International Journal of Contemporary Applied Researches Vol. 8, No. 1, January 2021
(ISSN: 2308-1365) www.ijcar.net

Predicting Indoor Comfort Conditions of Existing University Office Buildingsto Optimise Sustainable Design Principles

Morisade Omorinola ADEGBIE
Department of Architecture, Federal University of Technology, Akure, Nigeria
moadegbie@futa.edu.ng

Abstract
Thermal comfort directly affects level of energy consumption in buildings and it is the basis for sustainable designs. Sustainable design of university office buildings is important in order to reduce energy consumption for thermal comfort. This paper reports the outcome of the investigation on the comfort conditions of existing university office buildings within Akure in the Warm-Humid Tropical climate of Nigeria.Close ended questionnaire was designed to gather information about the perception of comfort conditions of users in the investigated office buildings within the study area. Stata Statistical Software version 10 was used for the analysis of the data gathered. The analyses consist of theunivariate (descriptive) analysis of all the variables under investigation and results presented in frequencies tables, percentages, pie charts and bar char; thebivariate analysis using Wilcoxon Rank Sum Test at 0.05 significant level to predict thermal comfort perception during rainy and dry seasons. Comfort votes for perception of thermal comfort was based on ASHRAE Seven Points Sensational Scale. Results indicate that users perceived heat stress or hot discomfort during rainy and dry seasons within the interior of the investigated office buildings but that of rainy season is milder. The recommendation is that the designs should be improved upon, using some sustainable design principle toreduce energy demand for thermal comfort.

Keywords: Thermal comfort, Office building, Sustainable, Design, Nigeria

1. Introduction

Study on thermal comfort in existing buildings provides information about the performance of the design to satisfactorily support users comfort conditions, wellbeing, productivity and controlling energy consumption. Predicting comfort condition of existing building is a step towards understanding thermal performance and further identifying the renovation regime that would be necessary to reduce energy demands and consumption. Occupants experience on indoor comfort conditions also play an important role to improve building performance, (Alhorr et al., 2015). Predicting comfort conditions of office buildings help to improve indoor thermal conditions and enhance environmental sustainability of the building stock.

Sustainable design of office buildings is an important aspect in the design process to enhance comfort of occupants, reduce negative impacts on their health and the environment. Designs and structural configuration of office building influence how comfort is perceived within the indoor spaces. Therefore, office buildings' designs are to be carried out with proper synergy with sustainable design practices. Where this is absent, it results in higher demand on energy to achieve thermal comfort in such office buildings.

Achieving thermal comfort through sustainable designs in office buildings is a topical issue especially in Nigeria where very little attention is given to sustainable designs practices in building sector. More over the hot climate nature of the country leads to accumulation of heat within buildings interior which raises air temperature and higher cooling energy demand. The International Energy Agency (IEA), (2013) states that buildings are the largest energy consumers globally, accounting for 40% of primary energy consumption. Global energy consumption is projected to increase by 30% by the year 2035. Therefore, the existing buildings are to be renovated through implementation of energy codes and minimum performance standards, while new buildings are designed to be of low energy(IEA, 2013). This is done to reduce pressure on global energy supply and contribute to environmental sustainability.

Incorporating sustainable design principles in university office buildings is paramount to reducing negative impacts on the environment through energy consumption. University office buildings accommodate academic, administrative and management staff members of the university. Majority of university office buildings serve the dual purpose of accommodatingstaff offices as well as students lectures rooms, laboratory and other supporting facilities needed for academic activities. This make university office buildings to be in operations almost throughout the day and significantly make use of resources for thermal and visual comfort, that is: cooling and lightning.

Previous studies have shown the direct relationship that exist between thermal comfort in buildings and sustainable environment. Smith and Pitts (2011) presents the role of sustainable buildings to provide healthy workplaces for users' comfort and satisfaction, evidence from the study shows that building users perceive sustainable buildings to be healthier and enhance work output. Comfort temperature in Indonasia was predicted as an initial step to reduce cooling energy consumption for a better indoor thermal environment and thus reducing carbon emissions (Karyono, 2015). Koh et al., (2018) assessthermal comfort of an office buildings in a tropical climate condition using ASHRAE comfort sensational scale.Forgiarini and Ghisi, (2017) predict thermal comfort in office buildings in a Brazilian temperate and humid climate by comparing comfort responses from office workers.

