation coefficient (classroom)	Mean Ventilation Coefficient (School)	Remarks: V.C. Greater or les than Global V.C. (0.6).
Achara Layout Primary Schools	COL	1.9	1.2	0.63	**0.7**	Greater than (G.)
	UPE	1.8	1.4	0.78		
	UBE	2.2	1.3	0.59		
Agbani Road Primary Schools	COL	1.7	1.4	0.82	**0.8**	Greater than (G.)
	UPE	2.0	1.9	0.95		
	UBE	1.6	1.2	0.75		
Niger Close Primary Schools	COL	1.5	1.4	0.93	**0.9**	Greater than (G.)
	UPE	1.6	1.3	0.81		
	UBE	1.5	1.3	0.87		
Idaw River Primary Schools	COL	1.6	1.4	0.875	**0.9**	Greater than (G.)
	UPE	1.4	1.3	0.93		
	UBE	1.8	1.5	0.83		
Igbariam Street Primary School	COL	1.8	1.5	0.83	**0.8**	Greater than (G.)
	UPE	1.8	1.6	0.89		
	UBE	1.8	1.4	0.78		
Robinson Street Primary School	COL	1.1	1.0	0.91	**0.8**	Greater than (G.)
	UPE	2.1	1.5	0.71		
	UBE	1.6	1.3	0.81		
Zik Avenue Primary Schools	COL	1.5	1.3	0.87	**0.8**	Greater than (G.)
	UPE	1.7	1.6	0.94		
	UBE	1.9	1.4	0.74		
MEAN (SCH.)		**1.7**	**1.4**	**0.82**	**0.8**	Greater than (G.)
MEAN (COL)		1.6	1.3	0.8		Greater than (G.)
MEAN (UPE)		1.8	1.5	0.9		Greater than (G.)
MEAN (UBE)		1.8	1.3	0.8		Greater than (G.)

The mean ventilation coefficient of the schools in Enugu-East L.G.A. was also 0.83. Trans-Ekulu primary schools recorded the highest mean ventilation coefficients (V.C.) of 0.9. The rest, Abakpa-Nike, Emene-Central, and Housing Estate primary schools, recorded mean ventilation coefficients of 0.8. On individual classroom performances: COL (Prototype 'A') classrooms recorded the highest individual classroom mean coefficient of 0.81 in Abakpa-Nike primary schools, 0.86 in Housing-Estate primary schools, and 0.94 in Trans-Ekulu primary schools. UPE (proto-type 'B') classrooms recorded the highest individual classroom mean coefficient of 0.88 in Emene-Central primary schools and the least scores of ventilation coefficients of 0.79 and 0.82 in Abakpa-Nike and Housing-Estate primary schools, respectively. UBE (Prototype 'C') classrooms also recorded the highest mean ventilation coefficients of 0.81 in Abakpa-

Nike primary schools and the second-best ventilation coefficients of 0.82 and 0.87 in Emene-Central primary schools and Trans-Ekulu primary schools, respectively (see Table 4).

Table 4. Mean Ventilation Coefficient for Enugu East L. G. A

Name of School	Classroom Typology	Outdoor mean wind speed	Indoor door mean wind speed	Mean Ventilation Coefficient (classroom)	Mean Ventilation Coefficient (school)	Remarks:V.C. Greater than or Less than Global V.C.
Abakpa-Nike Primary Schools	COL	1.6	1.3	0.81	**0.8**	Greater than G
	UPE	1.4	1.1	0.79		
	UBE	1.6	1.3	0.81		
Central Primary Schools Emene	COL	1.7	1.4	0.82	**0.8**	Greater than G
	UPE	1.6	1.4	0.88		
	UBE	1.7	1.4	0.82		
Housing Estate Primary Schools Abakpa	COL	1.4	1.2	0.86	**0.8**	Greater than G
	UPE	1.4	1.1	0.79		
	UBE	1.4	1.1	0.79		
Trans-Ekulu Primary Schools	COL	1.8	1.7	0.94	**0.9**	Greater than G
	UPE	1.7	1.4	0.82		
	UBE	1.5	1.3	0.87		
MEAN(School)		**1.6**	**1.3**	**0.83**	**0.8**	Greater than G
MEAN (COL)		1.6	1.4	0.9		Greater than G
MEAN (UPE)		1.5	1.3	0.8		Greater than G
MEAN (UBE)		1.6	1.3	0.8		Greater than G

Some natural climatic conditions, such as high available outdoor wind speeds within the periods of investigation, good topography (presence of hills—land breeze effects), vegetation, and the presence of seasonal streams (sea breeze effects), etc., favored the study area. Also, effective design strategies for natural ventilation, such as classroom forms, proper orientations, high porosity ratios, high outlet/inlet ratios, etc., may have accounted for the high natural ventilation efficiency (mean ventilation coefficients) of the studied classrooms.

