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Indoor Thermal Comfort for Commercial Buildings in Nigeria Urban Environment

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***Abstract:** Providing comfort for building inhabitants is difficult and essential in this era of climate change and global warming. This is a result of growing challenges facing designers to provide buildings that will be fit and comfortable for users in the 21st century. Thus, the purpose of this study was to examine indoor thermal comfort in commercial buildings in a warm-humid climate of Uyo Urban, Nigeria. The study revealed that the S-N and N-S orientations were considered optimum for thermal comfort in commercial buildings in Uyo Urban. It was found that higher values of MV corresponded to lower values of temperatures and the lower values of MV corresponded to higher values of temperatures. It was therefore inferred that thermal feelings increased in the direction of coolness with a reduction in temperature and increased in the direction of warmth with an increase in temperature. Therefore, building orientations strongly relate buildings to their natural environment, proper utilization of thermal inertia, sun, wind, prevailing weather patterns and topography which further create optimum thermal comfort for users. Hence, Planners and Designers should consider the S-N orientation and ensure that buildings are not closely clustered to ensure cross ventilation during overheating.*

***Keywords:** Thermal Comfort, Commercial Buildings, Urban Environment, Climate.*

1. INTRODUCTION

A home's energy efficiency can be improved by its orientation, making it more livable and less expensive to maintain (EcoWho, 2017). With the looming effect of climate change, it is pertinent to understand the thermal comfort range of commercial buildings concerning the increase in temperature and humidity caused majorly by human-induced activities. A lot of research has shown that comfortable occupants are more alert, have better energy levels, and use fewer sick days, which entirely translates to more productive and satisfied employees.

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Thermal comfort is seen as the temperature that the resident considers as comfortable to stay in. Indoor thermal comfort is achieved when occupants can pursue without any hindrance, activities for which the building is intended (Oluwafemi and Michael 2010). Hence, the hot and humid region is one of the hardest climates to ameliorate through building design. This is due to the high humidity and daytime temperatures that result in high indoor temperatures exceeding the ASHRAE 2008 (American Society of Heating, refrigerating and air conditioning engineer) summertime comfort upper limit of 26^{o}C for most of the year.
In addition, high humidity and temperature reduce moisture and evaporation rate from the human skin thereby increasing thermal discomfort. In achieving thermal comfort, cooling effects, shading devices and ventilation are always necessary. In a tropical climate, the solar heat, humidity, wind speed and rainfall initiate continuous evaporation from the human body due to the high amount of solar radiation received in the equatorial region. These excessive solar radiations cause discomfort condition of the indoor environment in buildings. Fanger (1970) defines thermal comfort as that condition of mind which expresses satisfaction with the thermal environment. This definition has been generally accepted by some international bodies, including International Standard Organization (ISO) 7730 and the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), and has served well for the temperate climate for which it was developed. However, its application in the tropics is still very much challenged as the actual thermal comfort standards are based upon laboratory studies carried out in climatic chambers, ignoring the complex interaction between occupants and their environments that could affect their comfort.
Much of what is known about the thermal comfort of users in buildings evolved from research works which focused on other countries. The attainment of indoor thermal comfort in commercial buildings in Nigeria is highly desirable because unfavourable environmental conditions will reduce the level of human performance. Thus, the purpose of this study was to examine indoor thermal comfort in commercial buildings in a warm-humid climate of Uyo Urban, Nigeria.

Climate and Location of the Study Area

Uyo Urban is a commercial centre of Uyo, the State capital of Akwa Ibom State, Nigeria. It is bordered in the east by Itu LG, West by Uruan LG, South by Etinan and Ibesikpo LGAs and North by Ibiono Ibom LGA of Akwa Ibom State. Uyo Urban has a tropical wet and dry climate (Köppen climate classification Aw), with a lengthy wet season and relatively constant temperatures throughout the year. The wet season runs from March through October, though August sees somewhat of a lull in precipitation. This lull nearly divides the wet season into two distinct wet seasons. November to February forms the city's dry season, during which it experiences the typical West African harmattan. The mean annual rainfall is between 2000-3420 mm, falling in approximately 262 days. Again, there are two peaks for rainfall, June and September. The mean maximum temperature is 29.8^{0} C, the minimum 23.2^{0} C and the relative humidity is 79.6% (Akpan, 2017).

