Establishing Indoor Comfort Temperature (Neutral Temperature) in Naturally Ventilated (NV) Office Buildings in Jos, Nigeria

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Abstract
The aim of the research is to grant understanding to the concept of thermal sensation, acclimatization and by extension establishing Neutral Temperature for office users. The Neutral Temperature is the indoor temperature in which an average office occupant feels comfortable without the aid of mechanical ventilation. Ten (10) naturally ventilated (NV) office buildings were randomly selected within Jos urban conurbation in northern Nigeria. Using research techniques established by Han et al (2007), Wang (2006) and Becker et al (2002) which are adaptive in nature, the research established a Neutral Temperature of 29.4ºC for the occupants of these building types. This Neutral Temperature is 4.34 ºC higher than that established by Ogbonna & Harris 2007 in similar locality i.e northern Nigeria. It is also 0.31 ºC higher than that executed in a warm humid climate of southern Nigeria (Adebamowo, 2007). It should be noted here that the aforementioned researches were conducted for residential buildings where factors such as activity level, adaptation, level of clothing of respondents and ambient weather differed. The research recommends further studies using similar methodology but in varying seasons and geographical locations. This is to establish further credence to indoor thermal comfort studies using the adaptive method.
Keywords: Neutral Temperature, Acclimatization, Thermal Sensation, Adaptive Model, Productivity, Sustainability.
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1.0 Introduction

Studies have shown that there are relationships between comfort of office workers and their performance, efficiency and productivity (See Charles et al, 2009 & Lan et al, 2010). Studies show that high temperature levels produce a feeling of lethargy and tiredness as a result of increased body temperature leading to possible efficiency decrease. While, low temperature levels induce decrease in efficiency due to cooler body heat and possible shivering.

Charles et al (2009), stated that indoor air quality and thermal comfort are most important factors for the worker's performance, satisfaction and well-being. Roelofsen (2002), also stated that the office workers had more negative emotions and required more effort to maintain performance under slightly warm or slightly cool environment conditions. Federspiel et al (2002), concluded that indoor room temperature of more than 25.4°C negatively affected the performance of office workers. A more detailed research conducted by Seppänen et al (2003), established a decrease in performance by 2% per ºC increase of the temperature in the range of 25-32 ºC, and no effect in performance of workers in temperature range of 21-25 ºC. These researches were however conducted mostly in temperate regions of Europe.

Several researches had hitherto been conducted in hot humid climates similar to that obtained in southern Nigeria, in natural ventilated buildings (NV) and obtained Neutral Temperatures ranging from 27.4^{0}C to 28.8^{0}C (See Table 1). These researches had been executed based on the concept of Neutral Temperature.

From the above stated, it is therefore paramount that a comfortable temperature be established by research. This must be localized for a given region because thermal comfort is highly subject to subjective variables such as habits and physiological expectations and the non-subjective variables such as temperature, humidity and air pressure etc. This will optimize performance and comfort of users of such building and by extension, improve sustainability. This optimized temperature for thermal comfort is referred to as Neutral Temperature.

Table 1: Findings of Previous Researches on Neutral Temperature in Hot Humid Climates for Naturally Ventilated (NV) Buildings.

S/No.	Year	Researcher	Building Type	Location	Neutral Temperature Indicated
01	1990	J.F. Bush	Office	Bangkok, Thailand	28.5^{0}C (ET) for NV Buildings
02	1991	R.J. de Dear, K.G. Leow et al	Residential and Office	Singapore	28.5^{0}C (To) for NV Buildings
03	1998	A.G. Kwok	Classrooms	Hawaii, USA	27.4^{0}C (To) for NV Classrooms
04	2003	N.H. Wong et al	Classrooms	Singapore	28.8^{0}C (To) for NV Classrooms
04	2008	A.C. Ogbonna et al	Residential	Jos, Nigeria	25.06^{0}C (To) for NV Residences

Source: Hwanga et al. (2006) and Ogbonna et al. (2007)

2.0 Aim of the Study

To determine Neutral Temperature of selected naturally ventilated office buildings in Jos Nigeria and thereby establish thermal comfort of occupants.

3.0 Sample Area Characteristics

Jos town in Plateau State is characterized by rocky terrain (topography) giving rise to plateaus and plains, hills and valleys and it enjoys a unique climate (temperate climate) than much of the rest of Nigeria. It is situated in the central part of Nigeria with an average altitude of 1,217m (3,993ft) above sea level. The wet season starts from April – October and the dry season starts from November- March. The month of August traditionally has the highest mean annual rainfall of about 320mm. The average monthly temperatures range from 21^{0}C-38^{0}C (69.8^{0}F-100.4^{0}F), and from mid-November to late January, night time temperatures can drop as low as 11^{0}C (52^{0}F). Daily solar radiation average of over 4300wh/m2 per annum is also recorded.

3.1 Population and Sampling

The Administrative Office Buildings of Federal and State government institutions and establishments located within Jos urban conurbation here in Nigeria constituted our target population. By random sampling within this accessible population, a sample of ten (10) buildings was selected for the purpose of this research. The research was comprised of three segments, namely:

1) A building type census; this was conducted to provide appropriate sampling frame for the research by providing infomation in broad context of subject under research (Building types and Occupants).
2) A thermal comfort survey; the aim is to obtain a broad understanding of occupants' thermal comfort sensations within the Administrative buildings. This is a contributing factor to energy demand and use (Nicol & Humphreys 2002). This was achieved with questionnaires and it produced subjective data that was presented using graphs and other pictorial means (See Fig 1-6).
3) A litany of measuring instruments germane to data required was used here. This produced objective data that was further interpreted into graph for further graphical regression (See Table 2 and 3).

4.0 Methodology of Study

The study was carried out in the month of May 2014 in Jos, Nigeria. The location had an average altitude above sea –level of 1286 meters. The GPS locations are listed in Table 2. All offices under study were selected randomly, east-facing and naturally ventilated (NV). The period of study was between 8.00hrs and 15.00hrs week days. These hours conveniently represent the official working hours of the buildings under study.

In all, two (2) survey sessions, in close succession, were conducted in this Naturally Ventilated (NV) building in the month of May 2014. The close succession is to ensure integrity and interoperability of data collected. The first session was to obtain objective data using instruments earlier enumerated. The second session was for the subjective data using the questionnaires.

