# Evaluating Neutral, Preferred and Comfort Range Temperatures and Computing Adaptive Equation for Kano Region

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*ABSTRACT: Provisions of international comfort standards may not be appropriate for all climates, it is therefore imperative to evaluate comfort requirements of indoor occupants in all regions, particularly where comprehensive standards are lacking. As part of an ongoing study on comfort in higher education facilities in Kano, involving lecture theatres and laboratories, an Indoor Environmental Quality field study was conducted by collecting a total of 1382 questionnaires in addition to physical measurements, covering a period of 10 months. In addition to measurements of air speed, air and radiant temperatures, relative humidity, a comfort survey was undertaken where activity levels and clothing insulations were obtained. Two neutral temperatures were arrived at based on operative and indoor running mean temperatures, 27.4 °C and 28.1 °C respectively. Similarly a comfort zone of 22 °C to 32 °C was realised. The results revealed that the adaptive equation using the weighted running mean outdoor air temperature had the highest coefficient of determination, with regression coefficient of 0.6, which is nearly twice those of ASHRAE 55 and EN 15251. The evaluated neutral and preferred temperatures show that subjects are comfortable even at 32 °C in naturally ventilated buildings in Kano region.*
*KEYWORDS: Neutral temperature, preferred temperature, comfort zone, adaptive equation, Sub-Saharan Africa*

## 1. INTRODUCTION

The assessment of thermal comfort in buildings makes it possible to determine the acceptable range of environmental parameters and permitting architectural recommendations that best fit each type of climate. It is also known that daily climatic patterns in all regions require climate-conscious building design strategies to achieve a comfortable thermal environment, this is therefore apt for the tropics. As vividly captured by Nicol (2004), that "the climatic, cultural and the allowance for time means that comfort surveys are needed in every area of the world, particularly in the tropics where current standards are weakest". He also stated that "…. the empirical findings of field surveys can be used as a guide for informing the design of buildings to provide comfortable conditions. Wherever possible this can be improved by the conduct of local field surveys to fully reflect local climate and culture". Nonetheless, thermal comfort studies for naturally ventilated buildings in the tropical context, are relatively under represented, this is especially true for the Sub-Saharan African region.

Two main models are popularly used to define thermal comfort, the predicted mean vote (PMV) and the adaptive thermal comfort (ATC). PMV-PPD equation was used in arriving at the recommendations of some international comfort standards, such as ISO 7730, EN 15251 and ASHRAE Standard 55. PMV is however confounded with the problem of limited applicability for predicting comfort temperatures in hot climates. Adaptive thermal comfort requirements for naturally ventilated (NV) spaces significantly differ from those defined by PMV/PPD model. An adaptive opportunity is the ability for the occupants to open doors or windows, put on/off ceiling fans, adjust clothing etc., as against the climate chamber-based assessment. The primary aim of this paper is to evaluate the neutral, comfort range and preferred temperatures, as well as developing an appropriate adaptive thermal comfort equation for naturally ventilated buildings in the hot (temperature ranges between 12 °C and 39 °C) and dry region (relative humidity ranges between 20% and 80%) of Nigeria.

### *1.1 Neutral temperatures from Nigeria*

Thermal comfort studies identified from Nigeria that calculated the neutral and comfort range temperatures and adaptive equations are very few. Ogbonna & Harris (2008) conducted a fieldwork in university classrooms and residential houses in Jos, using linear regression of thermal sensation votes (TSV) on operative temperature ($T_{op}$) across their samples, the study yielded a neutral temperature of 26.27 °C and a comfort range of between 24.88 °C and 27.66 °C. They also obtained a correlation $r^2$ = 0.57 from the regression line equation (TSV = 0.3589$T_{op}$ – 9.4285). Efeoma et al. (2014) undertook a thermal comfort assessment of office buildings in Enugu, eastern Nigeria (in February, when average air temperature reaches 38 °C), and obtained a range of comfort temperature of 24.7 °C to 32.9 °C. Another study conducted in the rainforest of Nigeria by BRE (1978) in Port Harcourt yielded a neutral temperature of 23.13 °C, indicating a wide disparity of up to 3.14 °C between the Jos and the Port Harcourt figures. Some more thermal comfort studies were recently conducted in the country but mostly in residential houses, where clothing is casual and light (Abdulkareem et al., 2018; Adaji et al., 2015; Munonye & Ji, 2017).

