EFFECTS OF CEILING FANS ON THE THERMAL COMFORT OF STUDENTS IN LEARNING ENVIRONMENTS OF BAYERO UNIVERSITY, KANO, NIGERIA

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ABSTRACT

It is well known that thermal comfort is influenced by major physical parameters; air and radiant temperatures, humidity, and air speed in combination with personal attributes; clothing insulation and activity level. Although temperature is conventionally considered in adaptive thermal comfort model, as the most important physical parameter where cooling is involved, moderate air speed can enhance thermal comfort during higher temperatures. Through convective and evaporative cooling, ceiling fans cool people by causing sweat from the occupant's body to evaporate. The northern part of Nigeria, being in the tropics, is known for higher temperature regimes for most part of the year. The use of air conditioning to achieve thermal comfort is not sustainable, for economic reasons and the lack of stable electrical energy. Therefore, a majority of naturally ventilated spaces could be kept thermally comfortable with the control of ceiling fans and operable windows. As part of a research work on learning environments in a Northern Nigerian university, this study reports on the effects of ceiling fans on the thermal comfort perception of the students in two lecture theatres. In addition to the measurements of air speed, air and radiant temperatures, relative humidity, a comfort survey was also undertaken in the spaces, from which activity levels and clothing insulations were obtained. Adaptive thermal comfort standards, ASHRAE 55 and EN 15251, state that thermal comfort can be maintained as air temperature rises with the use of ceiling fans operating at moderate speed. The results from this study show that reductions of 31% and 22% in overheating from the two lecture theatres were realised, as a result of ceiling fans usage, measured by the degree hour's exceedance indicator. These results were further corroborated by the students' acceptance of thermal conditions of the lecture theatres at temperatures above T_{max}.

Keywords: Ceiling fans, thermal comfort, overheating, Bayero University, Kano

INTRODUCTION

There is no rains and no cloud cover in the dry season in Northern Nigeria, resulting in warm weather conditions and making indoors environments thermally uncomfortable. Outside air temperature especially in April can reach 40 °C necessitating the use of air conditioners to keep a cool environment. However, this is complicated by the lack of stable energy supplies in Nigeria (Akande 2010). This makes the use of air movement to facilitate indoor comfort very attractive not only in Kano, a city in Northern Nigeria, but in all hot climates around the world (Nicol 2004). Even before the advent of fossils fuels, human beings learnt the art of excluding the effects of extreme weather from their dwelling units, in high latitude areas and elsewhere in the cold season fires were kindled, layers of clothing added to keep warm, and massive walls and roof constructed to store and utilize solar radiation. During the hot season however, lighter clothing was preferred, people changed their activities, others slept outdoors and in the daytime tree shades were sought for relaxation and hand held fans were widely used in order to keep cool (Candido, de Dear et al. 2010, Inusa and Alibaba 2017, Li, Zhou et al. 2017). Gradually buildings were made to perform environmentally with natural ventilation through openings; doors, windows and other architectural openings (Candido, de Dear et al. 2010). With the invention of electrically powered fans, ceiling and movable personal fans become popular in the hot and dry climates, and it was only in the first half of the Twentieth Century that air conditioning was invented (De Decker 2014). Although air conditioning (AC) is widely used as a means of meeting thermal comfort requirements where availability and affordability of energy permits, ceiling fans are technically simple, can be operated by non-technical occupants, are inexpensive and with relatively low electrical energy use (Aynsley 2005, Voss, Voss et al. 2013). Zhai et al. (2013) found out that the average energy consumed by the fans for maintaining comfort was lower than 10 W per person, making air movement a very energy-efficient way to deliver comfort in warm- environments. Fans are further different from ACs, because the latter provide a uniform thermal environment in a space, which may not be agreeable to all occupants, while fans, especially personal ones, allow the creation of different micro climates (Zhai, Zhang et al. 2013).

Air velocity is used to influence thermal comfort of occupants by encouraging heat loss from their bodies through convection and evaporation (McIntyre 1978, Schiavon and Melikov 2008). It is also understood from the guidance of TM52 that ceiling fans when operated under moderately controlled air speed, enhances thermal perceptions of indoor occupants (CIBSE TM52 2013). Accordingly, the guidance specifies that an air velocity of between 0.30 m/s and 0.8 m/s, raises the upper comfort temperature boundary (T_{max}). This is reiterated by the ASHRAE standard 55-2013 which states that a controlled increase in air speed from 0.2 m/s to 1.2 m/s in an occupied area raises the upper acceptable operative temperature (ASHRAE 2013).

