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ASSESSMENT OF VENTILATION IN PUBLIC PRIMARY SCHOOL: A CASE OF PUBLIC PRIMARY SCHOOL IN NIGERIA

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Abstract: Ventilation rates in classrooms often fall far short of the minimum ventilation rates specified in standards. There is compelling evidence, from both cross sectional and intervention studies, of an association of increased student performance with increased ventilation rates. In this research-work, six(6) study-visits to each of one hundred and eight (108) classrooms in thirty-Six (36) Public Primary schools [located in three South-western Nigerian cities of Abeokuta, Ibadan and Ilorin] were embarked upon, to obtain the values of indoor environmental-parameters [such as 'Indoor reference Windspeed (V_{ref})', 'Relative Humidity(*RH*)', 'Area of total effective Ventilation-opening (A_{net})', 'Classroom-dimensions(l, b and h)' and 'Occupancy(*N*)']; using the WM-200 Windmate wind-meter, the AcuRite 00613A1 top-digital Hygrometer, a measuring-tape, and by visual-observation. The values obtained were then inputted into empirical-models to determine the values of three ventilation-parameters i.e. Wind-driven Cross-ventilation rate (Q_w), Ventilation rate per person (Q_{wpp}) and Air Changes per Hour (*ACH*) for each of the 108 classrooms. A comparison of the values of these ventilation-parameters thus computed, with the bench-marks/limits [of Q_{wpp} = 8L/S/ (Person) and 1 *ACH* = 6 – 20Hr^{-1}], recommended by the ASHRAE and CIBSE for adequate ventilation in classrooms, showed that: majority [i.e. 91%] of the classrooms had *ACH* values that were within the recommended limits, and all [i.e. 100%] of the classrooms had Q_{wpp} values that were above the minimum recommended limit. Intriguingly, this research found a conformity with recommended standards of classroom ventilation-levels, and also proves that the rampant declining academic performance of Nigerian students in the selected public primary schools, is not necessarily linked with *IAQ*-related causes/conditions. The study recommended that with the use of adequate window type, sizing and positioning that ensures maximum entry of fresh air into classroom spaces, ventilation will be improved in classrooms. Also limit the number of users/students in a classroom to a number that can be accommodated within the Occupancy level of the available space.

Keywords: Classrooms, southwest Nigeria, *Windspeed, Relative Humidity, ACH*, *ASHRAE, CIBSE, IAQ, Occupancy, Ventilation.*

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1. Introduction

Children usually spend about six hours in school, which expose them to pollutants in their school indoor environment. Although studies have shown the effect of the indoor environment on humans [1], there are only a few studies on indoor environmental quality (IEQ) from developing nations including Nigeria [2] [3]. Just as the same in may African and poor Asian countries, the present rising numbers of Indoor Environmental Quality (IAQ)-related ill-health conditions, absenteeism and annually declining academic performance etc., of school students attending public primary and secondary schools in Nigeria, appears to be slowly, but gradually constituting a major national and global concern in today's borderless generation [4].

Nowadays, there is a rapidly growing consensus that: "the academic performance of Public Primary school students is directly linked with the Indoor Environmental Quality (IEQ) parameters of the classrooms in which they learn— and particularly ventilation and thermal comfort conditions"—this is based on the research findings of numerous scholarly researchers around the globe, some of which will now be cited as deemed appropriate. An increase of fresh air supply from 0.3 – 0.5 to 13.0 -16.0 L/S per Person resulted in an increased student's work rate by approximately 7% in addition ($P < 0.036$) and subtraction ($P < 0.052$) [5]. Furthermore to thermal comfort and health, one other important aspect that is seriously affected by poor environmental conditions, is the learning performance of school children [6]. A study of several thermally-uncomfortable and poorly-ventilated classrooms, recorded cases of associated impaired learning performance and rising rate of absenteeism on the part of school students [7], [8], [9], [10], [11].

British students gave more precise and considerably more expeditious replications when subjected to four Computer-predicated tests/tasks which were: Word-apperception, [by 15.0%], Picture-recollection [by 8.0%], Colour word Vigilance [by 2.7%] and Choice-recognition [by 2.2%]; at higher ventilation rates, in contrast with the results obtained under conditions of low ventilation rates. [12]. A study of elementary schools in California, USA, over a period of 24 months, concluded with the suggestion that, incrementing classroom ventilation rates above the subsisting state standard requisite/limit, is most likely going to result in paramount minimization in absenteeism of school students, and establish long-term economic benefits [13].

Several apperceived regulatory bodies such as the Chartered Institute of Building Accommodations Engineers (CIBSE), the American Society of Heating and Refrigerating and Air-Conditioning Engineers (ASHRAE) etc., have pellucidly verbalized the recommended values, that a minimum fresh air supply rate of 8 L/S/ (person) and an Air Change per Hour of 6 – 20 Hr-1, is required for the safety and salubrity of School students [14], [15], [16], [17]. In the same vain the United Kingdom's Department for Education in June 2006, published a draft document for public consultation, in which, while referring to the proposed performance predicated Standards, inhibited the quotidian Carbon (IV) Oxide gas [$CO_2(g)$] concentration to 1500ppm for schools; and recommended a minimum external air supply of at least 3L/S/Person in all occupied teaching and learning spaces; and further recommended that the average number of learning occupants should have within their control, the competency to achieve the zealous ventilation rate of 8L/S/Person, which may not always be compulsory, categorically when there is a defragmentation in the occupancy level [18].