Measurements were taken at intervals of 8.00hrs, 12.00hrs and 15.00hrs. These conveniently represent opening hours, mid-day break and closing hours of the offices under study (See Fig 1 to 6). Measurements obtained were indoor and outdoor Co^2 levels, outdoor and indoor wind velocity, operative temperature and humidity (See Table 2 and 3).

Subjective data collected from questionnaires were presented using simple bar graphs and percentages. While objective data obtained from measurement instruments were put through bivariate correlation analysis and scatter graph. To obtain a predictive value for any value of predictor and dependent variable combination, a regression formula was obtained from the above-mentioned bivariate correlation (See Fig 7 to 10). The instruments enumerated below were used to obtain objective data as tabulated in Table 2 and 3.

4.1 Global Positioning Measurements

A Cobra GPS 100 global Positioning System receiver was used to obtained global location of buildings of interest. This device provided accurate positioning to within 3 meters, if held in any position open to the sky. It offers information as to current positioning, altitude above sea level, bearing and time of the day.

4.2 Temperature Measurements

Air temperature is given as the measure of the heat in a given environment. The instrument used in measuring temperature is called the thermometer. This measures the ambient air heat in a given environment. In order to take into account, the impacts horizontal and vertical variations in temperature within the room, air temperature readings were taken at three different locations in each space and at two different levels corresponding to the body level and the ankle level in the offices corresponding to approximately 0.1m and 1.2m above floor levels respectively. An RS 1364 Humidity Temperature Meter with a thermostat sensor of measuring range: -20 to 60°C; 0.1°C resolution and sampling rate of 2 times per second was used.

4.2.1 Mean Radiant Temperature

The measurement of the mean radiant temperature was obtained from the readings of a Cyclops Compac 3 Infrared Thermometer. The infrared system recorded radiant temperatures on the different room surfaces; walls, floor, ceiling as well as the furniture immediately around the respondents. A simple average of the readings was adopted as the mean radiant temperature.

4.3 Methods of Subjective Data Analysis

For subjective data from questionnaires, data presented were analyzed using simple bar graphs and percentages. This is to grant visual correlation to relationships between the variables under study. This enhances understanding of subsequent objectives inputs and inferences (See Fig 1-6).

4.4 Methods of Objective Data Analysis.

For objective data obtained from measurement instruments, a bivariate correlation analysis of scatter graph was first produced to obtain a perfect +1 for Pearson correlation with a P-Factor (level of significance) of less than 005. This indicates that the two variables are perfectly related in a positive linear sense. To obtain a predictive value for any value of predictor and dependent variable combination, a regression formula is obtained from the above-mentioned bivariate correlation (See Fig 7 to 10).

5.0 Fieldwork

The field work consists of obtaining subjective and objective data for the purpose of analysis. Subjective data for this study was obtained from questionnaires while the objective data was obtained from measurement instruments. The purpose of the questionnaire was to obtain inputs as to indoor comfort levels of occupants of these offices while objective data obtained included Co^2 level, temperature and humidity readings under varying ventilation rates (See Table 2 and 3).

5.1 Recorded Environmental Variables

Table 2: Summary of Survey Locations' Environmental Variables

S/N	OFFICE ID	Lat. (N)	Long. (E)	Alt. (M)	Date	To (O^c)	Vo (cfm)	Rho (%)
01	**UJ/ADMIN**	09^0 57. 830	08^0 53. 630	1286	7th May 2015	32	672	49.5
02	**NIPSS/ADMIN**	O9^o 44.726	08^o 49.084	1263	8th May 2015	33	655	43.8
03	**PLASBIR**	O9^o 54.584	08^o 53.434	1233	8th May 2015	31	669	47.8
04	**PLSPC**	O9^o 54.538	08^o 53.660	1235	7th May 2015	32	612	45.7
05	**MIN/LGCA**	O9^o 53.207	08^o 52.075	1224	7th May 2015	32	598	42.5
06	**MIN/URBAN**	O9^o 53.727	08^o 52.791	1221	8th May 2015	31	731	49.9
07	**MIN/LSTP**	O9^o 54.982	08^o 53.242	1232	7th May 2015	32	611	46.8

S/N	OFFICE ID	Lat. (N)	Long. (E)	Alt. (M)	Date	To (O^c)	Vo (cfm)	Rho (%)
08	NFI/ADMIN	O9° 53.880	08° 53.625	1254	8th May 201	35	413	42.5
09	PLSP/ADMIN	O9° 52.916	08° 52.339	1250	8th May 2015	34	597	44.3
10	PLSH/ADMIN	O9° 53.961	08° 53.185	1246	8th May 2015	33	442	42.8

Where:
Lat: Latitude (°N)
Long.: Longitude (°E)
Alt.: Altitude (m)
To (oC) Average outdoor temperature recorded at the time of survey
Vo (cfm) Average outdoor wind velocity recorded at the time of survey
RHo (%) Average outdoor Relative Humidity recorded at the time of survey

Table 3: Summary of Indoor Climatic, Metabolic and Clothing Variables

S/N	BUILDING ID	AREA. (M^3)	Ta (^OC)	Vel. (M/S)	Tr (^OC)	RH (%)	LUX	Co_2 (ppm)	Ar (met)	Cl (clo)
01	UJ/ADMIN	40.32	28.30	0	27.87	38.2	554	524	1.2	0.57
02	NIPSS/ADMIN	50.24	26.60	0	29.37	43.9	256	533	1.2	0.57
03	PLASBIR	324	27.76	0	27.52	61.2	142	478	1.2	0.57
04	PLSPC	45.61	25.62	0	25.61	30.5	342	451	1.2	0.57
05	MIN/LGCA	74.3	26.10	0	26.47	72.5	544	465	1.2	0.57
06	MIN/URBAN	109.13	27.52	0	28.62	41.9	345	512	1.2	0.57
07	MIN/LSTP	53.14	26.20	0	29.54	63.4	560	423	1.2	0.57
08	NFI/ADMIN	120	28.40	0	27.52	62.7	172	546	1.2	0.57
09	PLSP/ADMIN	62.42	25.70	0	26.20	65.5	612	501	1.2	0.57
10	PLSH/ADMIN	75.61	29.45	0	28.76	42.3	278	502	1.2	0.57

Where:
Vol: Volume of air/space (Length x Breadth x height)
Ta: Air temperature (°C) (average at 2 heights and multiple locations in the room)
Vel: Air velocity (m/s) (average at multiple locations in the room)
Tr: Meant Radiant temperature (°C)(average of room surfaces)
RH: Relative Humidity (%) (Average across multiple locations in the room)
Lux: Lighting level (Lux) (average at task levels across the room)
Co2: Carbon dioxide levels (ppm) (average of several readings taken at center of the room)
Ar: Activity Rate (met) (ISO 8996)
Cl: Clothing Level (clo):

6.0 Analysis of Findings

6.1 Acclimatization

Works by Nicol & Humphreys (2002), which postulated that apart from other surrounding physical components, the opportunities for individual adaptation by the occupants (acclimatization) is quintessential to this research method. With the below specified duration of stay and working hours, it can be confidently stated that the respondents had naturally acclimatized to the tropical highland climate associated with Jos city and in their office spaces and thus their responses were cogent and germane (See Fig. 1). This 'adaptation' is also essential in the 'adaptive Model' implemented for the thermal studies.