## *2. METHODOLOGY*

This study was carried out in Bayero University, a conventional university situated in Kano, Nigeria. Kano lies on latitude 12 °N and longitude 8.17 °E, in the Savannah region of West Africa. Being situated within lower latitudes combined with high solar radiation and low humidity, Kano region is classified as having a hot and dry climate according to Koppen's classification. The fieldwork was undertaken from August 2016 to May 2017, and was conducted on three different occasions; during the rainy season of August, 2016 (warm and wet), then in January, 2017 (winter season) when it was cool and dry and finally in May, 2017 (summer season) when it was hot and dry. Both physical measurements of air speed, air and radiant temperatures, relative humidity (using spot and logging instruments) and surveys were conducted based on procedures consistent with ASHRAE standard 55-2013. The surveys were conducted via a paper-based questionnaire prepared and administered to 1382 respondents in six learning spaces in the university.

## *3. RESULTS*

The PMV & PPD, operative temperature, AMV, and the adaptive comfort indices based on EN 15251 and ASHRAE Standard 55, the running mean temperature ($T_{rm}$) and the mean outdoor air temperatures ($T_{out,mean}$) of the entire survey months were derived and presented in Tables 1 to 3 and were used in arriving at the neutral and preferred temperatures.

*Table 1: Derived Thermal Comfort Indices in Mid-season*

| Survey | LEARNING ENVIRONMENT | $T_{op}$ °C | $T_{rm}$ °C | PMV | PPD | $T_{out}$ °C | AMV | $T_n$ |
|---|---|---|---|---|---|---|---|---|
| Mid-season (first survey) | AKTH | 27.4 | 27.4 | +0.36 | 8% | 27.9 | -0.08 | 27.8 |
| | Dandatti | 29.8 | 28.8 | +0.89 | 22% | 29.1 | 0.12 | 28.3 |
| | FEES | 27.0 | 27.4 | +0.24 | 6% | 30.4 | -0.20 | 27.8 |
| | I H Umar | 30.4 | 30.6 | +1.28 | 39% | 31.0 | 1.50 | 28.9 |
| | MPL | 30.0 | 29.2 | +1.17 | 34% | 32.8 | 0.77 | 27.8 |
| | PHL | 27.7 | 30.2 | +1.00 | 26% | 27.9 | -0.38 | 28.2 |

*Table 2: Derived thermal comfort indices in the Winter*

| | LEARNING ENVIRONMENT | $T_{op}$ °C | $T_{rm}$ °C | PMV | PPD | $T_{out}$ °C | AMV | $T_n$ |
|---|---|---|---|---|---|---|---|---|
| Winter season (Second survey) | AKTH | 25.5 | 25.4 | +0.38 | 8% | 25.4 | -1.03 | 27.2 |
| | Dandatti | 23.1 | 23.8 | -0.21 | 6% | 23.8 | -0.74 | 26.7 |
| | FEES | 29.4 | 26.8 | +1.35 | 43% | 26.4 | -0.75 | 26.7 |
| | I H Umar | 25.0 | 24.8 | +0.25 | 6% | 30.8 | -1.03 | 27.0 |
| | MPL | 29.6 | 29.2 | +1.42 | 47% | 30.3 | 0.08 | 28.5 |
| | PHL | 23.7 | 25.4 | +0.35 | 7% | 23.6 | 0.33 | 26.8 |

*Table 3: Derived thermal comfort indices in the Summer*

| Survey | LEARNING ENVIRONMENT | $T_{op}$ °C | $T_{rm}$ °C | PMV | PPD | $T_{out}$ °C | AMV | $T_n$ |
|---|---|---|---|---|---|---|---|---|
| Summer (third survey) | AKTH | 34.9 | 36.5 | +2.02 | 78% | 35.6 | 0.93 | 30.8 |
| | Dandatti | 31.3 | 33.5 | +1.03 | 27% | 36.3 | 2.29 | 29.9 |
| | FEES | 33.2 | 34.4 | +1.56 | 54% | 34.8 | 1.44 | 30.2 |
| | I H Umar | 34.3 | 35.8 | +1.46 | 49% | 36.8 | 2.20 | 30.6 |
| | MPL | 33.6 | 36.3 | +1.29 | 40% | 35.6 | 1.23 | 30.8 |
| | PHL | 33.0 | 32.4 | +1.11 | 31% | 33.5 | 1.33 | 29.5 |