Predicting comfort conditions of existing office buildings to understand how the building performed have been identified in literatures. However, comfort condition in existing university office buildings in thewarm-humid tropical climate of Nigeriais hereby presented. The study uses subjective evaluation of thermal comfortto identify whether the design of the selected office buildings optimally support user's indoor thermal comfort conditions.

1.1 Meaning and Factors ofThermal Comfort

Thermal comfort is defined by ASHRAE STANDARD -55 (2004) as that condition of mind which expresses satisfaction with the thermal environment. It was argued by Cannistraro, Cannistraro and Restivo, (2014) that thermal comfort is not a direct measured quantity, but a subjective perception that is felt by persons in response to certain objective sensations. Thermal comfort in buildings has been very crucial and ranked first point to be considered when comfort issues in buildings are raised (Ward, 2004). Thermal comfort is directly related to human existence as extreme cold or hot thermal discomfort conditions can leads to death. Shelter and protection against the extremes of weather to provide comfort has been an earliest and primary function of buildings. The buildings physical enclosures create an indoor climate, where an acceptable indoor climate ensures that 80% of the users of a building are satisfied and there is no negative effect on their health (Dahl, 2010).

The dominant environmental factors that affect the perception of thermal comfort is the air temperatures. It indicates the quantity of heat present in the air and it is directly proportional to the mean kinetic energy of the air molecules (Nall, 2004). Air movement is another environmental factor that affect thermal comfort, it removes heat and provide fresh air in a space, increases evaporation from the skin and thus produces physiology cooling effect. The general design specification for air movement is that air velocity should not exceed 1.5m/s and normal fresh air quantity value is in the range of 6-15 litre per second (Auliciems and Szokolay, 2009). Other factorthat affect how occupants perceive comfort in a space is humidity. It is the amount of moisture present in the air. Increase in the level of humidity reduces the ability of the skin to loseheat through evaporation. Majority of building occupants are comfortable at the relative humidity. Clothing is a factor that affectsthermal comfort. It reduces body's heat loss, and grouped according to its insulation values. Clothing insulation is measured in Clo unit, 1 Cl`o is equivalent to $0.55m^{20}C$ /W this indicate a typical business suit, (Szokolay, 2008). Mean radiant temperature and metabolic rate also affect perception of thermal comfort within a space.

1.2 Sustainable Design Principles

There are six major principles of sustainable design. Optimising energy use is a key principle that ensure improvement on the energy performance of existing buildings. Other principles highlighted include optimising site potential, water conservation and protection, optimising building space and materials, enhancing indoor environmental quality and optimising operational and maintenance practices. Sustainable design of buildings is able to reduce or completely avoid the depletion of resources such as energy, water, land and raw materials. It could also prevent degradation of the environment and enhance comfortable, safe productive and livable built environment (Whole Building Design Guide, 2018).Sustainable environment could be improvedupon by reducing building environmental impacts (Levin, 2015).

The ever-increasing demand for fossil fuel and the impacts of climate change that is becoming more evident globally make it essential and necessary to reduce energy load, increase efficiency and maximise the use of renewable energy sources in buildings.Hayter and Kandit, (2011) suggested approaches to reduce energy consumption of existing buildings. These are: reducing the need for energy by implementing energy efficiency measure and offsetting the remaining building energy needs through the use of renewable energy systems. International Energy Agency (IEA, 2006) advised to first implement energy efficiency measure before renewable energy as the cost to invest in energy efficiency is almost half the cost of installing renewable energy.

2. Study area and Methodology

The study is conducted at the Obanla campus of the Federal University of Technology, Akure, Nigeria. Akure is a rapidly urbanising city in the South-Western part of Nigeria. It is located within Latitudes 7^{o} 17'N and Longitude 5^{o}18'E, at an altitude of 320m above sea level. Akure has warm-humid tropical climate and enjoys equatorial rain forest vegetation. The average rainfall is about 1500mm per annum with double maxima occurring in June/July and September/October. The Annual average temperature ranges between 21.4^{o}C and 31.1^{o}C while the mean annual relative humidity is about 77.1% (Ibitoye et al, 2014). Two seasons are experienced by the city - the wet or rainy season from April to October and the dry or Harmattan season from November to March. There is usually more than six hours of sunshine, even during the rainy season (Ogunrayi et al, 2016).