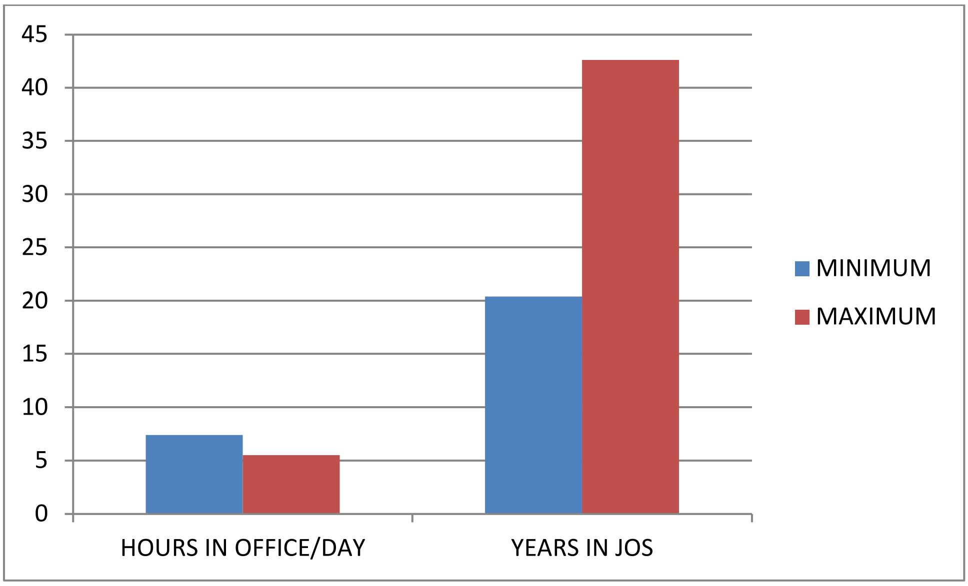

Fig 1 Acclimatization of Office Users

6.2 Predicted Mean Vote (PMV)

The subjective assessments obtained from questionnaires of the thermal environment by respondents were recorded through the use of several scales. These include the ASHRAE 7-point thermal sensation scale, the McIntyre thermal preference scale (cooler, no change, warmer), the Bedford Scale (much too cool + too cool + comfortably cool + comfortable + comfortably warm + too warm + much too warm) and a thermal acceptability scale (Acceptable, Unacceptable). Respondents were required to indicate their thermal sensations at the moment of the survey using these scales.

As to the thermal sensation votes, the subjective response reveals 47% were of the opinion of being slightly warm, while 31% felt cool (See Fig 2). This explained the thermal sensation preference of 56% of those whose natural response would be to prefer it cooler (See Fig 4). This is tempered by the fact that 56% would prefer a cooler temperature (See Fig 3).