Research further suggests that an air speed of about 1 m/s is capable of offsetting a 3°C increase in indoor temperature, and a 3 m/s effects about 7°C Aynsley (2005). Similarly Nicol & Humphreys (1973) in an analysis on thermal comfort conducted in Northern India and Iraq, found that air movement can result in the reduction of temperature by as much as 4 °C, this was further confirmed by Sharma & Ali (1986) when developing a tropical summer index with Indian subjects. These studies and similar others led the international thermal comfort standards to put forward a relationship between the comfort temperature and the increase in air velocity as demonstrated in Figure 1 (CEN 2007).

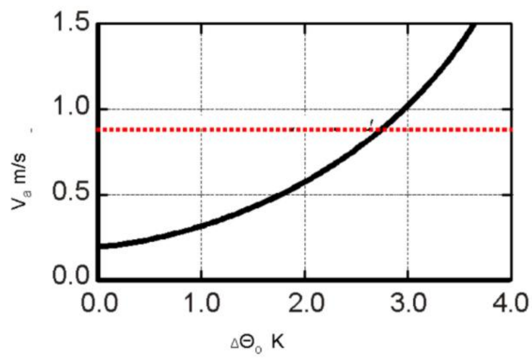


Figure 1: Air speed required to offset increased temperature (CEN 2007)

Ceiling fans are common features of interior spaces in tropical and sub-tropical regions (Nicol 2004, Candido, de Dear et al. 2010). Although the usefulness of ceiling fans is not in doubt, unlike in hot climatic regions, they are not commonly used in the temperate and the higher latitude regions. This could be partly because heating requirements are far greater than the cooling needs. However, some believe e.g. (De Decker 2014), that ceiling fan's usage and popularity were affected by the limit of 0.2 m/s indoor air movement recommended by ASHRAE standard 55 and ISO 7730, which was perhaps introduced to avoid drafts indoors. This limit is the same the whole year round, that is, for both winter and summer seasons. While in the winter, air movement indoors could be counter-productive, it is, however, desirable in the summer. Fortunately, the two last ASHRAE revisions, which brought in ASHRAE 55-2013, took care of the threshold by varying the air speed from 0.2 m/s up to 1.2 m/s, and for higher activity levels over 1.3 *met* higher air speed could be an advamtage (Nicol, Humphreys et al. 2012).

Figure 2: Photographs of learning environments furnished with ceiling fans

This paper therefore seeks to further investigate whether ceiling fans could keep the thermal comfort of an indoor environment at a reasonable level and to evaluate the levels of contribution they make in enhancing the thermal qualities of learning environments in Bayero University, Kano. This is to be achieved by evaluating levels of overheating in two selected lecture theatres, through physical measurements and survey data.

Figure 2 shows photographs of some learning environments furnished with ceiling fans in the University to facilitate indoor comfort.

FIELDWORK

This study was carried out in Bayero University, Kano (BUK). Kano, is situated on latitude 12 °N and longitude 8.17 °E, in the Savannah region of West Africa. It is the second largest and most populous city in Nigeria after Lagos. Maximum outdoor temperature reaches 40 °C in April and May and goes down to 12 °C in December and January (Mohammed, Abdulhamid et al. 2015). It receives an average of 3,117 hours of sunlight annually and it is sunny 71% of daylight hours. Relative humidity hovers between 15% and 70% and Kano receives its highest precipitation of about 900 mm in August (Inusa and Alibaba 2017). Being situated within low 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. Therefore, in Kano, the area of this research, cooling, minimizing heat gain, diversion of direct sunlight and humidification are required for indoor comfort.

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. The selected lecture theatres for the study were chosen from two campuses: New campus and Aminu Kano Teaching hospital (AKTH), and respectively from the Faculties of Earth and Environmental Sciences (FEES) and Clinical Sciences. Therefore, for brevity, the new campus theatre will be referred to as "FEES" and the one at the Teaching Hospital as "AKTH". The characteristics of the theatres are shown in Table 1.