4.1. Mean Climatic and Ventilation Coefficients Desired for Thermal Comfort in the Selected Classrooms

The results in Figure 4 revealed that 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. However, 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. Furthermore, the mean indoor climate of the studied classrooms desired for thermal comfort was 30°C, 55% relative humidity, and a wind speed of 1.3 m/s, against the accepted indoor climate of 60% relative humidity, a dry bulb temperature of 30°C, and 0.5 m/s wind speed desired for thermal comfort in the warm-humid climate. Details of the mean indoor climates of the various proto-type classrooms are presented in Table 5.

Table 5. Mean Climate of Classrooms Proto-Types

		Indoor Climate				**Outdoor Climate**				**Ventilation Coefficient (V.C.)**
		Ave. Temp (^{0}C)	**Ave. R.H. (%)**	**Ave Wind Speed (m/s)**	**Max Wind Speed (m/s)**	**Ave Wind Speed (m/s)**	**Ave Temp (^{0}C)**	**Ave. R.H. (%)**	**Max Wind Speed (m/s)**	
Mean of Classroom 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	54.6	1.3	1.5	1.6	30.8	51.4	2.0	**0.8**
Mean Climate of Classrooms		30	55	1.3	1.5	1.6	30.8	51.3	2.0	**0.8**
Stand. Arch. Model Indoor climate		30	60	0.5						**0.6**