Literature Review

Are (2018) noted that most people are comfortable at higher temperatures if there was lower humidity. In another study conducted by Rodrigues, Landin (2011) on the influence of building

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orientation on the indoor climate of buildings in Maputo city Mozambique to evaluate and gauge how much thermal comfort was lost due to inadequate orientations of buildings. The study result demonstrated that the temperatures within the volumes of the building NE-SW orientations were about 5 to 7°C high than the outdoor temperature and about 2°C more than the buildings E-W orientated throughout the year. The results concluded that the indoor temperatures of the buildings NE-SW orientation have had their thermal comfort negatively influenced in about 11%-42% compared to the buildings E-W orientation and in about 6.4%-17% of the thermal comfort from outdoor. The temperature drops and higher humidity levels are still within the comfort zone.

A field study conducted by Appah-Dankyi and Koranteng (2012) on students‟ and teachers‟ thermal comfort in a school building (St. Andrews Junior High School) at Madina, Accra. The building was chosen due to the sustainable design principles (e.g. form, orientation and ventilation) employed in the design and construction of the school. The study aimed to investigate people‟ perception of comfort as well as examine the prevailing thermal conditions in the classrooms. Moreover, a comparative analysis of the results with the worldwide accepted American society of heating, refrigerating and air conditioning engineer (ASHRAE) recommendations was carried out. One significant conclusion drawn was that the classroom spaces on the ground floor experienced lower temperatures, whilst those on the first floor had a higher temperature (difference of 2°C). The first-floor classrooms experienced higher thermal conditions as a result of the absence of a ceiling. In addition, though a large majority of the respondents accepted their overall thermal conditions, a number of them still voted below the standard set by ASHRAE of 80% positive votes by occupants for thermal comfort. The study also showed that respondents in tropical countries such as Ghana may have a higher heat tolerance since most of the interviewees accepted the existing thermal conditions which exceeded the standard of between 26°C and 28°C (summer comfort range) by 1°C to 5°C.

Research conducted by Olanipekun (2014) on the thermal comfort and occupant behaviour in a naturally ventilated hostel in a warm-humid climate of Ile-Ife, Nigeria showed that all the measured environmental variables fell below the comfort range recommended by ASHRAE standard 55 and ISO 7730 standard and concludes that in a warm-humid climate of Ile-Ife, during the hot season the desire for sustainable thermal comfort may not be achieved without mechanical ventilation system.

A study conducted by Are (2018) on the effect of orientation on indoor climates of residential buildings in the Ibadan metropolis revealed that North-south building orientations were more appropriate and sustainable than East-West building orientations due to their thermal comfort values. Adunola (2018) examined the indoor air temperature relationship with the thermal response of the subjects in residential buildings in Olubadan. He considered both the physiological and psychological factors of thermal comfort and modified the ASHRAE scale to 7 point sensation limit. The mean vote (MV) for each set of responses was calculated. It was found that higher values of MV corresponded to lower values of temperatures and the lower values of MV corresponded to higher values of temperatures. It was therefore inferred that thermal feelings increased in the direction of coolness with the reduction in temperature and increased in the direction of warmth with the increase in temperature.

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2. METHODOLOGY

The research was conducted in four selected commercial buildings in Uyo urban. The first part was preceded by fieldwork while the second part was a collection of empirical data (Temperature, Relative Humidity, Wind speed and Radiation) from the Nigerian Meteorological Agency (NIMET) covering a period of 30 years from 1988-2018. Published journals, articles, books and related literature were also consulted.

Four buildings were selected based on their similarities in wall-window ratio, wall thickness, volumes, colour, roof and business activity. As noted by Veal (2006), case study selection is comparable to sampling in quantitative research and cases were usually purposely selected. This meant that cases were identified for study due to their inherent qualities which aligned with the phenomenon under investigation Oluigbo (2010).