A study of Ventilation and Indoor Air Quality (IAQ) conducted in eight (8) UK schools per week, revealed amongst other things that: Classroom Ventilation rates were below the minimum value of 3L/S/Person, as is required by the School premises Regulation of 1999. Also, as stated in the year 2009 Report presented by the US government Accountability Office, half of all teaching spaces in USA, are associated with IAQ problems [19]. Unfortunately, the situation is appears to be worse in most African countries— and particularly in Nigeria, with its numerous persisting post-independence toothing problems and post-civil war issues. Nigeria is a developing country situated in the western part of Africa with a population of about 190 million people, 44% of which are children below the age of 15 [20]. However, in this study, research shall be limited to activities to three (3) metropolitan cities i.e. Abeokuta, Ibadan and Ilorin—being the capital cities of Ogun, Oyo and Ilorin states respectively in the South-Western geo-political zone of Nigeria.

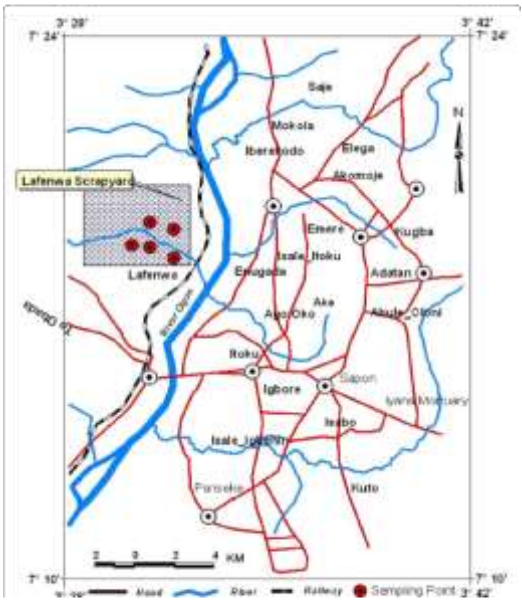
Ventilation is basically the supply and removal of air by either passive means [in which air-movement is actually driven by wind pressure variation (buoyancy) and temperature differences (stack effect) through specially provided openings such as windows and dormers etc., created on the walls or roofs of buildings]; or active means [in which air is supplied and/or extracted by applying mechanical methods which include air conditioning ducts and fans]; for the three-fold purpose of: providing air for living-things to breath, providing fresh-air to maintain good IAQ, and triggering & continuously driving air-movement to ensure thermal comfort of the occupants of a room/living-space [21]. Comparably, Ventilation could simply be defined as the process of ensuring the supply of fresh outdoor air and expelling stale (i.e. oxygen-deficient) and/or contaminated indoor air, into or from the living-spaces/rooms of a building; which usually consists of a carefully-planned combination of intentionally-provided ventilation and air-infiltration openings, by the application of either passive (natural) and/or active (mechanical) systems. From these and other definitions of Ventilation, it is clearly evident that, it is impossible to over-emphasize the vital role played by Ventilation, in its attempt to ensure that, the air composition in a room/living space is optimal, by way of increasing the mass of fresh air entering, diluting the concentration of air-borne contaminants, and by enhancing the resulting airflow distribution within the room/lining space [4].

The clear lack/deficiency of research data on the ventilation of classrooms in public primary schools located in these three Nigerian states of Ogun, Oyo and Ilorin states; has been the primary motivation for this research. Therefore, the aim of this research work is to scientifically assess the indoor ventilation conditions of classrooms in selected schools, located in three (3) metropolitan cities of 'Abeokuta', 'Ibadan' and 'Ilorin' in South-Western Nigeria.

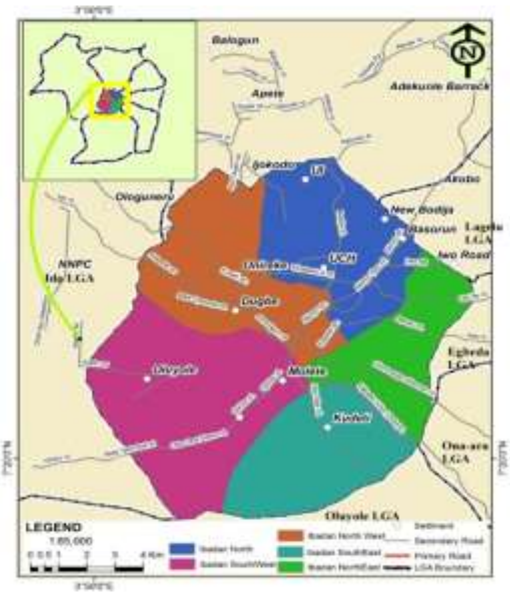
2. Methods

In view of its large geographical size/expanse of landmass/area, the study-area [being a part of the South-Western geo-political zone of Nigeria, consisting of three (3) capital-cities i.e. Abeokuta, Ibadan and Ilorin], was purposively divided on a city-by-city basis, into thirty-Six (36) distinct localities (towns, neighbourhoods or districts);as shown below:

- Abeokuta city was divided into twelve (12) localities, as follows: Kuto, Isale Igbehin, Pansake, Itoku, Igbore, Adatan, Lafenwa, Ago Oko, Iberekodu, Isabo, Sapon and Saje
- Ibadan city was divided into twelve (12) localities, as follows: Onireke, Dugbe, Molete, Kudeti, Oluyole, Ologuneru, Basorun, Bodija, Akobo, Ijokodo, Balogun and Apete
- Ilorin city was divided into twelve (12) localities, as follows: Tanke Ilewa, Oko Oba, Agbabiaka, Labale, Ahmad Bello, Mogaji Igbadun, Ita Alamu, Gaa Akanbi, Ero Omo, Isoko, Fate and Sobi