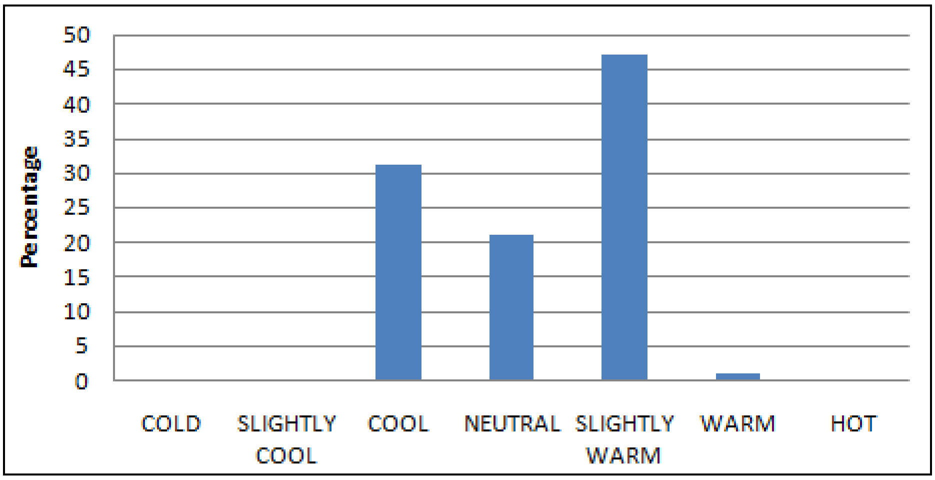

Fig 2 Thermal Sensation Votes

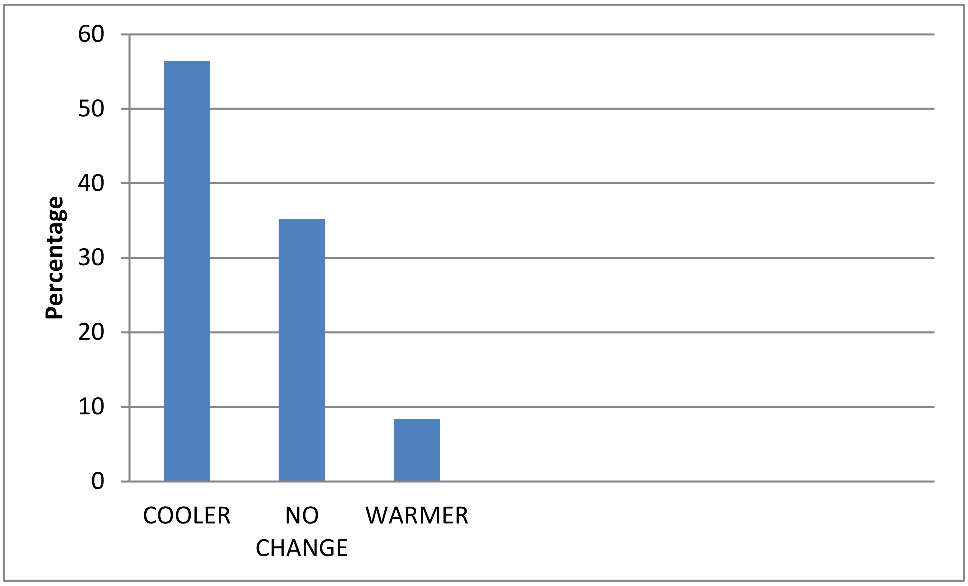

Fig 3 Thermal Comfort Votes

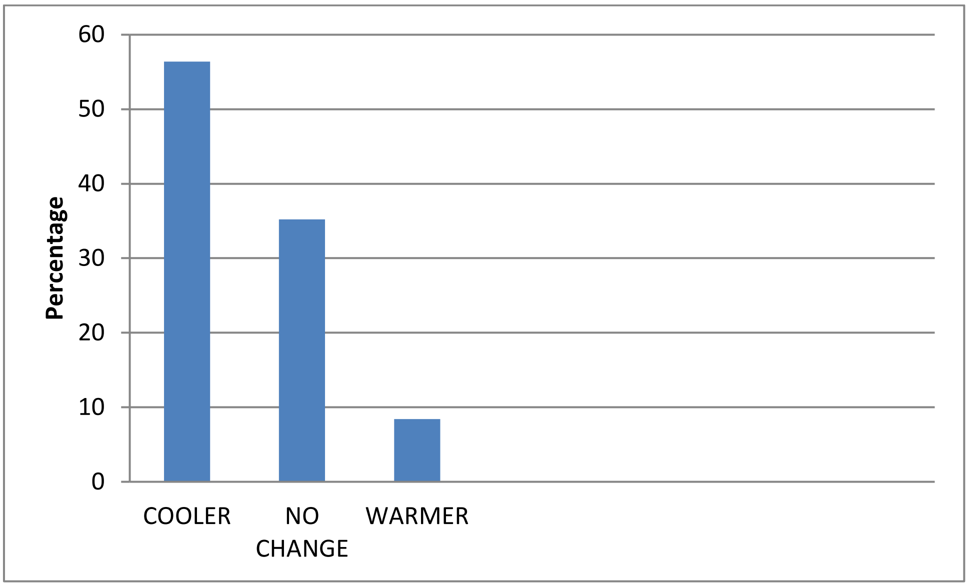

Fig 4 Thermal Sensation Preference

6.3 Temperature in Office

One of the sustaining theories of adaptive approach to thermal comfort studies is the concept that there seems to be a strong relationship between the comfort temperature and the average ambient temperature. This is also combined with the knowledge that outdoor conditions influence the perception of indoor thermal conditions too (Cena and deDear, 1998, Roaf et al, 2005). Simply put, there is a correlation between the neutral temperature and the prevailing ambient temperature of that location. This is the reason why, in Fig. 5, we see respondent's attempts at having a certain level of equilibrium between outdoor weather and indoor spaces by opening of windows to improve airflow (See Fig. 6).