Field measurement was focused on measuring three major thermal comfort parameters namely: indoor air temperature, relative humidity and wind speed. The four selected buildings measured had similar structural designs, volumes and makeup materials but different orientations. Their locations and orientations were ascertained with the aid of a GPS and magnetic compass. Microclimatic measurements were taken from each of the rooms that had similar volumes from the four selected building orientations. Thus, four Sling psychrometers and a digital anemometer were mounted on the selected shops to measure the indoor air temperature, relative humidity and air velocity concurrently on a 3hour interval from a standard local time (SLT) of 09:00-18:00 hours for 30 days.

The mean, minimum, maximum and standard deviation, the variance of air temperature, RH and wind speed were presented in tables.

(iii) Comfort zone: Szokolay method (2008) was adopted as a result of the fact that mean air temperature exceeded 30^0C. Comfort limit was calculated using the formula 0n=17.6x0.31 0m. Superior and inferior comfort limits were calculated as thus:17.6+(0.31x31.4) +2 = 29.3^0C and 17.6+(0.31x24.9)+2 = 23.9^0C

3. RESULTS

Using Szokolay indices to determine SET, the superior limit of thermal comfort was set at 29.3^0C and the inferior limit of thermal comfort was set at 23.9^0C. During the dry season, at 09:00 SLT; S-N, W-E, N-S and E-W building orientations had 15^1, 4^{12}, $5^{11}$and 1^{15} no of comfort and discomfort hours respectively. Discomfort hours at 09:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 15 and only 1 discomfort hour at 09:00SLT out of the 64 hours recorded in the dry season was seen as the most thermally comfortable building orientation at 09:00SLT. Results also revealed that W-E building orientation was seen as the most thermally uncomfortable orientation at 09:00 SLT having recorded only 1 thermal comfort hour and 15 discomfort hours, (Figure 1).

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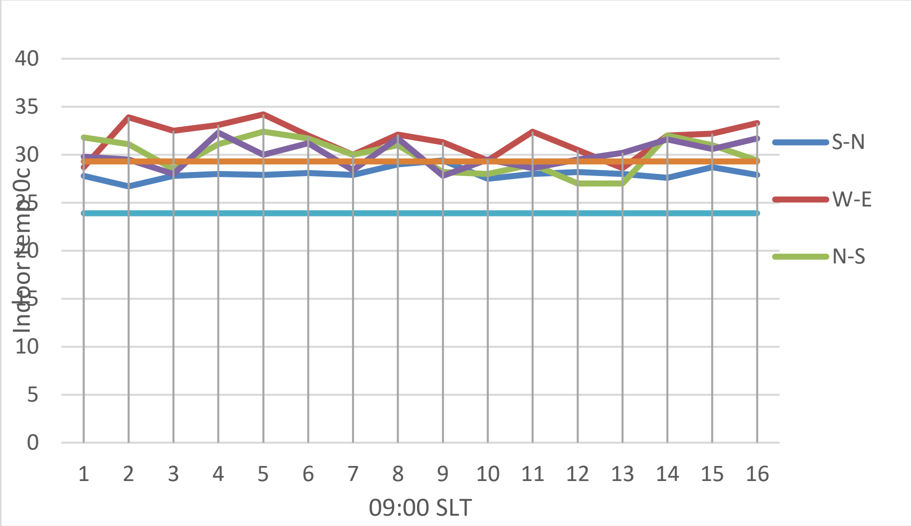

Figure 1: Comfort range of building orientations at 09:00 SLT in dry seasons
Source: Field data

In Figure 2, during the wet season, at 09:00 SLT; S-N, W-E, N-S and E-W building orientations had 14^0, 6^8 $8^6$and 2^{12} no of comfort and discomfort hours respectively. Discomfort hours at 09:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 14 and 0 discomfort hours at 09:00SLT out of the 56 hours recorded in the wet season was seen as the most thermally comfortable building orientation at 09:00SLT. Results also revealed that the W-E building orientation was seen as the most thermally uncomfortable orientation at 09:00 SLT having recorded only 2 thermal comfort hours and 12 discomfort hours than the rest of the building orientations.