Map Showing Abeokuta [22]



Map Showing Ibadan [22]

Map Showing Ilorin [23]

Thirty Six (36) localities were list after the division in the study area through a street-by-street tour of each of these localities using the 'Google earth map' and the cities' residents as guides. This was followed by the compilation of a comprehensive list of all major public primary within these localities. After which, a total of thirty (36) public primary schools, were finally chosen/considered for this study. The decision to choose/consider any particular school for the study, was basically informed by the fact:

(1.) It was solely built and managed by the government [federal or state] to serve the general public; (2.) It had been founded for a minimum of Five years;

(3.) Its physical structure was a style of building that is between ground floor and two storey; and (4.) It was attended by students whose ages randomly from 7 – 20 years.

Three (3) classrooms [one is opposite the relative direction of the prevailing wind, and two others on either sides of the first classroom, and are parallel to the relative direction of this prevailing wind] in all considered schools per locality were identified. Each of these three classrooms in each considered school, was experimentally investigated twice daily [9am – 11am (0900hrs – 1100hrs) & 12noon – 2pm (1200hrs – 1400hrs)] from Mondays through Wednesdays, during each of the three (3) on-the-spot experimental visits/assessments of classrooms, carried out twice [i.e. once in the dry season (October – December or January - April), and once in the wet/rainy season (May – September)] within the twelve (12) month study-period from October 2020 – September 2021.

The arithmetic-average figures were computed for all six (6) experimental visits/assessments' values, obtained and was then adopted for analyses of the results of this study. All measurements of climatic and ventilation parameters were performed, when the indoor relative humidity was 80% and above. During each of the two (2) daily experimentations per experimental visit, there were five (5) consecutive measurements/calculations of each of indoor reference Wind-speed ' V_{ref} ' (m/s), Window Area ' A_w' (m^2), Classroom space Volume 'Vol ' (m^3) and selected ventilation parameters [Wind-driven Cross ventilation rate 'Q_w' (m^3/s), Air Changes per Hour ' *ACH* ' (Hr^{-1}) and Ventilation rate per Person 'Q_{wpp}' (m^3/S/Person)]; were separately obtained/performed for each of one hundred eight (108) investigated classrooms. The above translates to seventy two (72) distinctly measured/calculated values per parameter per Classroom, and two hundred and sixteen (216) distinctly measured/calculated values per parameter per School. As was earlier mentioned, the averages were computed and conclusively adopted.

Indoor reference Wind-speed (V_{ref}) of classrooms was obtained using the WM-200 Windmate, while the Windows' and Classrooms' dimensions—[being constant values for each classroom, were used to calculate the various Window-areas and Classroom-areas] were carefully obtained by initial measurements using a 'Measuring-tape' etc. Occupancy [i.e. the sum of the number of students and teacher(s) in the classroom, was obtained by direct visual observation]. The 'WM-200 Windmate' is a handheld Wind-meter that measures wind/air-speed and air-temperature, while determining wind-direction [in degrees & compass-points] and windchill etc. It is fitted with a built-in visual wind-vane which helps with orientation to the wind, and a made-in USA fluxgate digital compass for digital measurements of wind-direction, while giving readings for head-wind, tail-wind and cross-wind. It is designed and produced with an inherent wind-speed accuracy of > ± 3%. Also, the indoor Relative Humidity (*RH*) values of the classrooms were checked to be equal to or greater than 80%, before and during the conduct of the experiments.

Considering the natural cross-ventilation systems in each classroom assessed, the following safe assumptions were made and observations noted.

- All the considered schools within the Study-area had similar architectural designs—being the commonly observed rectangular low-rise school buildings usually ranging from one to three storeys [i.e. having a ground-floor and two successively higher floors].
- All the investigated classrooms in each considered school, were virtually identical in design, dimension and geometry.
- The floor of each investigated classroom in each considered school was rectangular in shape.
- In the considered schools, the basic arrangement of classroom blocks (buildings) were usually in groups of the commonly-observed 'U' or 'L' shaped patterns.
- In the considered schools, the classroom blocks (buildings) were orientated in such a way that, the architects probably aimed at enhanced natural lighting and ventilation, with the local prevailing wind direction.

- Usually, for a particular set of 'U' or 'L' orientation-pattern, the longer dimension (side) of the first classroom-block (building) was approximately perpendicular [i.e. at 90°], or inclined at various angles ranging from 0° – 180° to the prevailing wind direction; while the other one or two classroom block(s)/building(s) [on either right and/or left of the first classroom-block (building)], were such that their longer dimension(s)/side(s) were approximately parallel to [i.e. at 0° or 180°] or inclined at various angles ranging from 0° – 180° to the prevailing wind direction.
- All the classrooms were basically designed for natural cross-ventilation—being the ventilation system available by default—usually with one or two doors and two or three pairs of side-hung casement windows, directly facing each other on both the leeward and windward walls.
- During school hours, for most parts of the year, the windows were observed to be fully opened allowing for conditions of maximum natural ventilation; while the door(s) were shut (closed), to prevent distraction and unauthorized exit and entry during learning periods—when measurements were taken.
- The difference in average pressure was the only factor that resulted in mass flow (airflow) within the classroom space.
- The values of 'Wind surface Pressure Coefficient Parameters (C_{pe} , $C_{pe\ ww}$ *and* $C_{pe\ iw}$)' that were obtained from Table 1, were adopted for empirical modelling [of the natural cross-ventilation systems], on a wall average basis. This is in view of the fact that, 'Wind surface Pressure Coefficient values, are rarely ever constant over an entire building surface. However, it is a known fact that, it varies mostly at points located near the edges of a wall surface. Furthermore, an architect is not likely to place a window—being a large ventilation-opening near the edge of a classroom-block (building).
- The effects of air-infiltration and fluctuating pressure were so negligible to be considered for analyses.
- Air mixing within the classroom-space was perfect.
- There were no pressure-drops, Partitions and Insect-screens in the classrooms.
- For each Classrooms, two critical conditions of dimensional-ratios were met i.e.:

(a) The Height-to-width ratio had a numerical value that was less than 0.5

Thus, $\left({}^{\mathrm{H}}/_{\mathrm{W}}\right) < 0.5$ --------------------- [24]

(b) The Length-to-Width ratio had a numerical value that lies between 1.5 and 4.0 Thus, it satisfied the inequality: $1.5 \leq \left({}^{L}/_{W}\right) \leq 4.0$ --------- [24]

For each of the three investigated classrooms in each of the thirty (30) considered schools, below is a simplified summary of the empirical-modelling approach, which was adopted in an attempt to model the real time natural cross-ventilation systems that were provided/available by default, during the field-work. The Indoor reference Wind-speed [V_{ref}] (m/s) was obtained by measuring the Indoor air-speed at eave-height, using the 'WM-200 Windmate' wind-meter; while indoor Relative Humidity [RH] was obtained using the AcuRite 00613A1 top-digital Hygrometer. Based on the measured dimensions (length and breadth) of windows in classrooms, obtained using a measuring-tape, as was earlier mentioned—[oftentimes identical in a particular school], for a classroom with two windows of Areas 'A_1' and 'A_2' on its windward wall, and another two windows of areas 'A_3' and 'A_4' on its leeward wall; its 'net window Area (A_{net})' was given by the expression in (1) below:

$$\frac{1}{A_{net}} = \left[\frac{1}{(A_1 + A_2)^2}\right] + \left[\frac{1}{(A_3 + A_4)^2}\right] \quad \text{--------------------1} \quad [25]$$

But, for another classroom having a set of three windows of areas 'A_1', 'A_2' and 'A_3' on its windward wall, and a second set of three windows of areas 'A_4', 'A_5' and 'A_6' on its leeward wall, then, its 'net window Area (A_{net})' was given by the expression in (2) below:

$$\frac{1}{A_{net}} = \left[\frac{1}{(A_1 + A_2 + A_3)^2}\right] + \left[\frac{1}{(A_3 + A_4 + A_6)^2}\right] \quad \text{--------------------2} \quad [25]$$

The respective values of 'Local external wind surface pressure coefficient (C_{pe})' [for all of the investigated classrooms], were determined by subtracting the 'Wind surface pressure coefficient on the windward wall (C_{peww}' from the 'Wind surface pressure coefficient on the leeward wall (C_{pelw})'—both of which were obtained from Table1 [17].

Then, three basic ventilation parameters ('Q_w', 'ACH' and 'Q_{wpp}') for each investigated classroom were calculated, using the following empirical models summarily presented below:

$$Q_w = C_d * A_{net} * V_{ref} * (C_{pe})^{0.5} \qquad \text{----------------------------3} \qquad [26]$$

Where:

'Q_w' is 'Wind-driven cross-ventilation rate' of classroom (m^3/s)

'Cd' is 'Discharge-coefficient' of ventilation-opening = 0.61 [being the constant value, adopted by BSI for large ventilation openings like windows].

$$Q_{wpp} = \frac{Q_w}{N} \qquad \text{--------------------------- 4} \qquad [27]$$

Where: 'Q_{wpp}' is 'Ventilation Rate per Person' of classroom (m^3/s/person)

'N' is 'Total number of students and instructor(s)/teacher(s)' in classroom

$$ACH = \frac{3600 * Q_w}{Vol} \qquad \text{----------------------------5} \qquad [28]$$

Where:

'ACH' is 'Air Changes per Hour' of classroom (Hr^{-1})

'Vol' is 'Space-Volume' of classroom (m^3) = L * B * H

'L' is the length of the classroom (m)

'W' is the width or breadth of the classroom (m)

'H' is the vertical height from the floor to the ceiling of the classroom (m).

