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Research article

Evaluation of the Influence of Natural Ventilation Variables on Indoor Thermal Comfort of Occupants of Secondary School Classrooms During Hot Season in Enugu Metropolis, Nigeria

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ABSTRACT

In tropical countries, the effect of climate change and its consequent temperature rise are sources of worry to many environmentalists and concerned citizen worldwide. Building sector consume great quantity of energy which involves burning of fossil fuel that contributes significant amount of greenhouse gas emissions into the atmosphere. Improving proving thermal comfort of occupants in a free-running building and avoiding active and fossil-based systems, is the main challenge in many cities all over the world. This paper therefore focused on the evaluation of the influence of natural ventilation on indoor thermal comfort of occupants of secondary school classroom during the hot season in Enugu Metropolis. Both primary and secondary sources of data were adopted. Data collecting instruments include Digital Anemometer and Thermometers. Results of the descriptive analysis of data collected showed that high indoor temperature range of between 29.8oC and 35.3o C was main the factor that caused indoor discomfort during dry season. There was also low air velocity range of between 0,11m/s and 0.5m/s and the existing Window-to-Wall Ratio (WWR) obtained spans between 13% and 21% for the classrooms examined. From the result of the regression analysis used to evaluate the influence of natural ventilation variables on indoor comfort, the probability values of indoor air temperature, indoor air velocity and indoor relative humidity were (0.0209), (0.0498) and (0.1382). This result implied that, indoor temperature and indoor air velocity had significant influence on the thermal comfort conditions of the classrooms as the probability values were less than significance level of 0.05. Whereas, indoor relative humidity had no significant influence on the thermal comfort condition as the probability value was above significance level of 0.05. The conclusion was that to improve indoor comfort in classrooms, efforts should focus on increasing air flow rate through the classrooms and this would facilitate the reduction of indoor temperature.

Keywords: *Natural Ventilation Variables; Indoor Thermal Comfort; Hot Season; Enugu Metropolis*

Introduction

Global warming is a worldwide issue that affects almost every aspect of human life. It is caused by high concentration of greenhouse gases (carbon dioxide, methane and oxide) in the atmosphere. Greenhouse gases are generated into the atmosphere by burning fossil fuels (coal, petroleum and natural gas) as source of power for various human activities. Some of the effects of global warming include rise in air temperature, flash flooding and rising sea levels. In an effort to save the planet from the impact of global warming building sector has been the focus as it consumes greater percentage of the world energy demand. The United National Environment Program (UNEP) in one of its reports emphasized that building sector contributes more than 30% of the yearly greenhouse gas emissions in both developed and developing nations. Building sector do not only contribute to the global warming but also it is negatively affected by the same problem (UNEP, 2009).

The various negative effects of the increase in temperature are felt more in other regions as a result of its proximity to the position of the sun. Nigeria as well as other African countries are located in the tropical zone and therefore, are equally experiencing adverse effects of global warming and Climate Change (Africa Progress Panel, 2015). Earth warming has increased the need for indoor cooling in order to improve comfort for building occupants. The method of using mechanical cooling unfortunately relies more on electricity for its operation. The inadequacy and cost of electricity especially in Nigeria makes the improvement of indoor comfort more difficult and challenging. Minimizing the impact of global warming and reducing he reliance on energy-driven mechanical cooling system, require focus on energy efficient ways of improving indoor comfort. Buildings that are energy efficient would require minimal cooling load to improve indoor comfort. This is necessary because the building cooling load alone is about 40% of electricity consumption by building sector in Nigeria (Shaeri, Yaghoubi, Alibadi, Vakilinazhad, 2018).

Urban centers within the tropical regions including Enugu Metropolis are affected by global warming more than the adjoining rural areas. Urban centers are influenced by heat waves as a result of high urban population, housing density, traffic congestion and industrial pollution. Though thermal comfort is required in both outdoor and indoor spaces but it is more critical for indoor spaces than in outdoor. Spaces, where people spend great percentage of their time for various activities and should therefore, be conducive for optimal output and rest. According to American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) guideline, people spend about 80-90% of their time indoors (ASHRAE, 2010; Yousef et al., 2016; EPA, 2014). Various human activities require different levels of comfort and concentration. For instance, educational institutions such as school environments require quiet and comfortable environment due to high level of concentration needed for optimum academic performance. Many studies have emphasized that indoor thermal comfort has significant influence on students' performance (Mumovic, Palmer, Davies, Orme and Ridley, 2009; Zeller and Boxem, 2009; Teli, Jentsch and James, 2012).