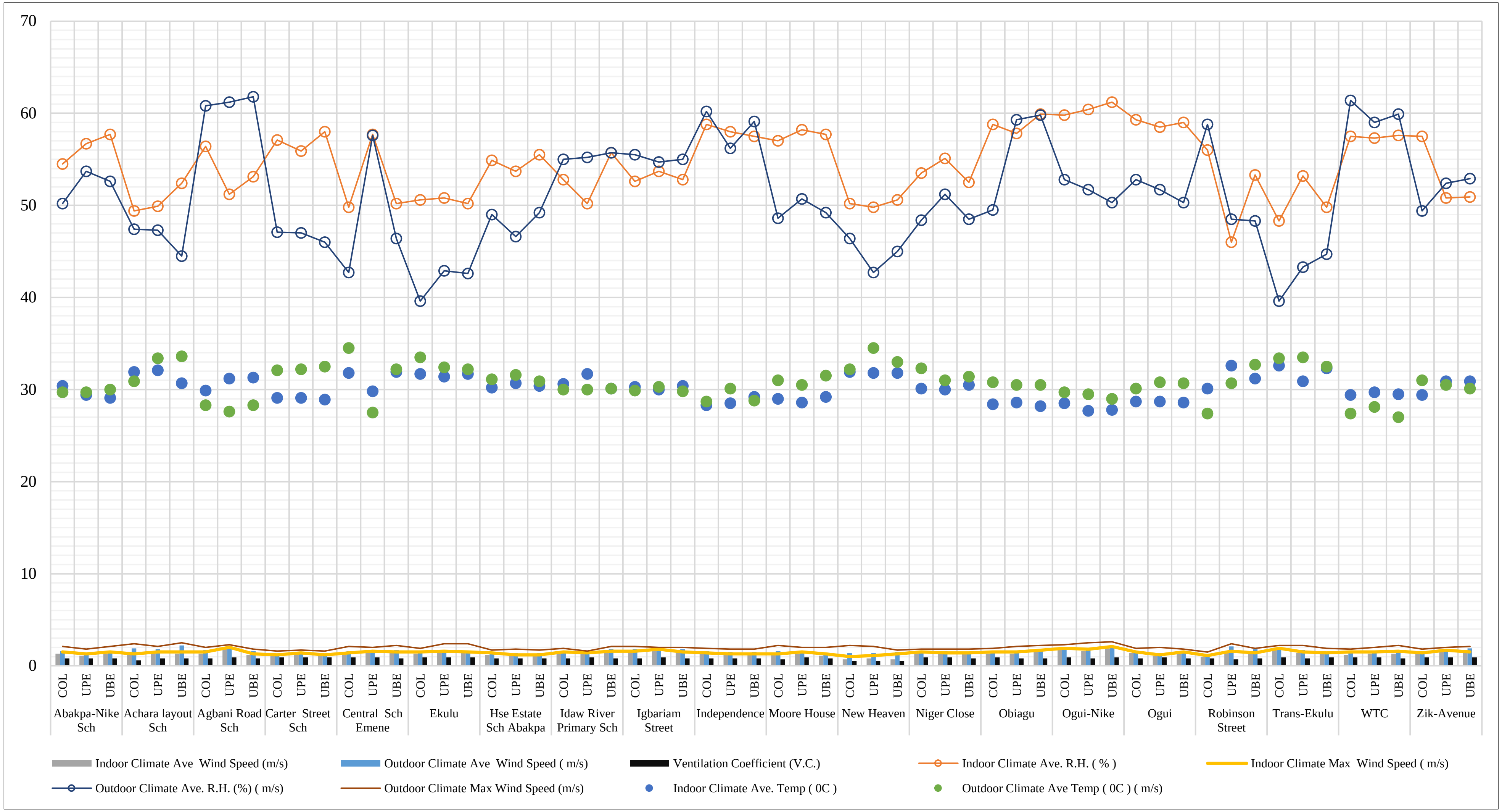


Figure 4. Weekly Mean Climate and Ventilation Coefficients of the Studied Classrooms in the Study Area

4.2. Hypotheses Testing

The hypothesis was formulated to test whether there is a significant relationship between ventilation coefficient and thermal comfort in the classrooms studied. The simple regression model produced R = 0.327, R^2 = 0.107, adjusted R^2 = 0.092, and P = 0.011 (Table 6).

Table 6. Natural Ventilation Coefficient and Thermal Comfort Model Summary

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate	Change Statistics				
					R^2 Change	F Change	df1	df2	Sig. F Change
1	0.327*	0.107	0.092	1.25380	0.107	6.966	1	58	0.011

* Predictors: (Constant), VC;

Since p-value is less than 0.05 ($p<0.05$), there is a significant relationship between natural Ventilation Coefficient and Thermal Comfort in the classrooms studied. Therefore, we reject the null hypothesis.

5. Discussion

It was discovered, based on the findings of the research reported in the previous section of this paper, that the mean ventilation coefficient of the classrooms with regards to known global ventilation coefficient models was 0.8. Fifty-seven out of sixty classrooms/buildings studied, constituting ninety-five percent (95%) of all subjects, had mean ventilation coefficients ranging from 0.6 to 0.9. The other three classroom buildings (5%) with double-pitch roofs and corridors on leeward sides had mean ventilation coefficients of 0.5 (see Figure 4). The fact that the mean ventilation coefficient of all the studied classrooms was 0.8 suggests that eighty percent 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 (0.6) reported by the CSTB [14]. This contradicts the previous studies of Ikechukwu et al. [30] that the ventilation coefficients of the studied classrooms in Yola, Nigeria, varied in a range of below 0.2 to readings 0.7 high, having a mean value below 0.5.

Some of the studied classrooms/buildings in New Haven Primary Schools were not sited at standardized setback distances from the perimeter fences. This led to obstructions of the prevailing dominant outdoor winds from entering the affected classrooms, resulting in a low mean ventilation coefficient of 0.5, below the global G (0.6). In addition, these classrooms also recorded very large/largest floor areas, resulting in very low Total Opening Area to Floor Area (TOA/FA) ratios. However, the available high outdoor wind mean speeds of 1.6 m/s (average) and 2.0 m/s (max.) during the periods of investigations favored the mean ventilation coefficients of the classrooms (see Table 5).

In the study area, the available average and maximum mean outdoor wind speeds were 1.6 and 2.0 m/s, respectively, and the average and mean maximum indoor wind speeds were 1.3 and 1.5 m/s. These were more than desired for thermal comfort, suggesting a high level of effectiveness of the classroom design for natural ventilation in the study area. This finding is in line with the studies of Mba et al. [15] and Tanabe and Kimura [44], who suggested that air velocities up to 1.6 m/s were still acceptable at temperatures up to 31°C. However, it tends to disagree with the earlier study by Ajibola [45] in Ile-Ife, Nigeria, where only 40 percent of the classrooms were reportedly effective in terms of natural ventilation in a hot-humid climate. A comparison with the global ventilation G (0.6) reported by the CSTB [14] may reveal some factors responsible for the high ventilation coefficients of the classrooms studied. Attainment of a mean ventilation coefficient of 0.6 greater than 0.4, as obtained by CSTB, and this finding contradicts the earlier work of Chand [8] in Roorkee, India, which reported a maximum attainable ventilation coefficient of 0.4.