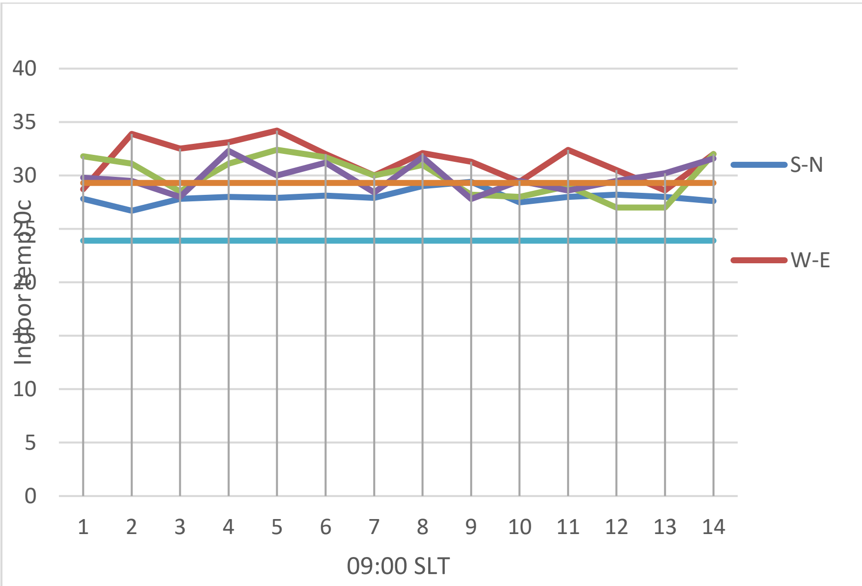

Figure 2: Comfort range of building orientations at 09:00 SLT in wet seasons
Source: Field data

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In Figure 3, during the dry season, at 12:00 SLT; S-N, W-E, N-S and E-W building orientations had 14^{2}, 0^{16}, $6^{10}$and 0^{16} no of comfort and discomfort hours respectively. Discomfort hours at 12:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 14 and only 2 discomfort hours at 12:00SLT out of the 64 hours recorded in the dry season was seen as the most thermally comfortable building orientation at 12:00SLT followed by N-S building orientation which had 6 comfort hours and 10 discomfort hours. Results also revealed that E-W and W-E building orientations had shared equal discomfort hours and no comfort hours. This was a result of the sun's trajectory on these orientations at that hour.