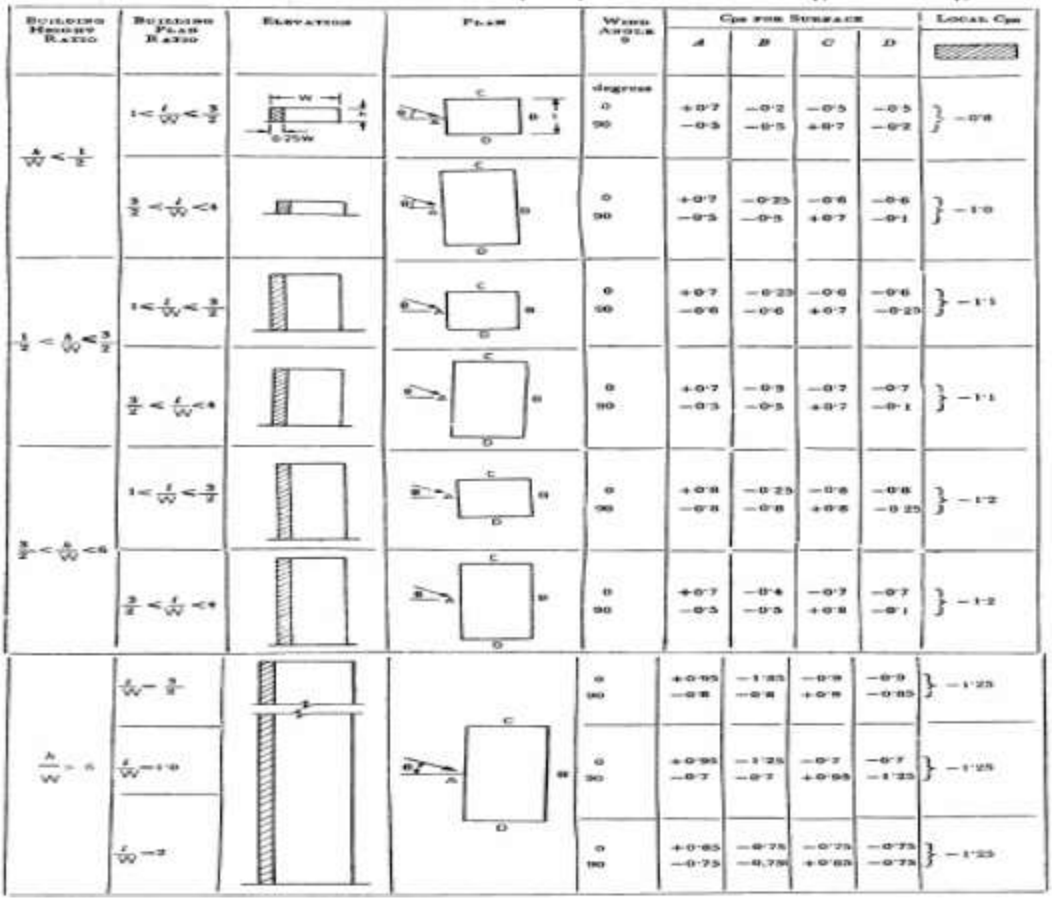
The average values of these ventilation parameters so obtained, were then collated, tabulated and analyzed by direct comparison with the standard values [of 1 ACH = 6 – 20Hr^{-1}, and Q_{wpp} = 0.008m^3 /S/ (Person) which is equivalent to 8L/S/(Person)], as recommended by the ASHRAE Standard 62.1-2004 and CIBSE Guide B (2004) for adequate ventilation of school classrooms.

3. Results and Discussion

Here goes the discussion of the tabulated results gotten during this research-work. The results are presented in four (4) tables, where by, Tables 2, 3 and 4 contain the values of Indoor reference Wind-speed (V_{ref}), Wind-driven cross-ventilation rate' of classroom (Q_w), Air Changes per Hour (ACH) and Ventilation rate per Person (Q_{wpp}) of each of thirty (30) investigated classrooms in the ten (10) selected public schools, located in Abeokuta city [in Ogun state], Ibadan city [in Oyo state] and Ilorin city [in Kwara state] respectively. However, Table 5 presented a summary of the results shown in the three preceding tables. Also included below is Table 1, which shows how the respective values of the 'Wind surface pressure coefficient on the windward wall (C_{peww})', the 'Wind surface pressure coefficient on the leeward wall (C_{peiw})' and the 'Local external wind surface pressure coefficient (C_{pe})'; for each of the ninety (90) investigated classrooms in the thirty (30) selected public schools, located in all three (3) cities were obtained. As shown in Table 5, a summary of the results presented in Tables 2 - 4, based on the assessments of some indoor ventilation parameters of the ninety (90) investigated classrooms in thirty (30) selected public schools, [located in the capital-cities of Abeokuta, Ibadan and Ilorin—all in the South-western climatic and geo-political zone of Nigeria], revealed that: while **Indoor reference Wind-speed** (V_{ref}) varied between 0.10 m/s and 0.82 m/s, with an average value of 0.37m/s—thus, these values clearly implied that, for majority of the daily school-hours, the indoor environmental assessments of the Classrooms were characterized by still air motion or the air motion with speeds slightly higher than that of still air. The **Wind-driven cross-ventilation rate**' of classroom (Q_w) varied between 0.42 m^3/s and 2.32m^3/s, with an overall average value of 1.29m^3/s. The implicative insinuation was that, the rate at which air molecules move/peregrinate from the windows on the windward walls to the windows on the leeward walls of the classrooms, or within the classroom-space generally, was much more gradual than is ideally required for optimal thermal comfort levels in classrooms.

Furthermore, based on the findings and results shown in Tables 2 – 5, the '**Air Changes per Hour'** of the classroom(ACH) ranged from a minimum value of 3.71 Hr^{-1} [i.e. < 4 Hr^{-1}] to a maximum value of 21.03 Hr^{-1} [i.e. > 20 Hr^{-1}], with an overall mean value of 13.14 Hr^{-1} [i.e. ~13 Hr^{-1}]. Thus, 8.9% of all the examined classrooms (i.e. 8 out of 108 classrooms) had ACH values that fell below the recommended 6 – 20 Hr^{-1} for School Classrooms. Likewise, 20.0% of the selected schools (i.e. 6 out of 36 schools), had maximum and average values of **Air Changes per Hour** (*ACH*) that were observed to be considerably lower than the minimal global requirement of 4 – 6 Hr^{-1} for learning spaces.