Table 1: Design Characteristics of the Learning Environments

Characteristics of the Lecture Theatres	Capacity (seats)	Volume (m^3)	Floor area (m^2)	Average Height (m)	Window-wall orientation	No. of Ceiling fans	Floor Situation	Window – Wall Ratio
FEES	120	1,368	263	5.2	East/North/West	12	Tiered	30%
AKTH	120	1,829	381	4.8	North/South	14	Tiered	54%

Physical Measurements

During the fieldworks, both the physical measurements and surveys were conducted based on procedures consistent with ASHRAE standard 55-2013. A number of instruments were used to measure the thermal comfort parameters. Air temperature and velocity and relative humidity were spot measured and only air temperature and relative humidity were logged. Hobo MX1102 were used to log air temperature and relative humidity, 150 mm matt finished globes fitted with Hobo pendants captured the radiant temperature and Testo 435-2 meter was used for air velocity. The spot measurements were conducted in five locations, each at 1.1m above the floor. Measurements were conducted in two situations, during occupied and unoccupied conditions. Photographs of the interiors of the lecture theatres and external views are shown in Figure 3.

Figure 3: Internal and external views of the lecture theatres: Top is AKTH and bottom is FEES

Subjective Measurements (Survey)

Paper-based questionnaires were prepared containing seven sections covering; thermal, acoustic and visual comfort, indoor air quality, clothing ensembles, sketches for occupants to indicate their locations and demographic information. As part of an extended PhD work involving an assessment of the indoor environmental quality (IEQ) parameters of various learning facilities, this study is reporting the thermal comfort aspect, which is directly influenced by the air movement. A total of 459 questionnaires (123 and 336 for the AKTH and FEES respectively) were subsequently distributed, filled and collected back, on the three occasions. Seven-point Likert type ASHRAE thermal sensation scales were used to assess both the thermal conditions and the air movement in the spaces as shown in Tables 2, 3, 4 and 5.

Table 2: Thermal comfort acceptability scale

1	2	3	4	5	6	7
Very Comfortable	Comfortable	Slightly comfortable	Okay	Slightly uncomfortable	Uncomfortable	Very uncomfortable

Table 3: Thermal sensation scale

-3 Unacceptable	-2 Unacceptable	-1 Acceptable	0 Acceptable	1 Acceptable	2 Unacceptable	3 Unacceptable
Cold	Cool	Slightly cool	Neither	Slightly warm	Warm	Hot

Table 4: Thermal preference scale

-3	-2	-1	0	1	2	3
Wanting cold	Wanting cool	Wanting slightly cool	Wanting no change	Wanting slightly warm	Wanting warm	Wanting hot

Table 5: Air movement acceptability scale

-3	-2	-1	0	1	2	3
Too draughty	Draughty	Slightly draughty	Okay	Slightly still	Still	Too still

Both the physical measurement and the survey results were used in evaluating the thermal conditions of the two theatres by following the grouping method system adopted by Al-Maiyah, Martinson and Elkhadi (2015). The 7-point scale was converted into three-point scale by merging the responses in the first two categories into one 'comfortable' category and merging the last two categories into 'uncomfortable' while the three central categories formed the 'moderately comfortable'. Similarly the recommendations of ASHRAE Standard 55 (2013) and CEN 15251 (2007) were followed. Further to this, degree hour's exceedance, an indicator of overheating, was also used to determine the deviation of thermal conditions in the theatres from the CEN 15251 adaptive comfort threshold. The predicted mean vote (PMV) model and adaptive approach using operative temperature were also employed in the analysis. Similarly, the chart in Figure 1, relating the air movement and comfort temperature, were used to determine the likely contribution of the air velocity to comfort in the spaces. The values of the measured and derived thermal comfort parameters found in the spaces are displayed in Table 6. It is worth noting however that the air temperature, relative humidity and air velocity measurements in the spaces were for occupied situations, the unoccupied values are not very critical for this study, because ceiling fans were seldom used during the winter in Kano, as shown by the low air velocities.