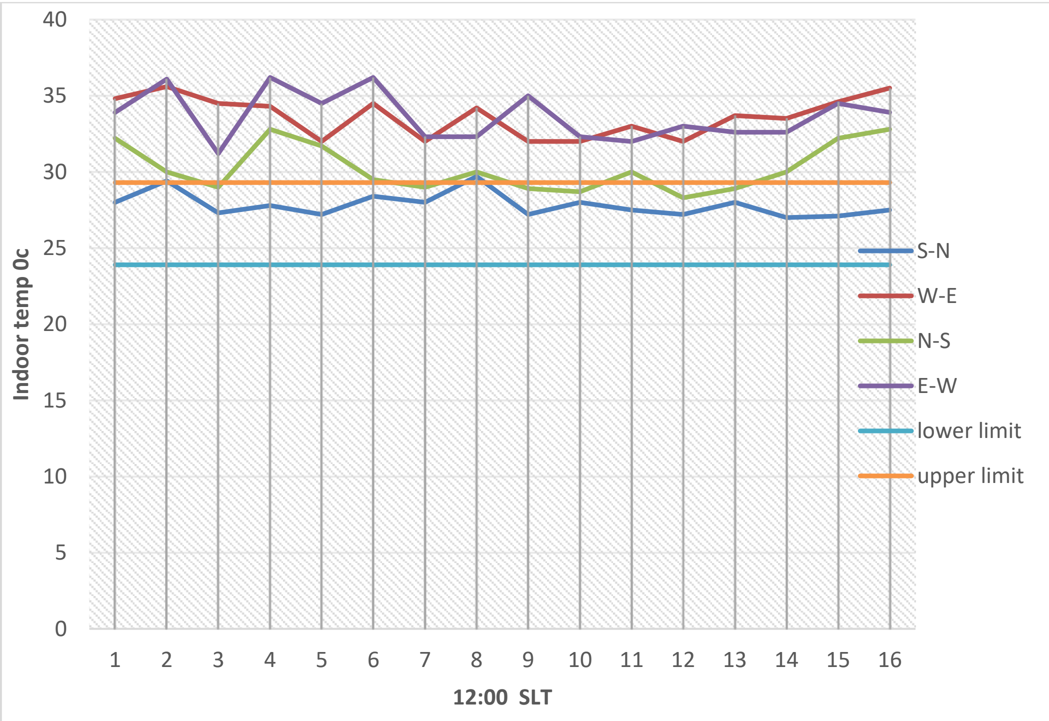

Figure 3: Comfort range of building orientations at 12:00 SLT in dry seasons
Source: Field data (2019)

In Figure 4, During the wet season, at 12:00 SLT; S-N, W-E, N-S and E-W building orientations had 13^{1}, $0,^{14}$ $5^{9}$and 0^{14} no of comfort and discomfort hours respectively. Discomfort hours at 12:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 13 and 1 discomfort hour at 12:00SLT out of the 56 hours recorded in the wet season was seen as the most thermally comfortable building orientation at 12:00SLT. Results also revealed that E-W and W-E building orientations were seen as the most thermally uncomfortable orientations at 12:00 SLT having recorded 0 thermal comfort hours and 14 discomfort hours each. Even during the wet season, the high value of relative humidity recorded in E-W and W-E orientations was sufficient to trap more heat from counter radiation. In addition, the relatively low air velocity value of 0.00 and 0.001m/s was not sufficient to aid air circulation and passive cooling in these orientations.

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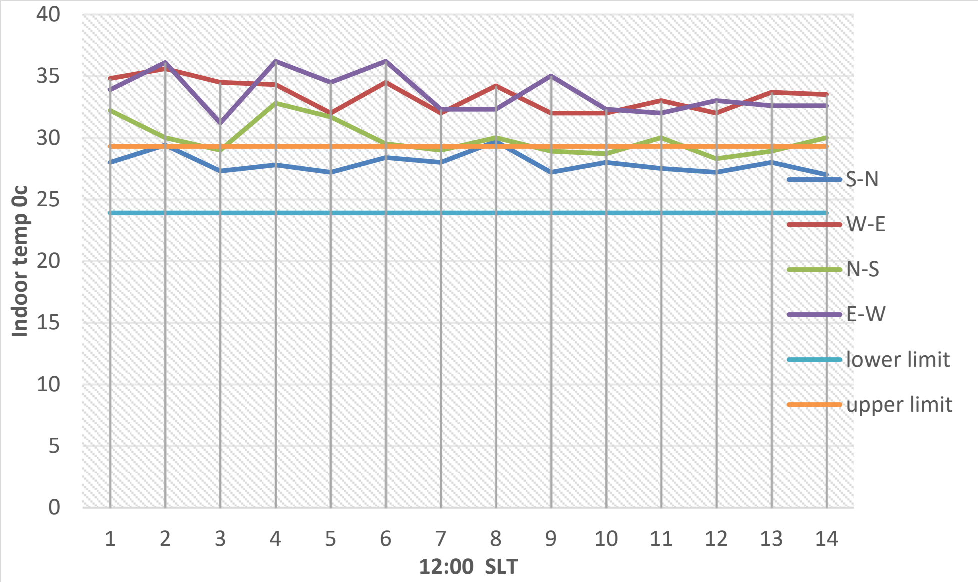

Figure 4: Comfort range of building orientations at 12:00 SLT in wet seasons
Source: Field data

In Figure 5, during the dry season, at 15:00 SLT; S-N, W-E, N-S and E-W building orientations had 7^9, 0^{16}, $3^{13}$and 0^{16} no of comfort and discomfort hours respectively. Discomfort hours at 15:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 7 and 9 discomfort hours at 15:00SLT out of the 64 hours recorded in the dry season was seen as the most thermally comfortable building orientation at 15:00SLT. Results also revealed that E-W and W-E building orientations shared equal discomfort hours and no comfort hours. This was a result of the prevailing westerlies.