Three office buildings were selected for the study which are the representative of other office buildings in the study area. These are: The Senate Building Phase II (SENATE) which houses only administrative staff of the university. It is a one storey office building with basement toward the east side of the building, its' construction was completed in the year 2013; School of Earth and Mineral Sciences (SEMS)is a school building accommodating lectures' office, conference rooms and reading rooms. It is a one storey building, having its' construction completed in the year 2006; School of Agriculture and Agricultural Technology Annex(SAAT) building mainly consist of office spaces for lecturers. It is a one storey building that has its' construction completed in the year 2011. Close ended questionnaire was designed to gather information about the perception of comfort conditions of users in the selected office buildings within the study area.

A total of 137 copies of questionnaires were administered in the three selected case buildings to all the users. This figure was obtained from the total number of occupants in the office spaces within the three office buildings selected for the investigated. Out of 137 copies of questionnaire administered in the three case study buildings only 106 copies were used for the analysis. The School of Earth and Mineral Sciences (SEMS) has thirty occupants; Senate Building Phase II has seventy- seven and School of Agriculture and Agricultural Technology has thirty-two occupants.

The questionnaires were distributed to the entire occupants in the three case buildings in accordance to the guidelines of ASHRAE Standard 55 (2004); on evaluating thermal comfort in existing buildings through user' perception. The guideline specifies that indoor thermal comfort can be determined from the responses of occupant survey. The survey can be distributed to the entire occupancy or a representative of the occupancy

3. Results and Discussions

3.1 Descriptive Analysis of the Data Obtained with the Questionnaire

3.1.1 Background Information of Users

The descriptive analysis of the data obtained with the questionnaire in the three case study office buildings consist of background information of users, information on office spaces and perception of heat and cold in the office space. The frequency analysis on background information of users from the survey show that out of a total of 106 respondents, 63.21% (67) are males while 36.21% (37) are females. Information on ages of respondents show that there are more older adults with 3.77% between age 23-27years, 3.77% are between ages 28-32years, 8.49% are between ages 38-42 years and 66.04% are between ages 43 and above. Moreover, analysis on staff category shows that 59.43% (63) are non- academic staff while 40.57% (43) are academic staff (Figure1).

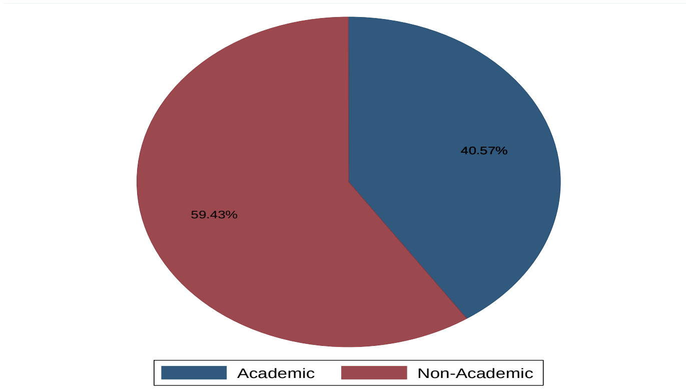

Figure 1: Graphical Representation of Category of Staff

Analysis on duration of occupancy in the office space shows that 3.77% (4) of the respondents stay less than four hours in the office space, 7.55% (8) stay between four and six hours while 88.70% (94) stay more than six hours.Quite a large number of the respondents, both academic and the non-academic staff stay longer in their offices which could have significant effect on the number of hourscomfort devices are used and consequently increase energy consumption.

Figure 2 shows the analysis on the type of dress most frequently worn to the office by the respondents. Shirt & trousers 42.45% (45) and skirt & blouse / gown 34.91% (37) are the most frequently worn. Other types of dresses worn are blazers, shirt & trousers (11.32%), complete national costume (8.49%)and blazer with skirt & blouse (2.83%). The Clo value of the most frequent types of clothing to the office is between 0.5clo- 1.0clo which signifies light clothing that will not impair thermal comfort. This indicates that light clothing is frequently worn since the environment is always hot. This will assist the respondents to get comfort in their offices.