Table 6: Measured and Derived Thermal Comfort Indices

Parameters/Theatres	FEES			AKTH		
	Aug/Sept (warm & wet)	Jan/Feb (cool & dry)	Apr/May (hot & dry)	Aug/Sept (warm & wet)	Jan/Feb (cool & dry)	Apr/May (hot & dry)
Air temp (˚C)	26.80	29.20	34.40	27.20	25.30	35.60
Standard deviation	0.82	0.31	0.25	0.73	0.44	0.26
Air velocity (m/s)	0.61	0.04	0.65	0.58	0.06	0.63
Standard deviation	0.05	0.03	0.06	0.07	0.04	0.05
External air temp (˚C)	30.40	26.40	34.80	27.90	25.40	36.50
Standard deviation	1.28	0.74	1.72	1.95	0.61	1.76
Relative humidity (%)	69.60	16.00	41.90	60.20	18.30	36.40
Standard deviation	2.48	1.03	2.29	1.06	1.87	2.52
Clothing insulation	0.66	0.72	0.65	0.65	0.71	0.60
Operative temp (˚C)	26.97	29.51	33.36	27.30	25.60	35.00
Standard deviation	0.39	2.13	1.87	0.51	1.75	1.76
Operative temp (no fan) (˚C)	27.10	29.45	32.55	27.45	25.60	34.55
Standard deviation	0.30	2.25	1.86	0.42	1.77	1.72
Running mean temp (˚C)	27.40	26.80	34.40	27.40	25.40	36.50
Predicted mean votes (PMV)	0.24	1.35	1.56	0.36	0.38	2.02
Actual mean votes (AMV)	0.57	-0.78	1.34	0.46	-1.03	1.49
Standard deviation	1.54	1.30	1.02	0.85	0.69	0.96
Neutral temp (˚C)	27.80	26.70	30.20	27.80	27.20	30.80
Comfort temp range (˚C)	24.8-30.8	23.7-29.7	27.2-33.2	24.8 – 30.8	24.2-30.2	27.8-33.8

MEASURED RESULTS

The air, mean radiant and external temperatures, air velocities and relative humidity are the main parameters measured and reported in Table 6 above. The table also contains values that were derived, including operative temperature (T_{op}), running mean temperature (T_{rm}), predicted mean vote (PMV), the adaptive neutral temperature (T_{comft}) and comfort temperature range, similarly fan modified neutral and comfort temperature range are shown. Other derived values from the questionnaires include: actual mean vote (AMV) and actual percentage dissatisfied (APD), which are processed from the results of the answers obtained from the survey questionnaires.

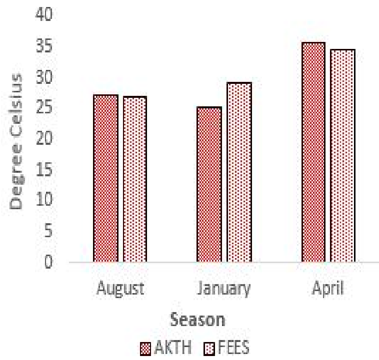
The operative temperature (T_{op}) is an important parameter in assessing the likely thermal comfort of the occupants of a building, known as dry resultant temperature, but renamed as operative temperature to align with ASHRAE and ISO standards. It is a simplified measure of human thermal perceived temperature derived from mean air temperature, mean radiant temperature and air speed (see equation 1). Where the air speed is less than 0.1m/s, the radiative and convective heat transfers may be similar, so T_{op} becomes the average of the air and mean radiant temperatures (Nicol, Humphreys et al. 2012). The calculated T_{op} with and without the influence of fans were also shown in Table 6 above.

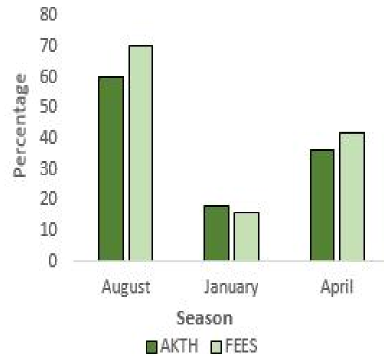
$$Top = \left(Tmr + \frac{Ta \times \sqrt{10Va}}{1 + \sqrt{10Va}} \right) \qquad \text{Equation 1}$$

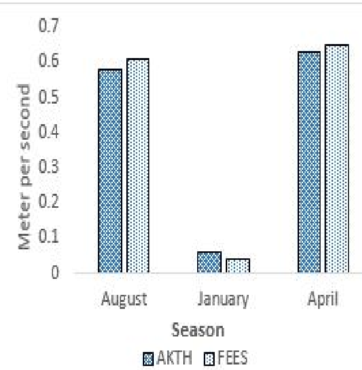
Where T_a is the air temperature, T_{mr} is the mean radiant temperature and V_a is the air speed (m/s).