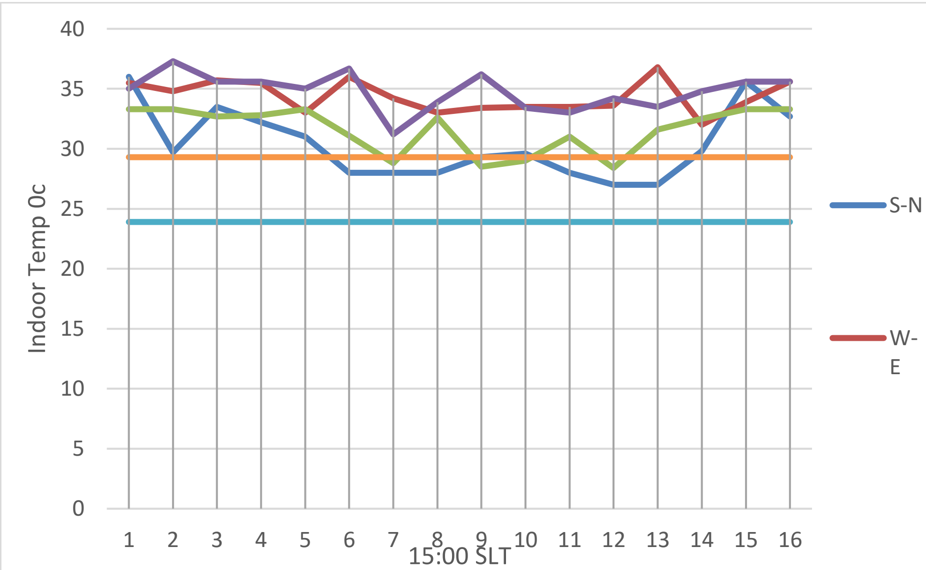

Figure 5: Comfort range of building orientations at 15:00 SLT in dry seasons
Source: Field data (2019)

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In Figure 6, During the wet season, at 15:00 SLT; S-N, W-E, N-S and E-W building orientations had 9^{5}, $0,^{14}$ $4^{10}$and 0^{14} no of comfort and discomfort hours respectively. Discomfort hours at 15:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 13 and 1 discomfort hour at 15:00SLT out of the 56 hours recorded in the wet season was seen as the most thermally comfortable building orientation at 15:00SLT. Again, results revealed that E-W and W-E building orientations were seen as the most thermally uncomfortable orientations at 15:00 SLT having recorded 0 thermal comfort hours and 14 discomfort hours each.