The energy crisis situation has necessitated and ignited many research studies on the use of passive techniques of achieving indoor comfort in the tropics (Adebamowo,2007; Oluowobi and Adenuga, 2012; Atolagbe and Ajayi, 2015; MuktarInusa and HalilZafer, 2017). Also, Thompson and Ahmad (2019) reiterated the global interest on how to reduce the level of energy consumption in building sector aimed at addressing the challenges arising from the energy crisis. In the tropical countries like Nigeria there is need for more of such quest to minimize reliance on energy based mechanical means of improving indoor comfort. This paper focused on the adoption of passive techniques to improve indoor comfort for occupants of secondary school classrooms in Enugu Metropolis. The objectives of this study are, to measure comfort variables in a free-running selected secondary school building during dry season, and to find the relationship between these variables with thermal comfort of occupants of secondary school buildings in Enugu Urban.

Study Area

Enugu is the capital city of Enugu State of Nigeria. The city was founded in 1915as settlement for coal miners, as well as, residential quarters for railway workers and European administrators (Nwachukwu and Ukpabi, 2008). The city of Enugu owed its growth to the exploitation of coal, hence the nickname Coal-city. The administrative units that make up Enugu Metropolis are Enugu North, Enugu South and Enugu East Local Government areas. The city occupies an area of about 72 square kilometers and is positioned at approximately between latitudes 5° 55′ 15′′ N and 7° 6′ 36′′ N, and longitudes 6° 55′ 39′ E and 7° 54′ 26′′ E (Nnam and Maduako, 2014).

The topography is characterized by undulating landscape that stretches eastwards from the foot of Udi hills. Enugu Metropolis is located on a very high relief of about 228.9m above sea level. The city falls within the equatorial climatic zone, with an annual rainfall that ranges between 1520mm and 2030mm. According to Nwachukwu and Ukpabi, (2008), the annual mean temperature of Enugu Metropolis is between 22°C and 30.8°C, and relative humidity fluctuates from 40-80%. The climate statistics of Enugu's temperature spreading a period of 30 years showed that the average maximum temperature is 35°C. February and March are the hottest months in Enugu. The lowest minimum temperature is experienced during the months of July and September. The population of Enugu City is about 722,664 according to the 2006 population census. Figure 1 is the map of Nigeria showing Enugu while figure 2 is the map of Enugu State showing Enugu metropolis.

Figure 1: Map of Nigeria showing Enugu
Source: Enugu State Ministry of Lands (2018)