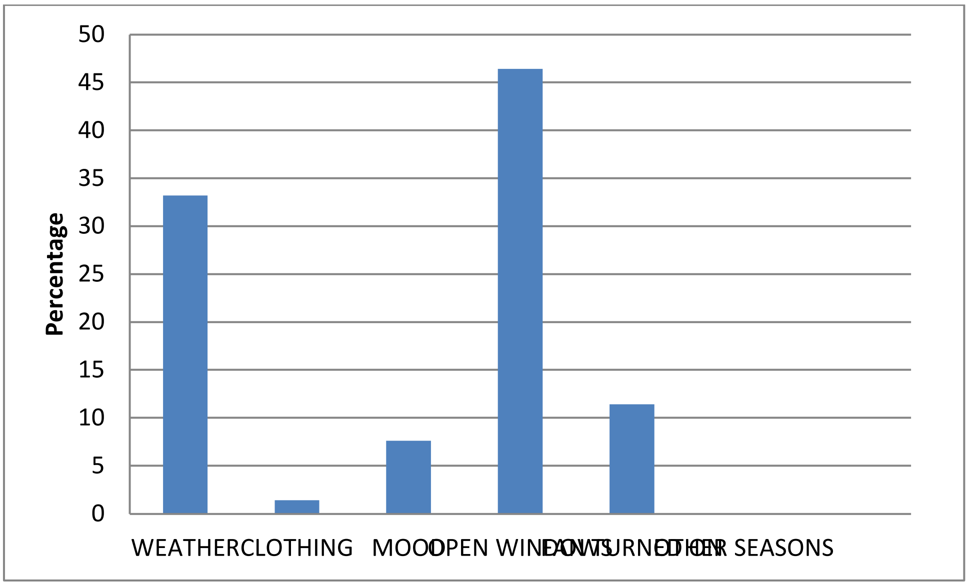

Fig 5 Factors Affecting Comfort

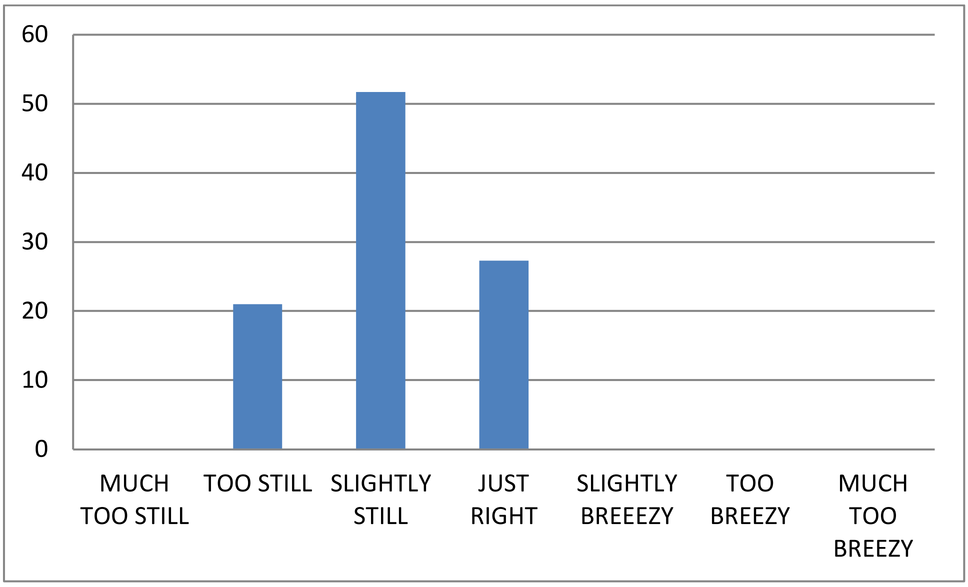

Fig 6 Response to Airflow

6.4 Adaptive Model Assessment

In the Adaptive Model technique, there was an intersection between Observed and Calculated Thermal Comfort sensation at 14.15hrs corresponding to 0.895 on the Thermal Sensation Scale (See Fig. 7). This is close to comfortably warm indicated as One (1) on the ASHRAE comfort scale. This signifies a congruence of thermal sensation (calculated and observed) at about the close of day which is usually at 15.00hrs. This congruency indicated a thermal sensation feeling of 0.895. This means that at 14.15hrs, calculation parameters agreed with indications from respondents that the respondents felt comfortably warm, towards the close of day, based on the ASHRAE Comfort Scale. These grants understanding to questionnaire's response indicating that 72% of respondents do require air-conditioning only at mid-day when temperatures starts an upward trend and a lower percentage of respondents (11%) felt the need for air-conditioning at morning hours and 17% at closing hours (See Fig. 8).

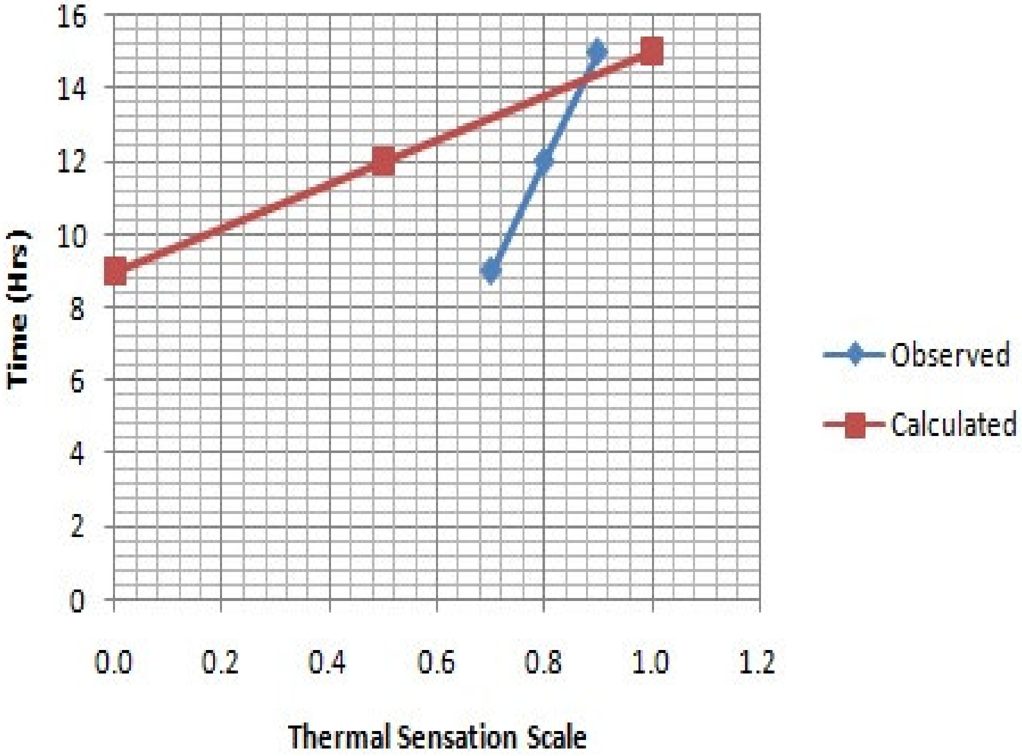

Fig.7: Observed and calculated Predicted Mean Votes (PMV) and Time

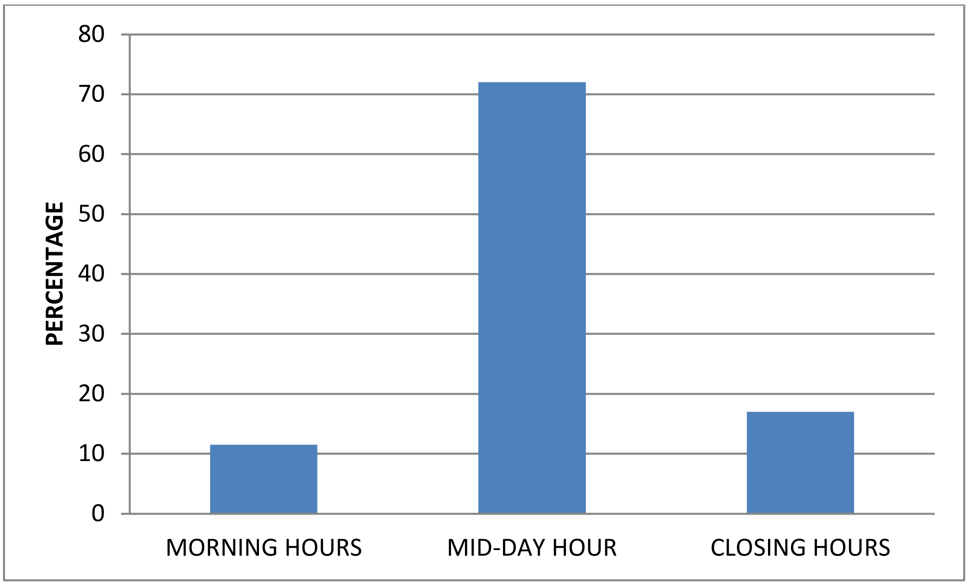

Fig. 8: Time of the Day When Air Conditioning is Required.

Here also, a graph of the Standard Deviation (Thermal Sensation against Time) showed a marked increase in deviation between the hours of 12hrs and 15hrs (towards the end of working hours) when temperatures were higher (See Fig. 9), while smaller deviations were observed between 9hrs and 12 hrs. This is in consonance with an earlier study by Becker 2002, which states that deviations or individual interpretation of thermal sensations are exaggerated at extremities of the ASHRAE Comfort Scale.