The operative temperature values were obtained by processing the values of air and mean radiant temperatures in equation 1 above and were used to determine the adaptive thermal comfort temperature ranges and neutral temperature. PMV was calculated using the Centre for the Built Environment (CBE) thermal comfort tool for ASHRAE, the clothing insulation (*clo*) values were obtained from the questionnaires while the metabolic rate (*met*) of 1.2 *met* for seating and listening was used (Tyler 2013). AMV is the mean of the thermal sensation votes of all participants of a survey in a real world setting as opposed to PMV, which is laboratory based. As mentioned earlier, this study combined the three central categories (-1, 0 & +1) of the thermal sensation scale and assessed them as acceptable, while the APD was calculated from the share of the two extreme categories (-3 & -2) and (+2 & +3) from the thermal sensation votes.

Table 6 and Figure 4 reveal that the April air temperature values were the highest in both theatres, as expected, it was the hottest period of the year in Kano, with the air temperature reaching as high as 35.6 ˚C recorded in AKTH. It is understood from the table that the internal air temperatures were following the external temperatures in the spaces during mid-season and summer, but that was not the case for FEES during the winter. The air velocity values recorded were both highest and lowest in FEES and were expectedly higher in April and lowest in January, when fans are not operated, they stood at 0.65 m/s (SD = 0.06) and 0.04 m/s (SD = 0.03) respectively. The design capacities of the two theatres are equal: that is 120 seats, but the occupancy levels during the surveys were different. AKTH was occupied by about one third of its design capacity across the three surveys, while FEES was full to its design capacity on all the three occasions.







A - Air Temperature B - Relative Humidity C - Air Velocities

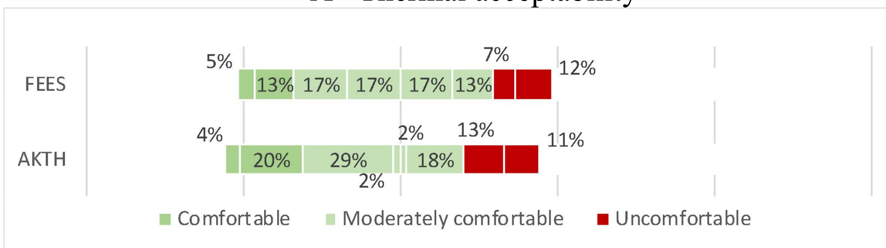
Figure 4: Seasonal Air Temperatures, Relative Humidity and Air Velocities in the Theatres

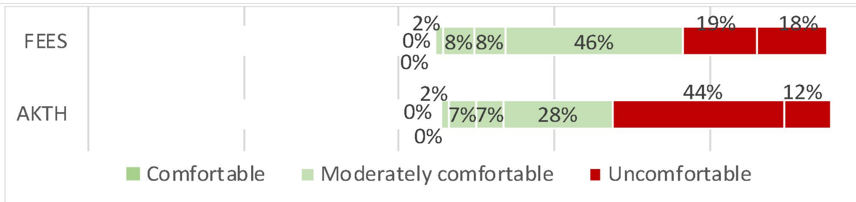
SURVEY RESULTS

The surveys were undertaken across in the three seasons, females accounted for 22% of the students-dominated respondents and 75% of them were 26 years and above. From the clothing ensembles section of the questionnaire, *clo* values were found to differ across the seasons. The highest mean value of 0.72 *clo* (SD = 0.13) was recorded in January and the least of 0.60 *clo* (SD = 0.11) was recorded in April. Whereas metabolic rate for lecturing and listening was fixed at 1.2 *met*.