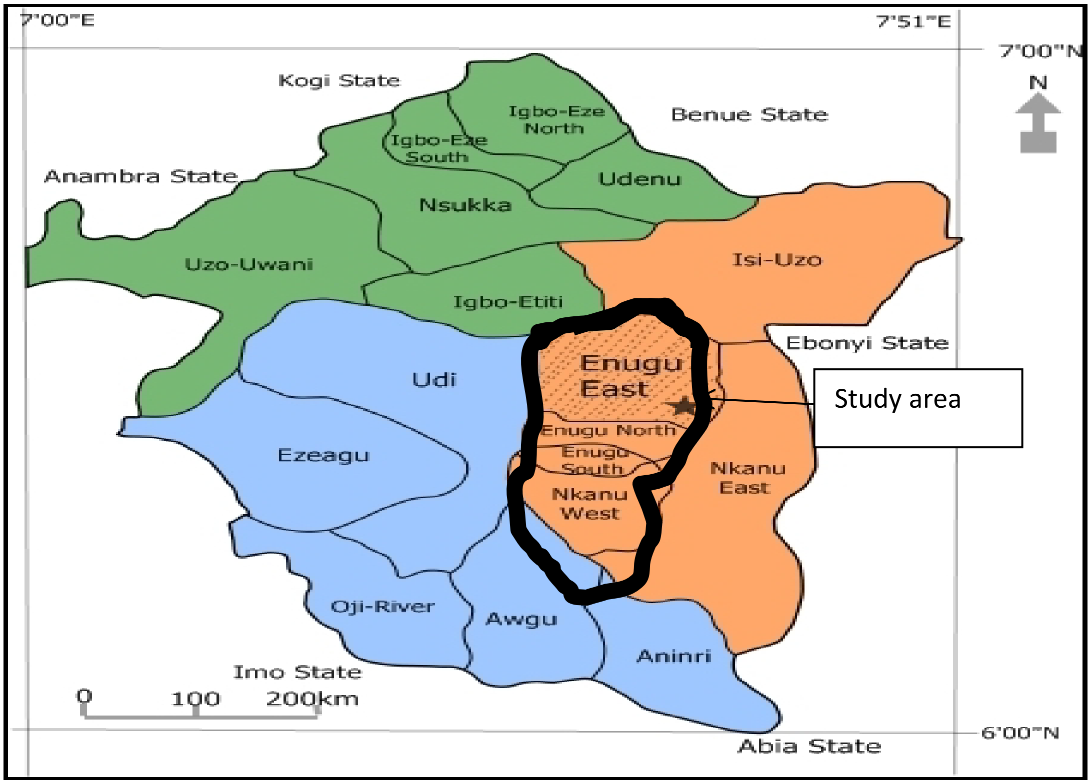

Figure 2: Map of Enugu State Showing Enugu Metropolis Source: Enugu State Ministry of Lands (2018)

Methodology

Sources of Data

Both primary and secondary sources data were explored for this paper. Primary data were collected using observational measurements of temperature, velocity relative humidity and WWR (measured with dry and wet bulb thermometers digital Anemometers and linear tape). Secondary data were obtained from the websites, books, previous studies, journal articles, and documents from Enugu State Ministry of Lands.

Sample Frame

The sample frame for this research composed of Government and Mission secondary schools in Enugu Metropolis from which some schools were selected based on 30% as recommended (Agbola, Egunjobi, Olatubara, Yusuf and Alabi, 2003). Government schools are the ones owned and controlled by State Government, while Mission schools are the ones owned by the church. Private secondary schools were excluded because the physical structures and environments in which they operate are entirely substandard from what a secondary should be. The total number of Government and Mission secondary schools in Enugu Metropolis were thirty-three (33) from which ten (10) were randomly selected. The locations of the 33 secondary schools based on local Government Council Areas are shown in Table 1.

Table 1: Government and Mission Secondary Schools in Enugu Metropolis Categorized Based on their Respective Locations within the three Local Governments Areas

S/N	*Enugu East*	*Enugu South*	*Enugu North*
1	ST. PatricksEmene	Union Sec. Sch.Awkunanaw	Queens S. Enugu
2	National Grammar S. Nike	Girls A. S. Awkunanaw	C. S. S. Iva-Valley Enugu
3	Girls S. S. Abakpa Nike	Idaw-River Girls S. S. Enugu	Urban G. S. S. Enugu
4	T. E. G. Enugu	Army Day S. S. Awkunanaw	City Girls S. S. Enugu
5	C. S. S. Ugwuogo Nike	C.S. S. IdiaguAmechi	Coal Camp S. S. Enugu
6	ST. Josephs C. Emene	Model High S. AmoduAwk.	Metro. G. S. S. Enugu (
7	Annunciation S. S. Nike	Comprehensive S. S. Akwuke	New Layout S. S. Enugu
8	C. H. S. Emene	Uwani S. S. Enugu	Day S. S. Independence L/O
9	New Haven Boys S. Enugu	H. R. C. Enugu	Govt. S. S. (GTC) Enugu
10	Umuchigbo H. S. Iji- Nike	C. I. C. Enugu	
11		M/Land S. S. Enugu	
12		C. S. S. ObeaguAwkunanaw	
13		Girls H. S. Uwani	
14		G. S. S. Ugwuaji	
	30% of 10 equal 3 schools	**30% of 14 equal 4 schools**	**30% of 9 approximately 3 schools**

Source: Post Primary School Management Board (PPSMB), Enugu (2022)

Sampling Techniques and Sample Size

Sample techniques adopted were purposive, stratified and simple random sampling method. This technique was considered adequate because the secondary schools were chosen based some characteristics (either Government or Mission), and these schools were considered on the bases of their location within the three local government areas (strata). Ten schools were randomly selected from 33 schools (3 each from Enugu East and North and 4 from Enugu South) as shown in Table 2.