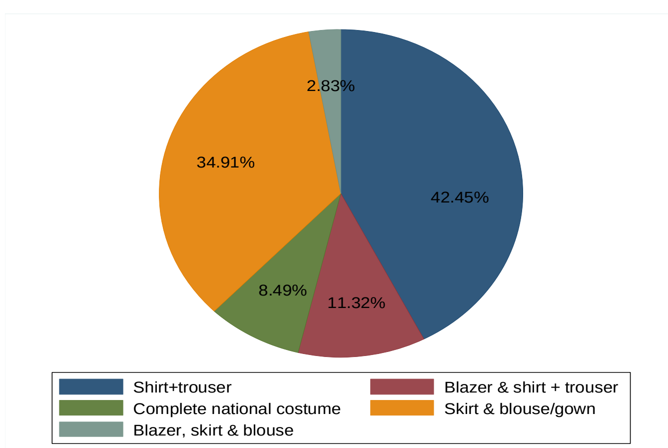

Figure 2: Type of Dress to Office most frequent

3.1.2 Information on Office Space

The frequency analysis on the information on office spaces shows that 98.11% (104) windows in the studied office buildings are operable as attested to by the respondents while only 1.89% (2) is fixed. This indicates that opening the windows are essential for air movement which is required for body cooling in the warm humid climate. This finding is in line with previous researches on essential of air movement to achieve adequate body cooling for thermal comfort in warm humid climate. The frequency distribution of types of window glazing indicates that sliding window glazing is the most frequently used in the investigated buildings with a percentage of 60.38 (64), while projected, casement and louvered window glassing are 16.04%, 1.89% and 20.75% respectively. Although, the sliding window is not the best for warm humid climate because it reduces the spaces that can be opened for ventilation and increases heat gains into building interior because of the additional glass panel.

Analysis on the use of mechanical device for ventilation shows that 33.02% use air conditioner, 18.87% use fan while 48.11% use fan and air conditioner. This implies that few offices use either fan or air conditioner for cooling while majority of the offices use both fan and air conditioner for cooling. This indicates that air conditioner is the most widely used mechanical device for ventilation in the investigated buildings. The length of time for use of air conditioner and fan during office hours as indicated by the respondents in the three case buildings clearly shows that air conditioner and fan are used for more than six hours with 46.23% and 39.62% respectively. Other time frame indicated by the respondents for the use of air conditioner and fan are zero hour 16.98% & 23.58%; <4 hours 18.87% & 16.04%; 4-6 hours 17.92% &20.75% respectively.

3.1.3 Perception of Heat and Cold in the Office Space

Perception of thermal comfort during dry periods was analysed based on the ASHRAE seven-point sensational scale and the results showed the sensational votes of the respondents. The responses are: very hot (19.81%), hot (46.23%), warm (18%), neutral (6.60%) and cool (10.38%). The comfort votes by the respondents show that much heat is perceived in the interior of the studied office spaces during the dry season. The votes for cool (10.38%) indicate that air conditioners are used always by those respondents, which do not allow the perception of heat in their office space during dry season.

Moreover, perception of thermal comfort during wet periods shows that 0.9% of the respondent votes for very hot sensation, 2.83% for hot, 32.08% warm, 16.04% neutral, 34.91% cool, 12.26% cold and 0.94% very cold. The result of the analysis points to the fact that heat stress is minimal during the rainy season compared to dry season, but there is still hot discomfort. The subjective nature of thermal comfort is further revealed which is in line with previous researches. Moreover, there is no extreme of hot discomfort in the warm-humid climate of Akure. The respondents' votes for time of the day thermal discomfort is mostly felt revealed that heat stress is at the maximum between 1pm-3pm with 94.17%, while 0.97% agreed to between 10am-12noon and 4.86% between 4pm-6pm (Figure 3). The time of the day thermal discomfort is mostly felt is the time when intensity of solar radiation is high.