Table 1 External Pressure Coefficients (C_{pe}) For Walls of Rectangular Buildings



Building Height Ratio	Building Plan Ratio	Elevation	Plan	Wind Angle θ (degrees)	C_{pe} for Surface A	B	C	D	Local C_{pe}
$\frac{h}{w} \leq \frac{1}{2}$	$1 < \frac{l}{w} \leq \frac{3}{2}$			0 90	+0.7 −0.5	−0.2 −0.5	−0.5 +0.7	−0.5 −0.2	−0.8
	$\frac{3}{2} < \frac{l}{w} < 4$			0 90	+0.7 −0.5	−0.25 −0.5	−0.6 +0.7	−0.6 −0.1	−1.0
$\frac{1}{2} < \frac{h}{w} \leq \frac{3}{2}$	$1 < \frac{l}{w} \leq \frac{3}{2}$			0 90	+0.7 −0.6	−0.25 −0.6	−0.6 +0.7	−0.6 −0.25	−1.1
	$\frac{3}{2} < \frac{l}{w} < 4$			0 90	+0.7 −0.5	−0.3 −0.5	−0.7 +0.7	−0.7 −0.1	−1.1
$\frac{3}{2} < \frac{h}{w} < 6$	$1 < \frac{l}{w} \leq \frac{3}{2}$			0 90	+0.8 −0.8	−0.25 −0.8	−0.8 +0.8	−0.8 −0.25	−1.2
	$\frac{3}{2} < \frac{l}{w} < 4$			0 90	+0.7 −0.5	−0.4 −0.5	−0.7 +0.8	−0.7 −0.1	−1.2
$\frac{h}{w} = 6$	$\frac{l}{w} = \frac{3}{2}$			0 90	+0.95 −0.8	−1.85 −0.8	−0.9 +0.9	−0.9 −0.85	−1.25
	$\frac{l}{w} = 1.0$			0 90	+0.95 −0.7	−1.25 −0.7	−0.7 +0.95	−0.7 −1.25	−1.25
	$\frac{l}{w} = 2$			0 90	+0.85 −0.75	−0.75 −0.75	−0.75 +0.85	−0.75 −0.75	−1.25

Source: Indian Standard: 8759(Part3): Wind Loads on Buildings and Structures- Proposed Draft and Commentary.

Most, importantly, were the computed values of a critical ventilation parameter called the '**Ventilation rate per Person** (Q_{wpp})', which based on the results given in Tables 2 – 5, ranged from a minimum value of 0.01m^3/s/(Person) to a maximum value of 0.12m^3/s/(Person), with an overall mean value of 0.08m^3/s/(Person). Thus, [in 100.0% of the above investigated classrooms (i.e. 108 out of 108 classrooms) and in 100.0% of the selected schools i.e. 36 out of 36 Schools)], all three values [i.e. lowest, highest and average] of the Ventilation rate per Person (Q_{wpp}) were higher than the minimum standardized-limit value of 0.008 m^3/s/(Person) [i.e. the equivalent of 8L/S/(Person)], as is recommended by international established national regulatory bodies [such as the ASHRAE and CIBSE, for good Indoor Air Quality (*IAQ*) of educational facilities.

Table 2 Selected Ventilation-Parameters' Data of Classrooms in Twelve (12) Public Primary Schools Located at Abeokuta City in Ogun state, Nigeria.

S/No	School No.	Classroom No.	Indoor reference Wind-speed V_{ref} (m/s)	Wind-driven cross-ventilation rate Q_w (m^3/S)	Air changes per Hour ACH (Hr^{-1})	Ventilation rate per Person Q_{wpp} (m^3/S/P)
1	1	1	0.15	0.55	5.55	0.10
2		2	0.10	0.47	4.75	0.10
3		3	0.26	1.22	12.34	0.10
4	2	1	0.15	0.48	3.99	0.12
5		2	0.19	0.78	6.49	0.12

6		3	0.23	0.94	7.85	0.12
7		1	0.61	1.95	19.65	0.10
8	3	2	0.42	1.72	17.36	0.10
9		3	0.37	1.52	18.36	0.08
10		1	0.78	1.83	20.47	0.09
11	4	2	0.59	1.78	19.87	0.09
12		3	0.23	0.69	7.74	0.09
13		1	0.37	1.18	9.84	0.12
14	5	2	0.52	2.13	17.75	0.12
15		3	0.48	1.97	16.39	0.12
16		1	0.50	1.60	14.60	0.11
17	6	2	0.24	0.98	9.00	0.11
18		3	0.43	1.76	16.12	0.11
19		1	0.36	1.32	14.76	0.09
20	7	2	0.19	0.89	10.00	0.09
21		3	0.23	1.08	12.10	0.09
22		1	0.32	0.75	6.87	0.11
23	8	2	0.45	1.36	12.39	0.11
24		3	0.39	1.17	10.74	0.11
25		1	0.38	1.21	13.57	0.09
26	9	2	0.31	1.27	14.21	0.09
27		3	0.39	1.60	17.88	0.00
28		1	0.50	1.60	14.60	0.11
29	10	2	0.24	0.98	9.00	0.11
30		3	0.43	1.76	16.12	0.11
31		1	0.37	1.18	9.84	0.12
32	11	2	0.52	2.13	17.75	0.12
33		3	0.48	1.97	16.39	0.12
34		1	0.15	0.55	5.55	0.10
35	12	2	0.10	0.47	4.75	0.10
36		3	0.26	1.22	12.34	0.10
Average			**0.37**	**1.29**	**12.60**	**0.12**

Now, the direct and/or immediate benefits of this condition [of adequate ventilation and good IAQ] in all [100%] of the selected public primary schools established study area of the country, are the prevention and/or a reduction in IAQ-related cases of: fatigue, thermal discomfort, distraction, reduced mental-concentration, headaches, shortness of breath, hyper-sensitivity, coughing & nausea and dizziness etc.