Table 2: Selected Secondary Schools for the Research

S/N	*Enugu East*	*Enugu South*	*Enugu North*
1	National Grammar School Nike, Enugu	Idaw-River Girls Secondary School, Enugu	City Girls Secondary School, Enugu
2	St. Patrick's Emene, Enugu	Union Secondary SchoolAwkunanaw, Enugu	Day Secondary School Independence Layout, Enugu
3	Annunciation Secondary School Nike, Enugu	Uwani Secondary School, Enugu	Govt. S. S. (GTC) Enugu
4		Girls' High School,Uwani, Enugu	
	Total: 3 schools randomly selected	**Total: 4 schools randomly selected**	**Total: 3 schools randomly selected**

Source: Researchers field survey (2022)

Instruments for Data Collection

The instruments for data collection were linen/surveyors' tape for physical measurements of the selected school buildings, dry bulb and wet bulb thermometers were used to measure indoor and outdoor air temperature and relative humidity. Digital Anemometers were used to measure air velocity of both indoor and outdoor environments. The specifications of the instruments used are shown in Table 3.

Table 3: Instrument Specifications

No	Instrument Name	Range	Accuracy	Resolution
1	Digital Anemometers	0.800m/s -30.00m/s	2.0% reading +50 characters	001m/s
1	Thermometers	-30^{o} Cto 100^{o} C	0.5^{o} C at 25^{o} C	0.01^{o} C

Source: Researchers compilation (2022)

Data Collection

The dry bulb and wet bulb thermometers were used to record indoor air temperature and humidity at one-hour interval throughout the study period in the selected classroom from each of the schools. The thermometers were held within one meter (1m) of the students' reading station to record the actual thermal conditions being experienced by students. The thermometers were also placed outside the buildings to record both the corresponding outdoor temperature and humidity. A hand-held device called digital anemometer was used in monitoring the air velocity of the classroom as indicated in Plates 1 and 2.


Plate 1


Plate 2

Data Analysis

Natural ventilation variables (temperature, relative humidity, air velocity and Window-to-Wall Ratio (WWR)) were measured from classrooms in each of the ten selected secondary schools. The dry bulb and wet bulb thermometers were used to record indoor air temperature and humidity at one-hour interval throughout the study period (February 2021 -May 2022). This was carried out within school days (Monday to Friday) and within school learning/teaching hours of 8.00am to 2.00pm. The average recordings of the independent variables for the four months of dry season (Feb.-May) are shown in Table 4. The variables measured are Window-to-Wall Ratio (WWR), indoor air temperature (IAT), outdoor air temperature (OAT), indoor air velocity (IAV), indoor relative humidity (IRH), outdoor air velocity (OAV) and outdoor relative humidity (ORH). From the recordings, the average indoor classroom temperature readings for the months under review in all the selected schools were above 31ºCwhich high for human comfort. Little variation in average temperature between different schools might be due to type of cross ventilations, classroom sizes, and shading devices obtained. Indoor classroom air velocity in the schools was generally very low and ranges between 0.1m/s-0.7m/s.

Table 4: Dry Season Mean Data of Independent Variables Measured in a Specific Classroom from the ten Selected Schools

DRY SEASON (February 2021 - May 2021)

SELECTED SCHOOLS	(%) WWR	(ºC) IAT	(ºC) OAT	\ m/s IAV	%IRH	m/s OAV	% ORH	\ ITC
National Grammar School Nike	16	33.5	33.6	0.25	58.5	0.55	65.5	33.17
St. Patrick'sEmene	21	32.55	32.3	0.1	78.5	0.2	78.5	33.28
Annunciation Sec Sch. Nike	13	34	32.3	0.2	70	1.1	79	29.81
Idaw-River Girls	17	32.77	33.8	0.3	62	1.3	73.5	28.91
Union Boys Awkunanaw	14	31	34.6	0.23	73.5	1	65.5	30.5
Uwani Boys Sec. Sch. Enugu	16	34.8	34.5	0.7	62	0.51	70.5	34.01
Girls High Sch.Uwani	18	33.8	35	0.3	65.5	0.78	66	28.78
City Girls Enugu	14	33.5	33.8	0.3	62.5	1	67	30.41
Day Sec. Independence Layout	13	32.8	32.3	0.1	78.5	0.2	78.5	33.65
Govt Sec. Sch. (GTC) Enugu	14	33	33.3	0.7	65	2.15	72.5	27.91