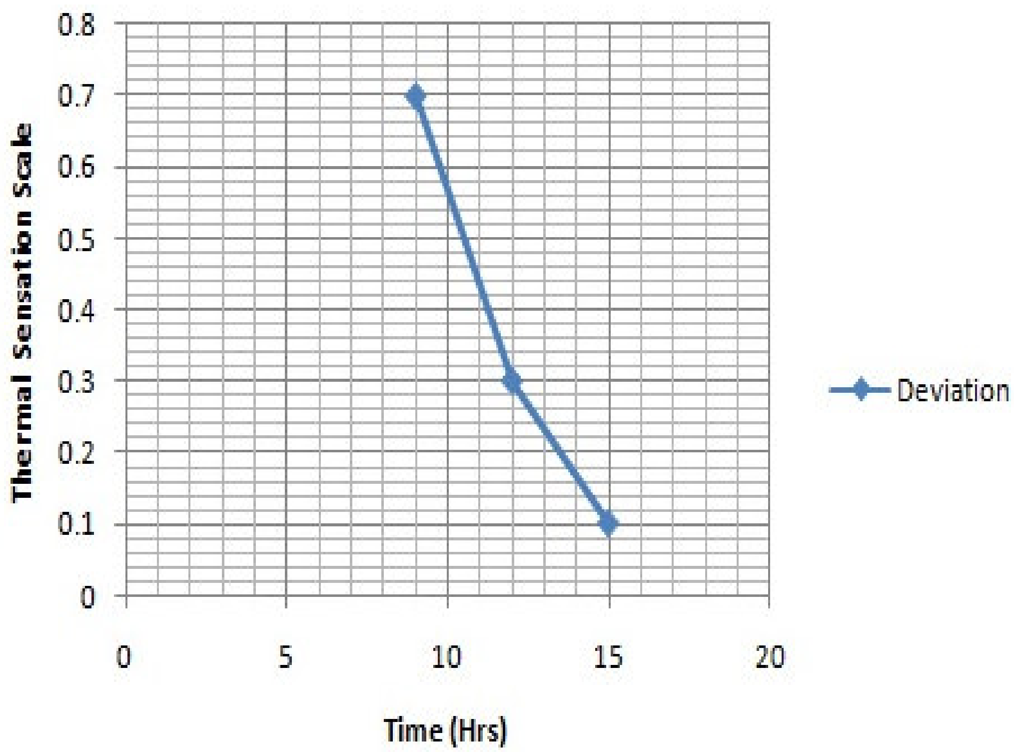

Fig. 9: Standard Deviation Against Time.

To determine the neutral temperature and its associated thermal comfort range, the values of thermal sensation votes where plotted against operative temperatures at corresponding locations (See Fig. 10 to 12). This approach to the analysis of field research data has been adopted in several studies (See Han et al 2007, Wang 2006, Becker et al 2002, Fanger &Toftum 2002 and de Dear & Brager 1998).

A plot of calculated and observed thermal sensation input against Operational Temperature show a confluence at 29.4ºC thereby establishing a neutral temperature. This indicates a preference for thermal conditions near 29.4ºC (See Fig. 10 to 12). This intersection is an indication of the suitability of this thermal comfort tool about this temperature range in naturally ventilated buildings. The regression line introduced in Fig. 13 gives the equation of the resultant slope providing a tool for estimating thermal neutralities and comfort range.

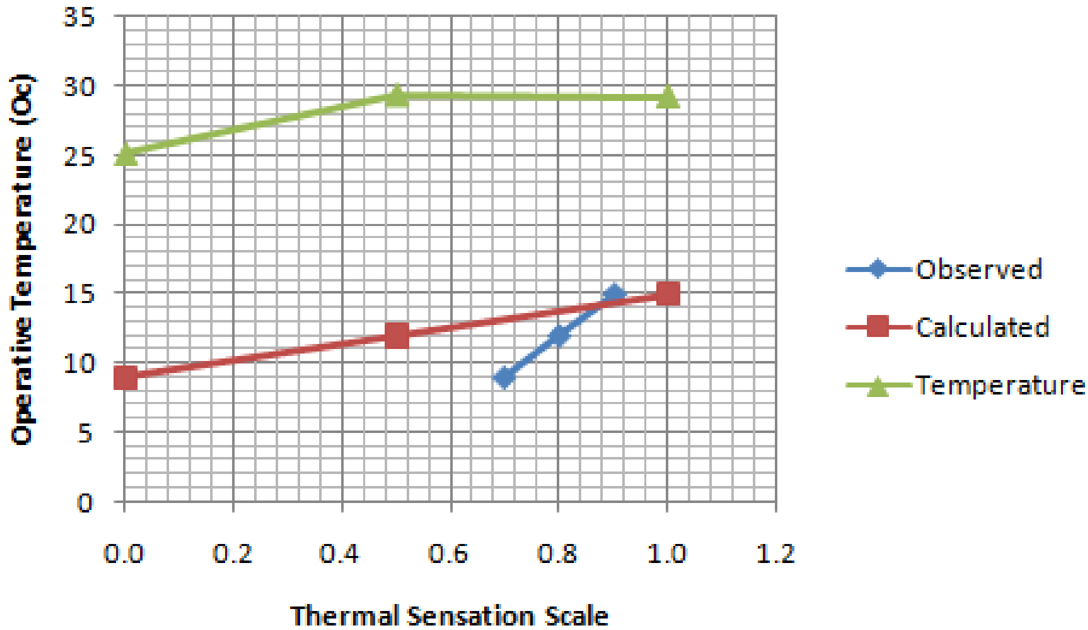

Fig. 10: Observed and Calculated Predicted Mean Votes (PMV) and Operative Temperature.