Also, the indirect and/or long term benefits that are obtainable from this experimentally determined condition of adequate ventilation/good IAQ in schools, include but are not limited to an outright prevention and/or significantly reduced risks of: spread of airborne infectious diseases such as tuberculosis etc., excessively high/low humidity, health-conditions of asthma & allergies, gradual increase in the levels of biological & chemical indoor contaminants, indoor dampness and Sick Building Syndromes (SBSs); in the Classrooms of these public primary Schools.

Table 3 Selected Ventilation-Parameters' Data of Classrooms in Twelve (12) Public Primary Schools Located At Ibadan City in Oyo State, Nigeria.

S/No	School No.	Classroom No.	Indoor reference Wind-speed V_{ref} (m/s)	Wind-driven cross-ventilation rate Q_w (m^3/S)	Air changes per Hour ACH (Hr^{-1})	Ventilation rate per Person Q_{wpp} ($m^3/S/P$)

37	1	1	0.49	1.15	11.13	0.02
38		2	0.47	1.42	13.70	0.03
39		3	0.61	1.84	17.79	0.04
40	2	1	0.20	0.64	6.72	0.01
41		2	0.33	1.35	14.24	0.03
42		3	0.38	1.56	16.39	0.03
43	3	1	0.27	0.99	9.58	0.02
44		2	0.30	1.41	13.67	0.03
45		3	0.19	0.89	8.66	0.02
46	4	1	0.56	1.31	14.69	0.03
47		2	0.34	1.02	11.45	0.02
48		3	0.64	1.93	21.55	0.04
49	5	1	0.29	0.93	10.36	0.02
50		2	0.44	1.80	20.17	0.04
51		3	0.37	1.52	16.96	0.03
52	6	1	0.33	1.21	10.08	0.03
53		2	0.36	1.69	14.11	0.03
54		3	0.25	1.18	9.80	0.02
55	7	1	0.36	1.15	9.58	0.02
56		2	0.50	2.05	17.07	0.04
57		3	0.49	2.01	16.73	0.04
58	8	1	0.18	0.42	4.53	0.01
59		2	0.18	0.54	5.81	0.01
60		3	0.36	1.08	11.72	0.02
61	9	1	0.52	1.22	13.64	0.03
62		2	0.26	0.78	8.76	0.01
63		3	0.40	1.20	13.47	0.03
64	10	1	0.40	0.94	7.82	0.02
65		2	0.49	0.75	6..27	0.01
66		3	0.49	1.48	12.29	0.03
67	11	1	0.56	1.31	14.69	0.03
68		2	0.34	1.02	11.45	0.02
69		3	0.64	1.93	21.55	0.04
70	12	1	0.29	0.93	10.36	0.02
71		2	0.44	1.80	20.17	0.04
72		3	0.37	1.52	16.96	0.03
Average			**0.38**	**1.28**	**12.89**	**0.03**

Moreover, [as is summarized in Table 5 and separately shown in each of previous three (3) tables, i.e. Tables 2 - 4], a city-by-city comparative assessment of each city's average values of the aforementioned schools'/classrooms' ventilation parameters clearly showed/indicated that: the highest value of **Indoor reference Wind-speed** (V_{ref}) per City of 0.82 m/s was recorded in ilorin, followed by an intermediate highest value of 0.78 m/s in Abeokuta, and the least highest value of 0.64 m/s in Ibadan.

Table 4 Selected Ventilation-Parameters' Data of Classrooms in Twelve (12) Public Primary Schools Located At Ilorin City In Kwara State, Nigeria.

S/No	School No.	Classroom No.	Indoor reference Wind-speed V_{ref} (m/s)	Wind-driven cross-ventilation rate Q_w (m^3/S)	Air changes per Hour ACH (Hr^{-1})	Ventilation rate per Person Q_{wpp} (m^3/S/P)

73	1	1	0.82	1.92	19.41	0.10
74		2	0.57	1.72	17.31	0.10
75		3	0.63	1.90	19.13	0.10
76	2	1	0.15	0.48	4.64	0.10
77		2	0.53	2.17	21.03	0.10
78		3	0.25	1.02	9.92	0.10
79	3	1	0.26	0.95	9.23	0.10
80		2	0.25	1.18	11.39	0.10
81		3	0.41	1.93	18.68	0.10
82	4	1	0.47	1.50	16.79	0.03
83		2	0.16	0.66	7.33	0.02
84		3	0.24	0.98	11.00	0.04
85	5	1	0.18	0.42	3.71	0.02
86		2	0.35	1.05	9.27	0.04
87		3	0.21	0.63	5.56	0.11
88	6	1	0.38	1.21	12.24	0.10
89		2	0.47	1.93	19.43	0.10
90		3	0.33	1.35	13.64	0.10
91	7	1	0.64	2.04	19.79	0.10
92		2	0.47	1.93	18.65	0.10
93		3	0.40	1.64	15.87	0.10
94	8	1	0.13	0.42	4.64	0.09
95		2	0.18	0.74	8.25	0.09
96		3	0.20	0.82	9.17	0.09
97	9	1	0.54	1.27	11.14	0.11
98		2	0.25	0.75	6.62	0.11
99		3	0.77	2.32	20.39	0.11
100	10	1	0.41	1.50	16.81	0.09
101		2	0.30	1.41	15.78	0.09
102		3	0.33	1.55	17.36	0.09
103	11	1	0.16	0.66	7.33	0.02
104		2	0.47	1.50	16.79	0.03
105		3	0.24	0.98	11.00	0.04
106	12	1	0.21	0.63	5.56	0.11
107		2	0.35	1.05	9.27	0.04
108		3	0.18	0.42	3.71	0.02
Average			**0.36**	**1.24**	**12.44**	**0.09**