3.1 Neutral temperature

Two sets of regression analyses were conducted between the mean thermal sensation votes calculated as actual mean votes (AMV) and two different indoor temperatures (operative temperature = $T_{op}$, and running mean temperature = $T_{indrm}$) for comparison. This method was followed by Mishra & Ramgopal (2014) and Baruah et al. (2014). The neutral temperatures were calculated by equating the obtained equations of the comfort index (AMV) to zero, which is the point at which most occupants felt neither warm nor cold, while the comfort temperature ranges are based on -1 to +1 on the 7-point scale. Figure 1 shows the fitted line plots of the relationships of the comfort index with the $T_{op}$ and $T_{indrm}$. The equations formed by these relationships, the $r^2$, $p$ values, neutral and comfort range temperatures are tabulated and presented in Table 4. The $T_n$ obtained by correlating the AMV and the indoor running mean temperature was the strongest with an $r^2$ = 70%, as against that of $T_{op}$ of 59%.

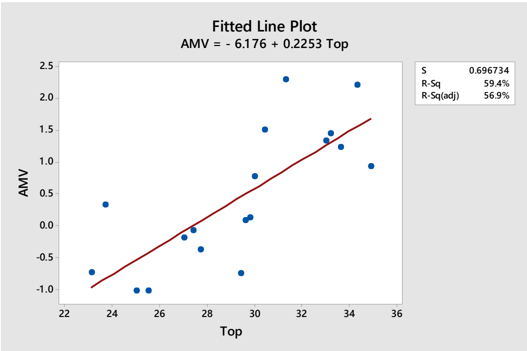


*Figure 1a = AMV Vs $T_{op}$*

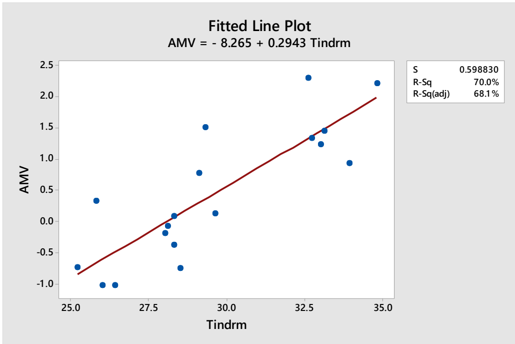


*Figure 1b = AMV Vs $T_{indrm}$*

*Figure 1: Correlations of AMV versus $T_{op}$ and $T_{indrm}$*

*Table 4: Neutral temperatures based on $T_{op}$ and $T_{indrm}$*

| Equations | $r^2$ and $P$ values | $T_n$ (°C) | Comfort Range (°C) |
|---|---|---|---|
| AMV = -6.176 + 0.2253 $T_{op}$ | $r^2$ = 59.4% ($P$ = 0.000) | 27.4 | 23.0 - 31.9 |
| AMV = -8.265 + 0.2943 $T_{indrm}$ | $r^2$ = 70.0% ($P$ = 0.000) | 28.1 | 24.7 - 31.5 |

3.2 Preferred temperature

To obtain the preferred temperature, further analysis was carried out based on the results of the preference votes on the seven-point McIntyre preference scale. According to the answers to the questions on the questionnaire: “this time what do you prefer in this space; much cooler, cooler, slightly cooler, no change, slightly warmer, warmer or much warmer”? In arriving at the want cooler and want warmer votes, the sum of all votes under “much cooler, cooler and slightly cooler” were merged to form the want cooler. Similarly, the sum of all the votes under “slightly warmer, warmer and much warmer” formed the want warmer category. This method was followed by a number of studies, such as de Dear et al. (2014); Tao & Li R. (2014); and Ye et al. (2010). During each season, operative temperatures of each space were obtained, and in each space at each operative temperature there were people who preferred “wanting warmer”, “wanting no change” and “wanting cooler” conditions. Therefore, the cumulative frequencies of the “wanting warmer” and “wanting cooler” categories were classified into an operative temperature bin of 1 °C. These are shown in Figures 2 to 4, respectively for the winter season, the summer season and for the mid-season.

3.2.1 Winter preferred temperature

Figure 2 shows a chart with two quadratic equations obtained from the fitted line plots of wanting warmer and wanting cooler conditions for the winter season and the respective equations are shown as Equations 1 and 2:

Equation 1: Want cooler = - 7.9957 + 0.5453$T_{op}$ - 0.0082$T_{op}^2$ … ($r^2$ = 0.9851)

Equation 2: Want warmer = 0.2497 + 0.149$T_{op}$ - 0.0052$T_{op}^2$ … ($r^2$ = 0.9775)

The preferred temperature for winter season was then calculated by equating the two quadratic equations obtained, this gave a value of 25.9 °C. This was further validated by the intersection of the two curves; “want cooler” and “want warmer” in Figure 2.