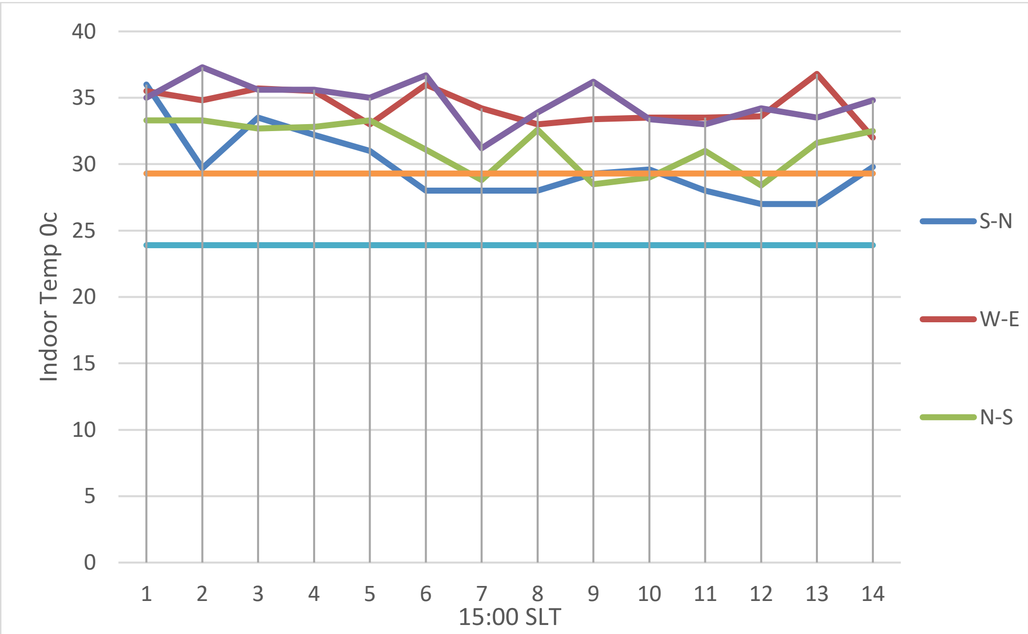

Figure 6: Comfort range of building orientations at 15:00 SLT in wet seasons
Source: Field data

In Figure 7, at 18:00 SLT; S-N, W-E, N-S and E-W building orientations had 9^{7}, 3^{13}, $7^{9}$and 1^{15} no of comfort and discomfort hours respectively during the dry season. Discomfort hours at 18:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 9 and 7 discomfort hours at 18:00SLT out of the 64 hours recorded in the dry season was seen as the most thermally comfortable building orientation at 18:00SLT. Results also revealed that a cooling effect influenced by prevailing easterlies on the E-W building orientation reduces thermal heating on the orientation, this, in turn, made W-E building orientation have the most discomfort hours at 18:00 SLT.

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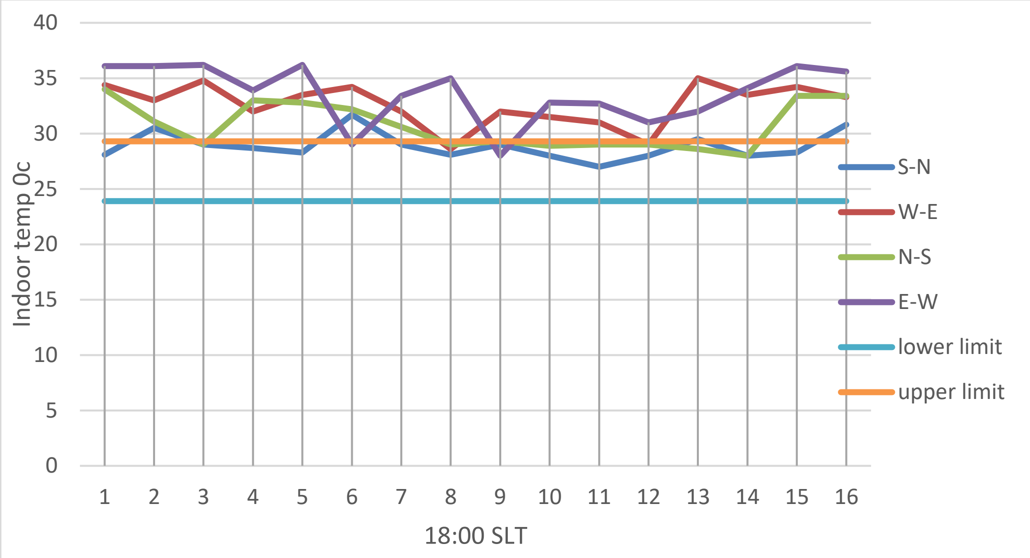

Figure 7: Comfort range of building orientations at 18:00 SLT in dry seasons
Source: Field data

In Figure 8, During the wet season, at 18:00 SLT; S-N, W-E, N-S and E-W building orientations had 10^4, $2,^{12}$ $6^8$and 0^{14} no of comfort and discomfort hours respectively. Discomfort hours at 18:00SLT are shown in superscripts. Therefore, S-N, having comfort hours of 10 and 4 discomfort hours at 15:00SLT out of the 56 hours recorded in the wet season was seen as the most thermally comfortable building orientation at 18:00SLT. Again, results revealed that E-W building orientations were seen as the most thermally uncomfortable orientations at 18:00 SLT having recorded 0 thermal comfort hours and 14 discomfort hours.