Inferential Data Analysis

Regression Analysis

Regression analysis was adopted for this paper because of the need to explain the relationship between single dependent variable and more than one independent variable both of which are continuous**.** These Independent variables as represented in Table 4 are Window-to-Wall Ratio (WWR), Indoor Air Temperature (IAT), Indoor Air Velocity (IAV), Indoor Relative Humidity (IRH), Outdoor Air Temperature (OAT), Outdoor Air Velocity (OAV), and Outdoor Relative Humidity (ORH) The dependent variable is Indoor Thermal Comfort (ITC). The Statistical Package for Social Sciences (SPSS version, 22) software was used. Table 1 shows the obtained values of independent variables for the dry season (February 2021 – May 2021), used to run the analysis.

Table 5: Results of Regression Analysis for Dry Season
Dependent Variable: ITC
Method: Least Squares
Date: 08/27/21 Time: 06:19
Sample: 1 10
Included observations: 10

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	191.4139	89.41255	2.140794	0.1656
IAT	-3.012886	2.422490	-1.243715	0.0396
IAV	15.44866	14.83127	1.041628	0.0070
IRH	-31.56203	11.27752	-2.798667	0.0253
OAT	-0.476482	1.152538	-0.413420	0.0194
OAV	6.467229	3.326046	1.944419	0.0413
ORH	-17.50147	9.355540	-1.417975	0.0220
WWR	2.738636	2.658791	1.030031	0.0113

R-squared	0.818217	Mean dependent var	67.94000
Adjusted R-squared	0.181975	S.D. dependent var	4.267516
S.E. of regression	3.859743	Akaike info criterion	5.529640
Sum squared resid	29.79524	Schwarz criterion	5.771709
Log likelihood	-19.64820	Hannan-Quinn criter.	5.264092
F-statistic	1.286015	Durbin-Watson stat	1.710298
Prob(F-statistic)	0.504505		

Source: Eviews computation

Terms units
WWR = Window- to-Wall Ratio %
IAT = Indoor Air Temperature ^oC
IAV = Indoor Air Velocity m/s
IRH = Indoor Relative Humidity %
OAT = Outdoor Air Temperature^oC
OAV = Outdoor Air Velocity m/s
ORH = Outdoor Relative Humidity %
ITC = Indoor Thermal Comfort
ECT (-1) = Error correction mechanism

Discussion and Findings

The findings of the study indicated that indoor air temperature, indoor relative humidity, outdoor air temperature and outdoor relative humidity have negative relationship on thermal comfort condition in the selected secondary schools in Enugu Metropolis during dry season. However, indoor air velocity, outdoor air velocity and window-to-wall ratio have positive relationship on thermal condition on the average. The coefficient values of the variables are shown in Table 5. More so, the study revealed that a unit increase in indoor air temperature would lead to -3.012886 decreases in thermal comfort condition whereas a unit increase in outdoor air temperature would lead to -0.476482 decreases in thermal comfort condition on the average. However, a unit increase in indoor air velocity would lead to 15.44866 increases in thermal comfort condition whereas a unit increase in outdoor air velocity would lead to 6.46729increases in thermal comfort condition on the average. The study also revealed that a unit increase in indoor relative humidity would lead to -31.56203 decreases in thermal comfort condition whereas a unit increase in outdoor relative humidity would lead to -17.50147 decreases in thermal comfort condition on the average. Finally, a unit increase in window- wall-ratio (WWR) would lead to 2.738636 increases in thermal comfort condition.

From the study, all the observed variables have significant impact on the thermal comfort, it implies that indoor air velocity, outdoor air velocity, indoor temperature, outdoor temperature, indoor relative humidity, outdoor relative humidity and window to wall ratio have significant impact on the thermal comfort condition as the probability values are less than 0.05 level of significance.