### 3.2.2 Summer preferred temperature

Similarly Figure 3 shows two quadratic equations obtained from the fitted line plots of wanting warmer and wanting cooler conditions for the summer season and their respective equations are shown as Equations 3 and 4:

Equation 3: Want cooler = $-53.433 + 3.5445T_{op} - 0.0577T_{op}^2$ .... ($r^2 = 0.9774$)

Equation 4: Want warmer = $-16.926 + 0.8637T_{op} - 0.01\ T_{op}^2$ ....... ($r^2 = 0.9749$)

The summer preferred temperature was also calculated by equating the two quadratic equations obtained, which gave 33.1 °C. This was also validated by the intersection of the two curves; “want cooler” and “want warmer” in Figure 3, this however has exceeded the comfort temperature of 32 °C.

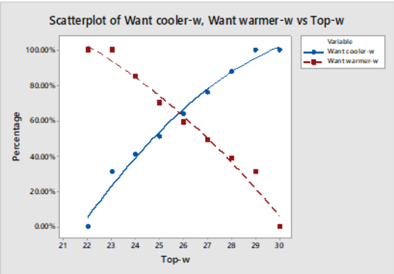


*Figure 2: Winter preferred temperature*

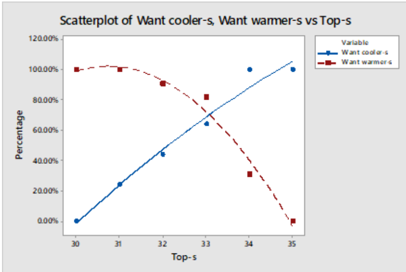


*Figure 3: Summer preferred temperature*

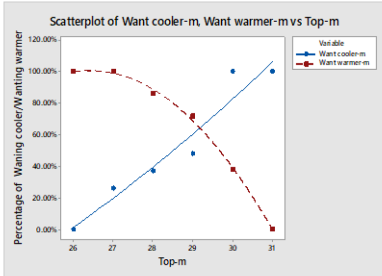


*Figure 4: Midseason preferred temperature*

### 3.2.3 Mid-season preferred temperature

Likewise Figure 4 shows two quadratic equations obtained from the fitted line plots of wanting warmer and wanting cooler conditions for the mid-season and their respective equations are shown as Equations 5 and 6. The mid-season preferred temperature is then calculated by equating the two quadratic equations obtained, which is 29.3 °C. This is also approximately indicated by the intersection of the two curves; “want cooler” and “want warmer” in Figure 4.

Equation 5: Want cooler = $-0.5366 - 0.1366T_{op} + 0.0061T_{op}^2$ .... ($r^2 = 0.934$)

Equation 6: Want warmer = $-32.661 + 2.5482T_{op} - 0.0482\ T_{op}^2$ .... ($r^2 = 0.997$)

### 3.2.4 Adaptive comfort equation for Kano

This study used the Griffiths’ equation and a 0.5 constant, the comfort temperatures were calculated on the day of each survey and were correlated with three different conditions to produce the adaptive equations appropriate for Kano. The conditions included the weighted running mean outdoor temperature ($T_{rm}$) and the outdoor mean temperature ($T_{out,mean}$), See

Equation 7: $T_{comf} = T - AMV/\alpha$

Figures 5 and 6 for the respective fitted line plots. This is done in line with the ASHRAE 55 and the EN 15251 standards with a view to finding which of them is most applicable in predicting the comfort temperature for the region. The obtained adaptive comfort equations, their $r^2$ and $p$ values are further presented in Table 5.

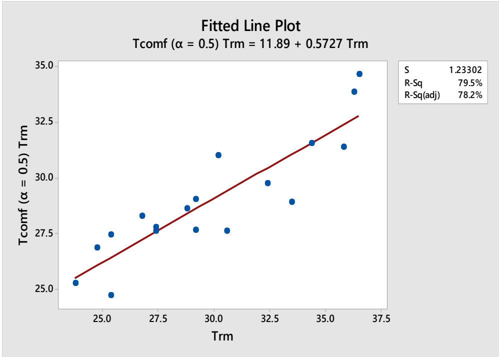


*Figure 5: Regression line of $T_{comf(Trm\ and\ \alpha = 0.5)}$ Vs Trm*

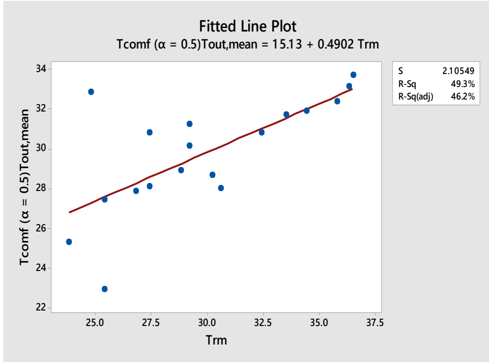


*Figure 6: Regression line of $T_{comf(Tout,mean\ and\ \alpha = 0.5)}$ Vs $T_{rm}$*