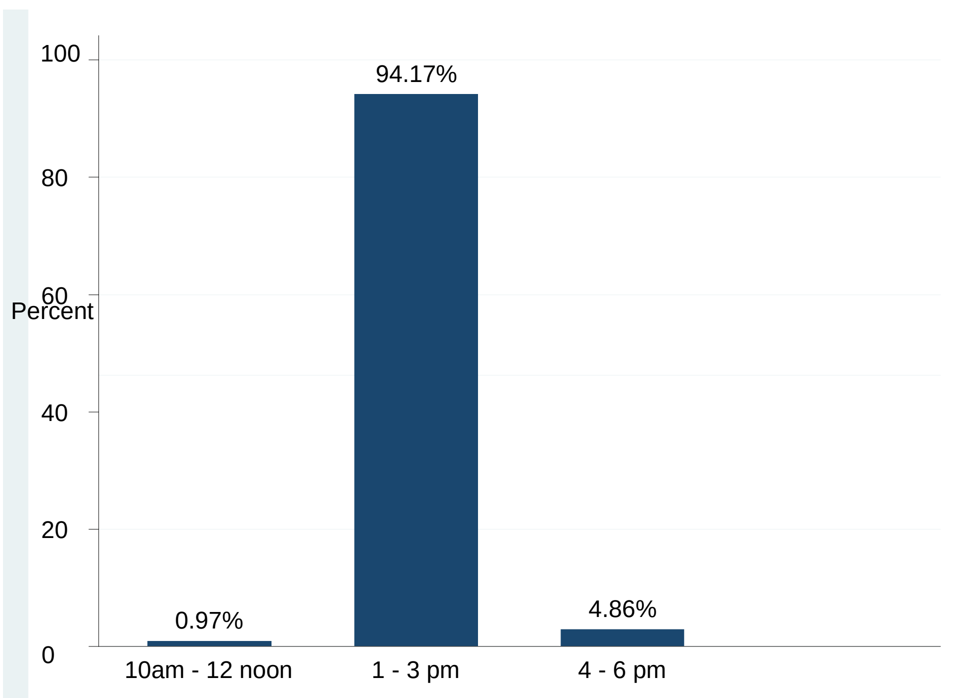

Figure 3: Time of the Day Thermal Discomfort Mostly Felt.

The analysis on how respondents achieve comfort at times when there is no electricity power supply to operate cooling devices reveals that 19.81% open windows alone, 79.25% open windows and doors and 0.94% takes no action (Figure 4). Some of the respondents that open windows alone did so in order to avoid distraction during task performance in their office spaces. Opening windows and doors help to achieve sufficient air movement through cross ventilation and increased pressure driven wind. It also shows the adaptive behaviour of the respondents to achieving thermal comfort as it is been established in literature.

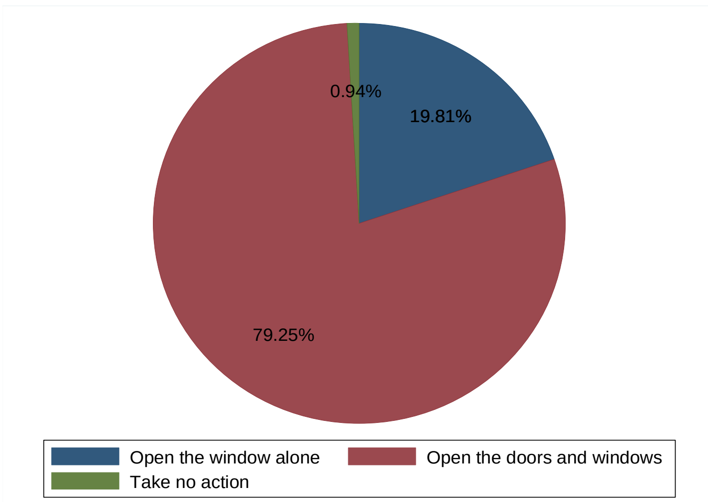

Figure4: Achieving Comfort at Times Electric Power Goes Off.

Rating the general comfort condition of respondents' office spaces when there is no electricity power supply, the votes for slightly comfortable and not comfortable are 47.17% and 48.11% respectively, while very comfortable is 4.72%. The result of the analysis shows respondents' dissatisfaction about the thermal comfort condition of their office spaces at times when mechanical devices for cooling are not in operation. Analysis of the question whether thermal discomfort affect respondents' working performance shows that 91.5% of the respondents are affected while only 8.49% are not affected. This implies that thermal comfort is important in productive task performance. When people are not comfortable in their work stations, work output will be low and may eventually leads to non-performance of task.

3.2 Bivariate analysis

3.2.1 Predicting Difference in Comfort Condition during Rainy and Dry Periods

The difference in comfort conditions in the three case buildings during the rainy and dry seasons of the year was predicted using Wilcoxon rank-sum test at 0.05 significant value. The probability z value 0.0000 is less than r value 0.05. This implies that there is a significant difference between comfort condition during dry and wet periods. This result is in line with the frequencies analysis on comfort votes of users during rainy and dry season based on the ASHRAE Standard-55 Comfort Scale. Users attested to it that heat stress during rainy season is not as high as during the dry season of the year. There is a significant difference in the thermal comfort perception of users in their office spaces during the two seasons, although there are records of high temperatures in some months during rainy season. The Wilcoxon rank-sum test computation by Stata Statistical Soft Ware is shown as:

```
*Difference between comfort wet and dry
.  ranksum therm_comfdry_01, by(code1)
Two-sample Wilcoxon rank-sum test
      code1 |      obs rank sum    expected
-------------+---------------------------------
Thermal comf |     106       15262       11289
 Thermal dry |     106       7316       11289
-------------+-----------------------------------
combined |      212       22578       22578
unadjusted variance   199439.00
adjustment for ties    -8755.17
adjusted variance     190683.83
Ho: therm~01(code1==Thermal comfort wet) = therm~01(code1==Thermal dry)
z =   9.098     Prob > |z| =   0.0000
```