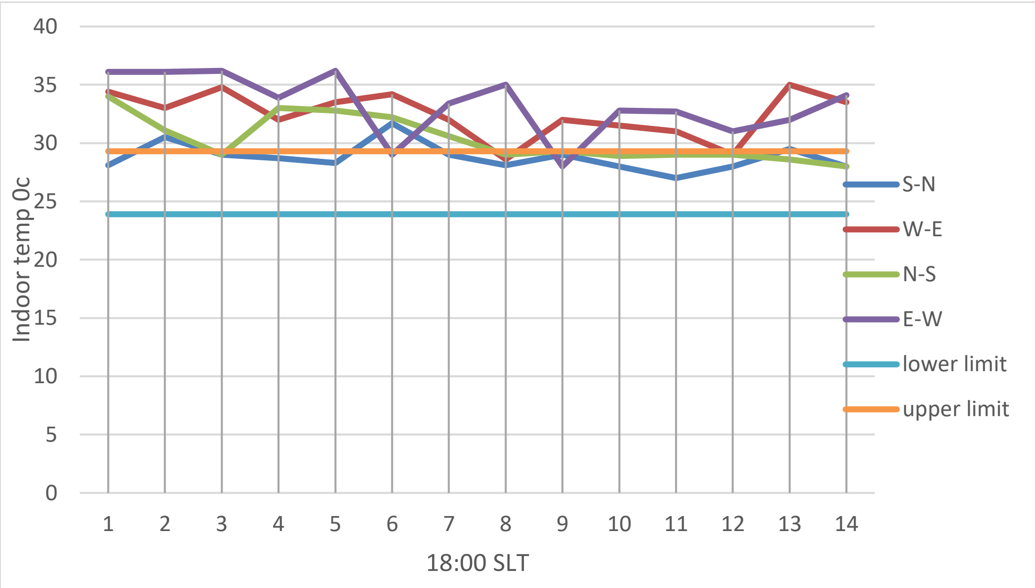

Figure 8: Comfort range of building orientations at 18:00 SLT in wet seasons
Source: Field data

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4. DISCUSION AND CONCLUSION

In the study area, orientation may be strongly determined by Uyo Capital City Development Authority (UCCDA) and other local regulators yet decisions made in site planning and building orientation will have significant effects on the thermal and visual comfort of users and the performance of buildings over their entire life cycle. Thus the S-N and N-S orientations were considered optimum for thermal comfort in commercial buildings in Uyo Urban. This inference conforms with a study conducted by Are 2018 on the effect of orientation on indoor climates of residential buildings in the Ibadan metropolis revealed that North-south building orientations were more appropriate and sustainable than East-West building orientations due to their thermal comfort values. It also agrees with a study done by Adunola (2014) when he examined the indoor air temperature relationship with the thermal response of the subjects in residential buildings in Olubadan. The mean vote (MV) for each set of responses was calculated. It was found that higher values of MV corresponded to lower values of temperatures and the lower values of MV corresponded to higher values of temperatures. It was therefore inferred that thermal feelings increased in the direction of coolness with a reduction in temperature and increased in the direction of warmth with an increase in temperature. Building orientations strongly relate buildings to their natural environment, proper utilization of thermal inertia, sun, wind, prevailing weather patterns and topography can create optimum thermal comfort for users.

Planners and Designers should consider the S-N orientation and ensure that buildings are not closely clustered to ensure cross ventilation during overheating. Bio-climatic aspects like planting flowers besides building facades and windows should be encouraged. Government agencies like UCCDA should ensure that the best orientations are included in building plans or layouts before approval.

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