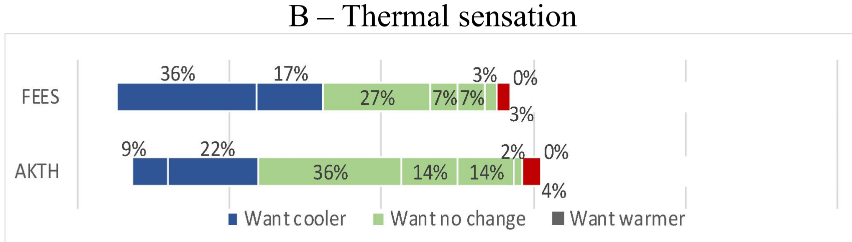
It is during the summer that the effect of high temperature is more problematic in the Kano region, therefore the analysis of the possible overheating using the subjective votes is restricted to the summer results only. It is also noteworthy that during this season ceiling fans were operated practically in every naturally ventilated building in the region, therefore the thermal acceptability levels in both spaces were calculated based on this fact. The levels of thermal acceptability shown by the respondents in AKTH and FEES were respectively 75% and 81%. Indoor climates of the learning environments during the survey were on average four degrees warmer than the ASHRAE comfort standard prescriptions but caused less thermal discomfort than expected. However, despite the high levels of acceptance, 56% and 37% of the respondents reported that the theatres were respectively "hot". On the question of their preferences, 30% in AKTH and 53% in FEES preferred cooler environments, and surprisingly up to 5% of them in AKTH wanted to be warmed. In AKTH up to 96% of the respondents were happy with the air speed of 0.63 m/s while 80% showed their acceptance of 0.65 m/s air speed in FEES. Figure 5 shows the thermal acceptability, sensation, preference and acceptability of air movement of the students in both theatres during the season.

A- Thermal acceptability

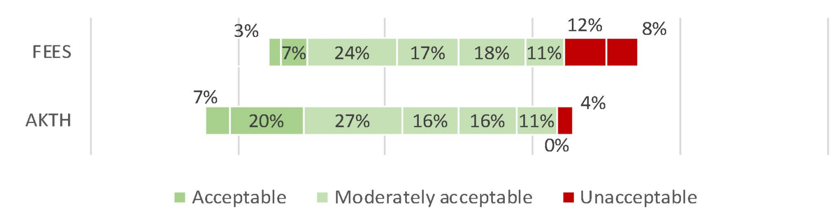




B – Thermal sensation



C – Thermal preference



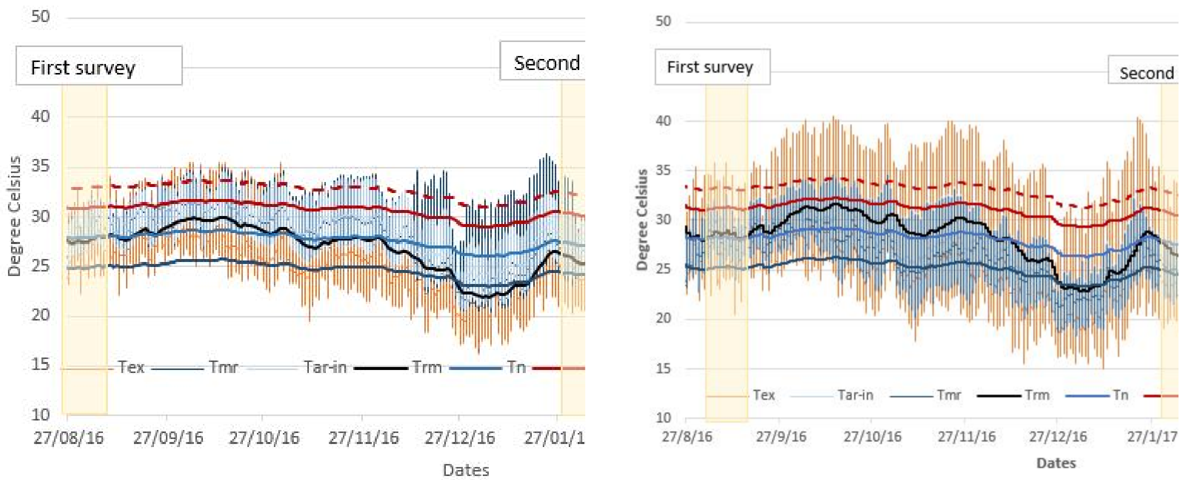
D – Air movement

Figure 5: Thermal Acceptability, Sensation and Preference and air movement during the Summer

Overheating Analysis

A space is said to be overheated during the occupied hours when the operative temperature exceeds a threshold comfort temperature and the severity of the overheating in any given day is a function of its duration and a rise in temperature above the threshold (CIBSE TM52 2013). TM52 (2013) offers a pass mark to any indoor space that meets any two of the following three criteria:

- Threshold temperature should not be exceeded by more than 3% of occupied hours per year;
- Daily weighted exceedance shall be less than or equal to six-degree hours; and
- Operative temperature not exceeding the threshold upper limit (T_{upp}).