| *Table 5: Adaptive Comfort Equations based on α = 0.5* | |
|---|---|
| $T_{comf(Trm)} = 11.89 + 0.5727\ T_{rm}$ | $r^2 = 79.5\%$ ($p$ = 0.000) |
| $T_{comf(Tout,mean)} = 15.13 + 0.4902\ T_{rm}$ | $r^2 = 49.3\%$ ($p$ = 0.001) |

Equation 8: $T_{comf} = 0.57T_{rm} + 11.89$ ............................ (Using $T_{rm}$)

Equation 9: $T_{comf} = 0.49T_{rm} + 15.13$ ........................... (Using $T_{out,mean}$)

Equation 10: $Y = 0.49x + 15.13$ ........................... (Using $T_{out,mean}$)

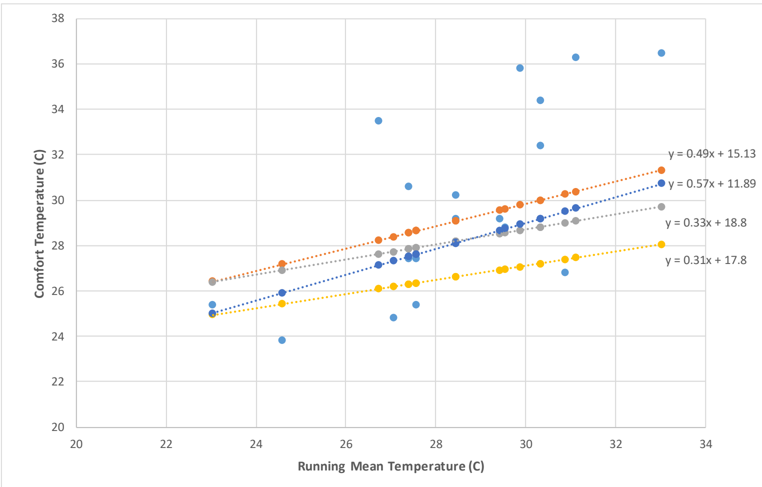


*Figure 7: Comparison the obtained equation with adaptive thermal comfort standards' equations*

## 4. DISCUSSION AND SUMMARY

From the foregoing analysis, two different neutral temperatures were obtained for Kano based on operative and indoor running mean temperatures, these are 27.4 °C, and 28.1 °C respectively. All the evaluated neutral temperatures are higher than two out of the three neutral temperatures earlier evaluated in Nigeria; Port Harcourt (23.13 °C) and Jos (26.27 °C), but that of Enugu (28.8 °C) is higher than both.

The obtained winter preferred temperature of 25.9 °C, as expected, is lower than the mid-season preferred temperature of 29.3 °C by 3.4 °C, and also lower than that of the summer (33.1 °C) by 7.2°C. Interestingly the preferred temperature during the winter falls below the neutral temperature (27.4 °C), while the mid-season preferred temperature is slightly higher than its correspondent neutral temperature. Therefore using the said neutral temperature of 27.4°C, which is based on the operative temperature, a comfort zone of 23 °C to 32 °C with a range of 9 °C was realised and is found to be higher than the range of ASHRAE (7 °C) and that of EN 15251 (6 °C).

Using Griffiths' method, weighted outdoor running mean and outdoor monthly mean temperatures the adaptive comfort equation was obtained. Although the one based on the $T_{rm}$ has the highest $r^2$ value, the one based on the $T_{out,mean}$ is closer to those of ASHRAE 55 and EN 15251. Nigeria with its tropical climate, electrical energy issue and with a population size which demands more higher education facilities, could greatly benefit from the development and implementation of an adaptive comfort standard. This paper therefore recommends the adoption of EN 15251 Equation for the country, and the use of Equation 10 (see Figure 7), obtained using the $T_{out,mean}$, however it could be further explored to ascertain its efficacy.

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