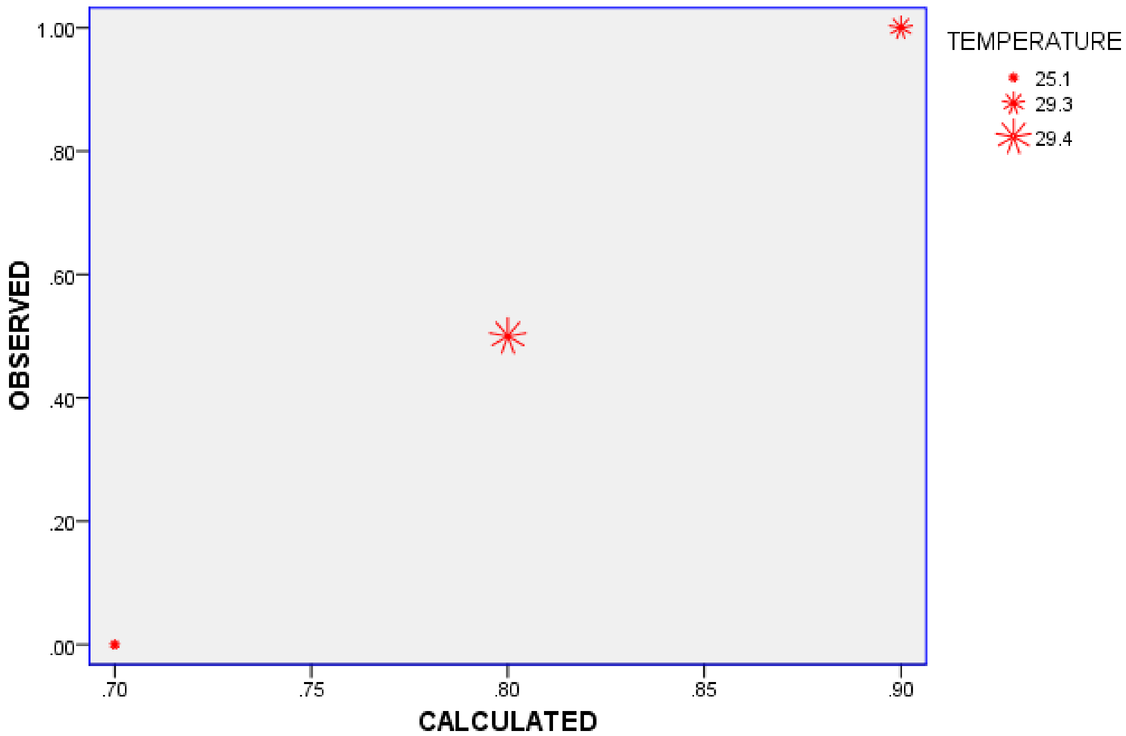

Fig. 11: Observed and Calculated Predicted Mean Votes (PMV) and Operative Temperature.

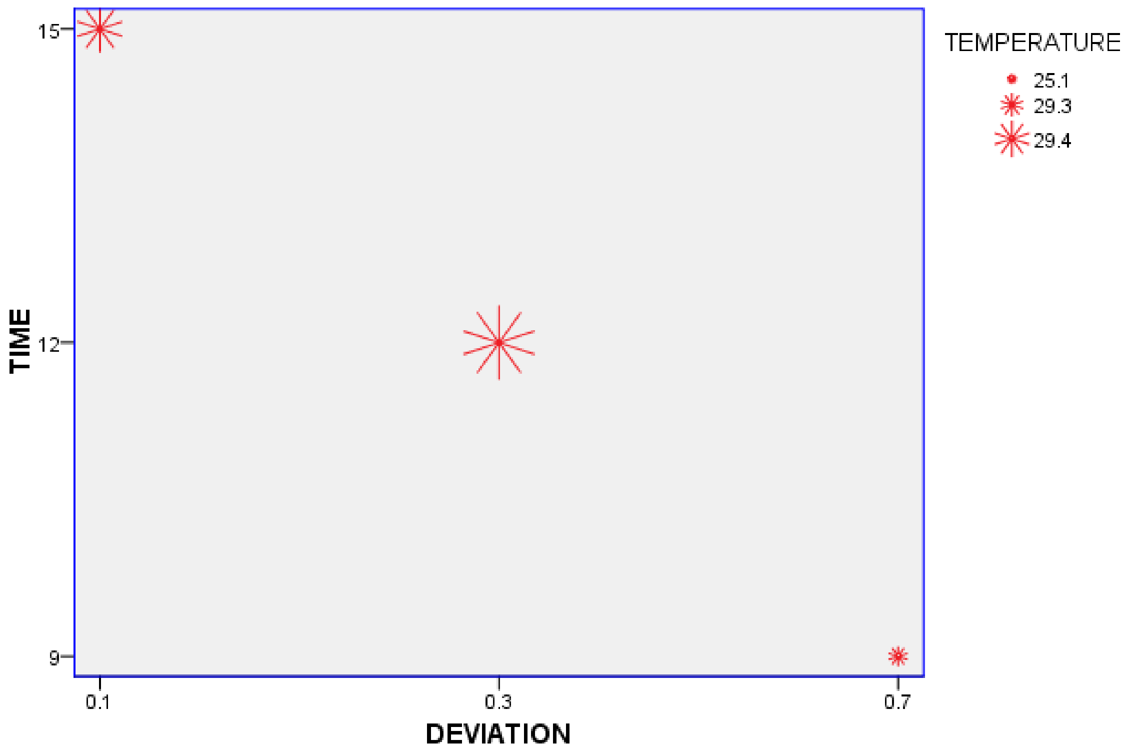

Fig. 12: Relationship between Operative Temperature, Time and Standard Deviation.