More so, the result further indicated through the value of the Regression (R^2) that the rate at which the independent variables (indoor and outdoor relative humidity, indoor and outdoor temperature, indoor and outdoor air velocity, and window-to-wall ratio) explained the behavior of the thermal comfort condition is 81.8% which is believed by the researcher to be relatively high.

The Durbin Watson statistics which is used to measure if there was serial correlation among the values of the independent variables, using the rule of thumb, “there was no serial correlation if the value of Durbin Watson statistics draws closer to 2.0, the result of the Durbin Watson statistics indicated that there was no serial correlation among the series of the independent variables

References

Adebamowo, M. A. (2007). Thermal Comfort in Urban Residential Buildings in Lagos Metropolis, Ph. D Thesis, Department Geography and Planning, Lagos State University, Ojo, Nigeria.

African Progress Panel (APP, 2015), Power, People, Planet; Seizing Africa's energy and Climate opportunities

Agbola, T., Egunjobi, L., Olatubara, C., Yusuf, O. and Alabi, M. (2003). Contemporary Social Science Research Methods. MURLAB Searchwisdom Education Services Lagos, pp 133

ASHRAE American Society of Heating, Refrigerating and Air-conditioning Engineers. (2010), ANSI/ASHRAE; Standard 55-2010. Thermal environment conditions for human occupancy. Atlanta, USA. ASHRAE.

Atolagbe, A. M. O. and Ajayi, O. O. (2015). Natural Ventilation and Body Heat; An Evaluation of Residents Satisfaction in Ogbomoso, Nigeria. I*nternational Journal of Civil Engineering, Construction and Estate Management, 3 (2) 7-15*

Environmental Protection Agency EPA (2014). www.epa.gov.(accessed December 20, 2014).

Muktar, I. and Halil-Zafer, A. (2017). Application of Passive Cooling Techniques in Residential Buildings; A Case Study of Northern Nigeria. *Journal of Engineering Research and Application. 7, 24-30*

Mumovic, D. J., Palmer, M., Davies, M., Orme and Ridley I. (2009), Winter indoor air quality, thermal comfort and acoustic performance of newly built secondary schools in England. - *Built Environ. 44, 1466-1477*

Nnam, V. C. and Maduako, I. (2014). Assessment of Spatial Urban Dynamics in Enugu City Using GIS and Remote Sensing. Kuala Lumpur Malaysia.

Nwachukwu, M. U. and Ukpabi, N. I. (2008), The Impact of Housing Conversion on Residential Land use Development in Nigerian Cities; A Case Study of Enugu Metropolis. *Environmental Studies and Research Journal University of Nigeria Virtual Library*

Olufowobi, M. B. and Adenuga, O. A., (2012). Towards the specification of window sizes for natural ventilation in a warm- climate, Nigeria. Journal of Building Performance, 3

Shaeri, J., Yaghoubi, M., Alibadi, M., Vakilinazhad, R. (2018). Experimental Study of temperature, relative humidity and wind speed of traditional houses at hot and humid climate of Iran (Case study

Teli, D., Jentsch, M. and James, P. (2012). Naturally ventilated classrooms. An assessment of existing comfort models for predicting the thermal sensation and preference of primary school children*, Journal on Energy Building, 53, 166-182*.

Thompson, E. and Ahmad, T. (2019). Energy efficient building design in Nigeria; An assessment of the effect of the sun on energy consumption in residential buildings. *Journal of Engineering and Architecture vol.7 (1) 1-18*

United Nations Environment Program (UNEP, 2009). Annual Report 2009; Seizing the Green Opportunity

Yousef, A., Moohammeh, A., Martha, K., Ahmed, M., Amit, K. and Esam, E. (2016), Impact of indoor environmental quality on occupants' well-being and comfort; A review of the literature. *Gulf Organization for Research and Development International Journal of Sustainable Built Environment* 5(1) 1-11

Zelle, W. R. and Boxem, G. (2009). Effect of thermal activated building systems in schools on thermal comfort winter. *Journal on Build. Environ, 44, 2308-2317.*