A - AKTH temperature time series B - FEES temperature time series

Figure 6: Temperature time series of the theatres

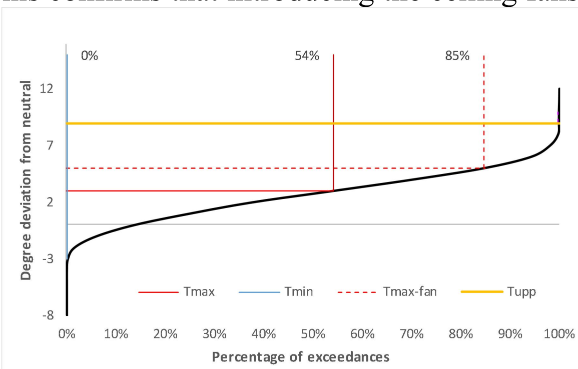
The charts in Figure 6 above show the temperature time series of AKTH and FEES respectively, for the entire period of the fieldworks, bounded by upper and lower temperatures (T_{max} and T_{min}). Various other values of temperatures were displayed in the charts, external (T_{ex}), internal ($T_{ar\text{-}in}$), mean radiant (T_{mr}), running mean outdoor (T_{rm}) and fan assisted modified upper ($T_{max\text{-}fan}$). The upper limit temperature (T_{max}) as defined by the international comfort standards was found to be raised because of the action of the ceiling fans in the spaces by 2 °C ($T_{max\text{-}fan}$). Using the running mean temperature (T_{rm}) as an indicator, it can be seen from the charts that, for the majority of the period the T_{rm} was within the original comfort zone, in line with the adaptive comfort approach (ACA) for 80% acceptability (see Equations 2 and 3) (CEN 2007). However, in both spaces, the T_{rm} crossed the T_{max} in FEES theatre from March, 26 onwards and from April 02, in AKTH. However, due to the fans' action the theatres became acceptable, as can be seen from the charts that the T_{rm} did not cross the new limit ($T_{max\text{-}fan}$).

$$T_{min} = 0.33T_{rm} + 15.8 \quad \text{Equation (2)}$$

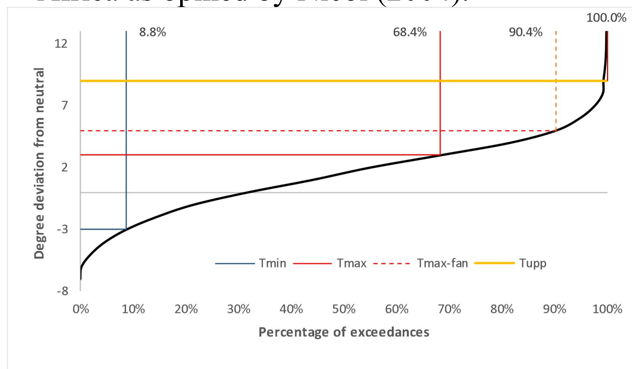
$$T_{max} = 0.33T_{rm} + 21.8 \quad \text{Equation (3)}$$

Where T_{min} and T_{max} are the lower and upper ranges of allowable temperatures for 80% acceptability limits and T_{rm} is the exponentially weighted running mean outdoor temperature (CEN 2007).

The charts in figure 7 below shows the percentages of exceedances (x-axis) and number of degree deviation away from the neutral temperature (y = 0) in AKTH and FEES respectively for the occupied period of the surveys. The charts indicate the percentages of times in the theatres crossed the T_{max} for the entire period. The dotted and yellow lines in the charts ($T_{max\text{-}fan}$ and T_{upp}) denote the action of ceiling fans in the theatres as a result of which overheating was reduced by 31% and 22% in AKTH and FEES and reduces discomfort to 15% and 10% of the time respectively. The charts in Figure 8 however, show the percentage of degree day's exceedances the internal temperatures led to overheating, but the fans' actions reduced the discomfort to less than 5% in both spaces. This confirms that introducing the ceiling fans can improve the thermal qualities of naturally ventilated indoor spaces even in sub-Saharan Africa as opined by Nicol (2004).