Also, the highest maximum value of Wind driven cross-ventilation rate (Q_w) per City of 2.32 m3 /s was recorded in ilorin, next to an intermediate maximum value of 0.78 m/s in Abeokuta, and the least maximum value of 0.64 m/s in Ibadan. Also, the highest value of **Wind-driven cross-ventilation rate** (Q_w) per City of 2.32m^3/s was recorded in Abeokuta, next to an intermediate highest value of 2.13m^3/s in Abeokuta, and the least highest value of 2.05m^3/s in Ibadan. Comparably, the highest value of **Air Changes per Hour** (*ACH*) per City of 21.55 Hr^{-1} was recorded in Ibadan, followed by an intermediate highest value of 21.03 Hr^{-1} in Ilorin, and the least high value of 20.47 Hr^{-1} in Abeokuta.

Conclusively, the data from **Table 5** shows that the highest value of the **Ventilation rate per Person** (Q_{wpp}) **per City** of 0.12 m3/s/ (Person) was recorded in Abeokuta, followed by an intermediate highest value of 0.11m3/s/ (Person) in Ilorin, and the least high value of 0.04m3/s/ (Person) in Ibadan.

Table 5 Lowest, Highest and Average Values of Ventilation Parameters for the thirty- Six (36) Classrooms, in Twelve (12) Public Primary Schools, Located at Abeokuta, Ibadan and Ilorin Cities in South-Western, Nigeria.

Location / Parameter	Abeokuta			Ibadan			Ilorin			The Three (3) Studied Cities combined		
	Lowest	**Highest**	**Ave.**	**Lowest**	**Highest**	**Ave.**	**Lowest**	**Highest**	**Ave.**	**Low.**	**High.**	**Ave.**
Indoor reference Wind-speed V_{ref} (m/s)	0.10	0.78	0.37	0.18	0.64	0.38	0.13	0.82	0.36	0.10	0.82	0.37
Wind-driven cross-ventilation rate Q_w (m^3/S)	0.47	2.13	1.29	0.42	2.05	1.28	0.42	2.32	1.24	0.42	2.32	1.27
Air changes per hour *ACH* (Hr^{-1})	3.99	20.47	12.60	4.53	21.55	12.89	3.71	21.03	12.44	3.71	21.55	12.64
Ventilation rate per Person Q_{wpp} (m^3/S/P)	0.08	0.12	0.12	0.01	0.04	0.03	0.09	0.11	0.09	0.01	0.12	0.08

From the tabular analysis above it could be stated that, the public primary schools in Abeokuta town [of Ogun state] have the highest natural ventilation rates, followed by those in Ilorin town [of Kwara state] and Ibadan town [of Oyo state] respectively.

4. Conclusion

Indoor environmental parameters [such as 'Indoor reference Wind-speed', 'Classroom dimensions' 'Occupancy' and 'Area of total effective Ventilation-opening'—being equivalent to the 'Net Window Area' in this Case-study] of One hundred and Eight (108) Classrooms in thirty (36) naturally ventilated Schools, in three (3) South-western Nigerian cities of 'Abeokuta', 'Ibadan' and 'Ilorin'; have been repeatedly measured [at relative humidity values of 80% and above], and then, inputted into empirical models, to determine the corresponding values of some ventilation parameters [such as 'Wind-driven cross-ventilation rate', 'Air Changes Hour' and 'Ventilation Rate per Person']. The overall average values of Indoor reference Wind-speed and Wind-driven cross-ventilation rate were 0.37 m/s and 1.27 m3 /S respectively—both values being generally low, for optimal thermal comfort of the school students in a typical school classroom. However, the data of 'Air Changes per Hour' and 'Ventilation rate per person' for each Classroom when compared with two (2) existing internationally accepted standard specifications—[ASHRAE Standard 62.1-2004and CIBSE Standard (2004)]; proved that, there is adequate Air Changes per Hour in the vast majority [91%] of all 108 investigated school classrooms, and adequate Ventilation rate per person in all [100%] of the 108 investigated school classrooms—which allays the fears of IAQ-related conditions of general ill-health, thermal discomfort, absenteeism and Sick Building Syndromes etc., that would have culminated in poor academic performance of public school students in the South-western Nigerian cities of Abeokuta, Ibadan and Ilorin.

5. Recommendations

Addressing the growing concerns of inadequate ventilation in other public primary schools, located within this South-western and other zones of Nigeria, that were not investigated during this study; the following recommendations is hereby made to the Nigerian government and Architects:

- Adequate headroom should be ensured in designing/renovating subsequent public primary school classrooms.

- Designing new schools that is housing proper siting and orientation in the classrooms should be adopted.
- Adequate type, sizing and positioning of windows, that ensures maximum entry of fresh air into the classroom space.
- Trees and flowers should be planted at the outdoor environments of the classrooms, to improve Indoor Air Quality.
- Limit the number of users/students in a classroom to a number that can be accommodated within the Occupancy level of the available space.

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