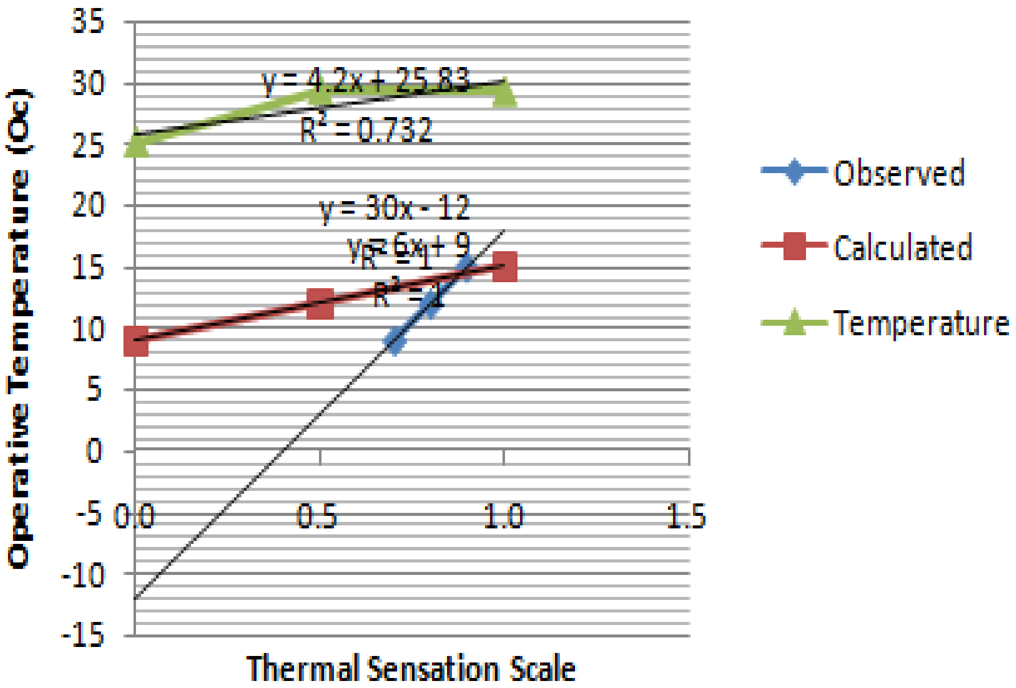

Fig. 13: Equation of the Resultant Slope Providing a Tool for Estimating Thermal Neutralities and Comfort Range

7.0 Recommendations

1) In the context of human preferences, thermal Comfort Range and Neutral Temperature are fundamental to the study of thermal comfort. The indoor Thermal Comfort Range and Neutral Temperature established in this research at 29.4ºC are at variance with that established by Ogbonna & Harris at 25.06⁰C (2007) for Jos. Though, the focus of their research was on residential buildings and factors such as adaptation, age, level of clothing of respondents and ambient weather at the time of that research differed. The next step would be further research into these thermal comfort fundamentals using different building types, target groups from different regions of the country and sub-continent in order to determine its relevance across the region and beyond.

2) By physical measurement, the research established an average ambient temperature 27.16⁰C for all the offices measured (See Table 3). By calculation, the research established a Neutral Temperature as 29.4ºC for a naturally ventilated office building in Jos, Nigeria. In other words, the occupant of the office buildings studied would require a warmer environment. This is supported by a thermal sensation votes and the subjective response revealing 47% preferring slightly warmer offices (See Fig. 2). Therefore, the use of mechanical ventilation becomes superfluous in the offices examined. This finding is of great benefit in making environmentally sustainable decisions in the context of energy use.

3) This research was conducted in the month of May 2015 in Jos, Nigeria. It coincides with rainy season in the sub-Saharan region of which the research was conducted. There would also be the need for similar research to be conducted in other seasons and other location within developing countries, thereby exposing this research framework and associate tools to further use and thus granting validity to these tools. This would enable a complete and comprehensive picture of energy performance assessment for administrative buildings in sub-Saharan region of Africa.

8.0 Conclusion

In the present era of global warming and climate change, studies into all aspect of human comfort in the context of thermal conditions becomes more paramount. The constant and unmitigated erosion of finite energy resources in an unsustainable manner also comes to fore here. The appropriate and measured use of energy for micro climate control in working environment not only ensures productivity in terms of workers output but reduces wasteful expenditure of energy in other to ensure thermal comfort of building occupants. This research has established by measurement, optimum thermal values within its research delimitations. These values, hopefully, would serve as guide for policy formulators and stake holders in the built environment for sustainable development.

9.0 References

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

Becker, S., Potcher, O., & Yaakov, Y. (2002). Calculated and observed human thermal sensation in an extremely hot and dry climate. *Energy and Buildings, 35*(2003), 747-756.

Busch, J.F. (1990) "Thermal response to the Thai office environment" ASHRAE Transactions, Vol. 96 (1), pp. 859-872.

Charles, R., Reardon, J.T., & Magee, R.J. (2009). *Indoor air quality and thermal comfort in open- plan offices. Construction Technology Updates*. Ontario: Institute for Research in Construction (IRC): National Research Council, Canada.

de Dear, R.J., Leow, K.G. and Ameen, A. (1991) Thermal Comfort in Humid Tropics. Part 1. Climate Chamber experiments on Temperature Prefrence in Singapore. ASHRAE Transactions 97 (1).

de Dear, R.J., Brager, G., & Cooper, D. (1997). *Developing an adaptive model of thermal comfort and preference*. Atlanta: Final Report ASHRAE.

de Dear, R.J., & Brager, G.S. (2002). Thermal comfort in naturally ventilated buildings: Revisions to ASHRAE Standard 55. *Energy and Buildings, 34*, 549-56.

Fanger, O.P., &Toftum, J. (2002). Extension of the PMV model to non-air- conditioned buildings in warm climates. *Energy and Buildings, 34*, 533- 536.

Han, J. Z., Zhang, Q., Zhang, J., Liu, J., Tian, L., Zheng, C., Hao, J., Lin, J, Liu, Y., &Moschandreas, D.J. (2007). Field study on occupants' thermal comfort and residential thermal environment in a hot-humid climate of China. *Building and Environment, 42*, 4043-4050.

Hwanga, R., Linb, T. And Kuoa, N. (2006). Field Experiments on Thermal Comfort in Campus Classrooms in Taiwan, Energy and Buildings 38, (1):53-62.

Kwok, A.G. (1998) Thermal Comfort in Tropical Classrooms, ASHRAE Transactions 104 (1b), PP. 1031-1047. View Record in Scopus.

Lan, L., Lian, Z.W., Pan. L., & Ye, Q. (2009). Neurobehavioural approach for evaluation of office workers' productivity: The effects of room temperature. *Built Environment, 44*, 1578–1588.

Lan, L., Wargocki, P., & Lian, Z. (2011). Quantitative measurement of productivity loss due to thermal discomfort. *Energy Build, 43*, 1057–1062.

Ogbonna, A.C., & Harris, D.J. (2007). Thermal comfort in Sub-Saharan Africa: Field research report in Jos, Nigeria. School of the Built Environment Heriot Watt University. Retrieved from http://www.sciencedirect.com.

Roelofsen, P. (2002). The impact of office environments on employee performance: The design of the workplace as a strategy for productivity enhancement. *Journal of Facility Management, 1*(3), 247–64.

Seppänen, O., Fisk, W. J., & Lei, Q. (2006). *Effect of temperature on task performance in office environment. Laboratory for Heating Ventilating and Air-conditioning.* Helsinki: Helsinki University of Technology, Finland.

Wang, Z. (2006). A field study of the thermal comfort in residential buildings in *Harbin Building and Environment, 41*, pp 1034-1039.