The ventilation investigations of Ajibola [29] carried out in classrooms in southwestern Nigeria (Ile-Ife) and the experiment of Kwok [46] in Hawaii targeting residential and institutional buildings in Hong Kong are research concerned with micro-climatic conditions conducted in various locations and climates. These studies align with the perspectives of Nnaemeka-Okeke [47], Oforji [48], and Szokolay [49], emphasizing the significance of a well-designed natural ventilation system that considers the micro-climatic analysis of specific locations.

From the analysis of Table 5, all studied classroom prototypes have a mean ventilation coefficient of 80%. Though the colonial classroom design maintained the lowest temperature values of 30.1ºC and this disagrees with the submission of Okafor [28], who opined that the indoor temperatures of traditional warm, humid buildings are 28.8ºC. Furthermore, with the colonial classroom building design having slightly higher relative humidity levels in comparison with the other classroom prototypes, the colonial building will feel cooler and more thermally conducive. This result provides support for the findings of Okpalike et al. [6] and Nwalusi et al. [50] on colonial building designs in Nigeria. They both theorized that colonial building design in warm, humid regions in tropical Nigeria has architectural features and design elements tailored to accommodate the climatic conditions of the region and perform optimally in terms of passive cooling. The implication of the ventilation coefficient study is that ventilation coefficient values are inversely proportional to the air population potential of a designed habitable space. Therefore, the study samples, especially the colonial-era prototype and, apart from New Haven primary school classrooms, could be used as reference buildings for future primary school building projects in warm, humid regions of sub-Saharan Africa.

6. Conclusion and Recommendations

In this study, ventilation coefficient as a parameter for effective natural ventilation efficiency for good thermal comfort of users in a public primary school in Enugu Metropolis, Nigeria, was investigated. It is a POE that could inform policy action on educational facilities to the extent necessary to either validate existing building designs or review them and add to the body of knowledge. From the findings, it can be concluded that the natural ventilation coefficient desired for thermal comfort in the classrooms in Enugu Metropolis was 0.8, which is higher than the global ventilation coefficient of 0.6. This means that around 4/5th of the available free wind outside was admissible into the classrooms. Furthermore, the research also revealed that 57 out of the 60 classrooms studied (95%) met the required level of natural ventilation effectiveness desired for thermal comfort. The implication of this is that the mean ventilation coefficient of the classrooms in the study area was higher than the global ventilation coefficient recommended by the CSTB model, resulting in a lower rate of air pollution within the classroom spaces. Specifically, the findings suggest that colonial classroom prototype buildings be adopted as a model for classroom designs in a tropical, warm, humid environment.

Although the outcomes of this research indicated that the classroom buildings had a high ventilation coefficient for natural ventilation efficiency sought for thermal comfort in the study area, potential for improvement still exists. The following recommendations are made in light of this: Climate change, in terms of global warming, has some inevitable effect on human comfort. The weather is now warmer and more unpredictable. Therefore, climate-integrated architectural design strategies that seek to take advantage of climate issues like temperature, humidity, rainfall, and natural wind patterns to produce effective ventilation are advocated. Specifically, classroom building designs should encourage a greener environment (that is, shading the whole building and landscaping with flowers, shrubs, trees, etc.) and employ lightweight (low-mass) construction with low-depth floor plans (short width) to encourage proper cross ventilation and ventilate roof spaces, if possible, for optimized results.

7. Declarations

7.1. Author Contributions

Conceptualization, E.J.M. and F.O.O.; methodology, E.J.M., F.O.O., and E.C.E.; software, E.J.M.; formal analysis, F.O.O.; investigation, E.J.M. and E.C.E.; writing—review and editing, E.J.M., F.O.O., and E.C.E.; supervision, E.J.M.; project administration, E.J.M. and F.O.O. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available on request from the first named author.

7.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.4. Institutional Review Board Statement

Not applicable.

7.5. Informed Consent Statement

Not applicable.

7.6. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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