4. Conclusion

This study has generated information about thermal comfort conditions of occupants in the investigated university office buildings in Akure, Nigeria. Responses from the questionnaire survey show that occupants perceived hot discomfort during rainy and dry seasons of the year, although, thermal distress during rainy season is milder than that of dry season. Evidence of high energy consumption was indicated by the number of hours both academic and non-academic members of staff stay in their office spaces, during which air conditioners and fans were operated to achieve cooling. It is evident that the design of these university office buildings does not perform optimally to enhance thermal comfort of occupants. It is therefore recommended that the designs should be improved upon, using some sustainable design principle to reduce energy demand for thermal comfort.

References

Alhorr, Y., Arif, M., Katafygiotou, M., Mazroei, A., Kaushik, A., &Elsarrag, E., (2015). Impact of indoor environment on occupant well-being and comfort: A review of the literature. *International Journal of Sustainable Built Environment*, 5(1), 1-11.

Auliciems, A., & Szokolay, S. (2009). Thermal comfort. *Passive and low energy architecture*. International Design Tools and Technique Note 3.

ASHRAE STANDARAD-55, (2004). Thermal environmental condition for human occupancy.

www.fh.almas-hvac.ir/download/ASHRAE_Thermal_Comfort_Standard.pdf

Dahl, T. (2010). *Climate and architecture.* London: Routledge

Forgiarini, R. &Ghisi, R., (2017). Predicting thermal comfort in office buildings in a Brazilian temperate and humid climate. *Energy and Buildings*, 144 (1), 152-166.

Hayter, S. &Kandt, A. (2011). Renewable energy application for existing buildings. *48th, AiCARR International Conference*, Baveno-Lago Maggiore, Italy. September 22-23.

Ibitoye, M.O., Aderibigbe, O.G, Adegboyega, S.A., & Adebola A.O. (2016). Spatio-Temporal analysis of landsurface temperature variations in the rapidly developing Akure and its environs, Southwestern Nigeria using Landsat Data. *Ethiopian Journal of Environmental Studies & Management.* 10(3), 389-403.

IEA, (2006). The World Energy Outlook 2006 maps out a cleaner, cleverer, and more competitive energy future. www.iea.org/press/pressdetail.asp?press_rel_id=187

IEA, (2013). Mordernising building energy codes to secure global energy future.

www.iea.org/reports/policy-pathway-mordernising-building-energy-codes-2013

Karyono, H. T., (2015). Predicting Comfort Temperature in Indonasia, an initial step to reduce cooling energy consumption. *Buildings*, 5(3), 802-813.

Koh, K., Hal-Kayiem, H. &Kurnia, J. (2018). Thermal comfort assessment of an office buildings in tropical climate conditions. *MATEC Web of Conference*. (225), 01003 (2018).

Levin, H. (2015). Sustainable building design: Theory and practice. *Conference of Healthy Buildings, Boulder Colorado, U.S.A*. ResearchGate www.researchgate.net/publication/275891877

Nall, D. (2004). Climate-adaptive buildings in the United States & Europe. *The Construction Specifier*. 57(2), 50-56.

Ogunrayi, O., Akinseye, F., Goldberge, V., &Bernhofer, C. (2016). Descriptive analysis of rainfall and temperature trends over Akure, Nigeria. *Geography and Regional Planning*, 9(11), 195-202.

Smith, A. & Pitts, M. (2011). Sustainable workplaces and building user comfort and satisfaction. *Corporate Real Estate*.http//:doi/1108/14630011111170436.

Szokolay, S. (2008). *Introduction to architectural science: The basis of sustainable design* (2nd.ed). Architectural Press.

Ward, I. (2004). *Energy and Environmental Issues for the Practising Architect*: *A Guide to Helpat the Design Stage*. Thomas Telford Ltd.

Whole Building Design Guide, (2018). Sustainable overview. www.wbdg.org/design-objectives/sustainable