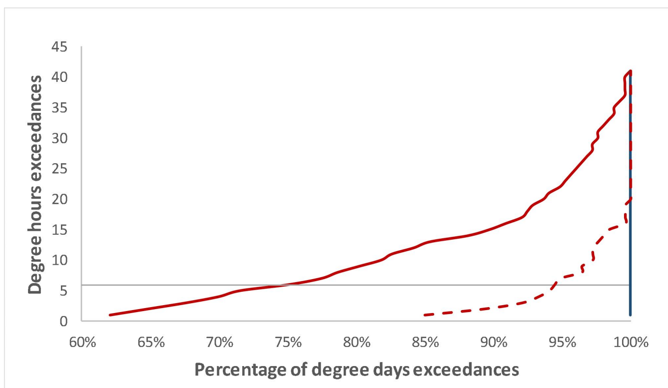


A - AKTH Theatre

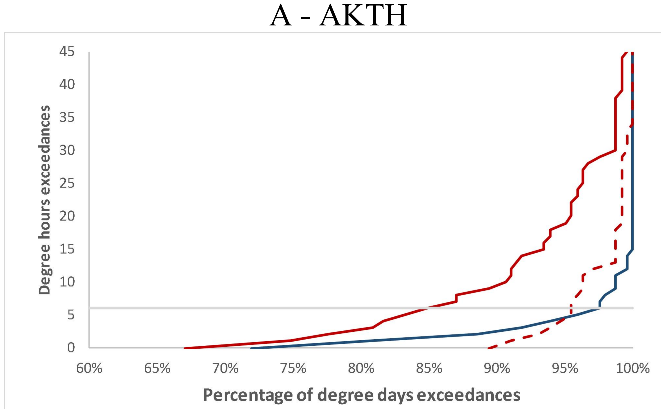


B - FEES Theatre

Figure 7: Percentage of exceedances in the theatres



A - AKTH



B - FEES

Figure 8: Percentage of degree day's exceedances in the theatres

DISCUSSION

The ASHRAE Standard 55-2013, which sums up the recommendations of the major international comfort standards, specifies the values of air velocity required to compensate for elevated temperatures. These values range from 0.2 m/s up to 1.2 m/s are said to offset elevated temperatures above summer comfort threshold under occupant control up to a limit of 30 °C. The results and subsequent analysis from this study indicate that the overall thermal sensation in both theatres was warm during the summer. These values were arrived at using PMV model, following the provisions of the thermal comfort standards such as (ISO 7730 2005). Similarly, the overheating analysis from Figures 6, 7 and 8 also confirmed that the two spaces were overheated during the season, however the cooling effect brought about by the action of the ceiling fans made them acceptable to vast majority of the occupants. The increment of 2 °C in comfort temperature because of the elevated air speed was obtained using the ASHRAE 55 or ISO 7730 or CEN 15251 charts from Figure 1. It is to be noted that the highest air velocity measured during the surveys in this study was 0.65 m/s, which offset 2 °C, it therefore means that only about 1.3 °C could further be offset should the air velocity reach the allowable 1.2 m/s using the same chart.

The study found differences in magnitude in the results of AMV with those of PMV during the surveys. This is shown by correlating the differences in thermal mean votes (PMV minus AMV) against the air velocity, the regression line depicts a strong negative relationship, meaning that with an increase in air velocity the difference between the two indices reduces (see Figure 9). This is in agreement with studies conducted in similar climatic regions of the world (Brager, Paliaga et al. 2004, Nicol 2004, Candido, de Dear et al. 2010, Zhai, Zhang et al. 2013). The results of the AMV during the surveys were different to those of PMV model, though the differences were not so large, it still shows that PMV/PPD model predicted a warmer perception than was found in actuality during both summer and winter, this is also in agreement with especially the adaptive thermal comfort studies around the world (Humphreys and Nicol 2002, Buratti and Ricciardi 2009, Nicol, Humphreys et al. 2012).

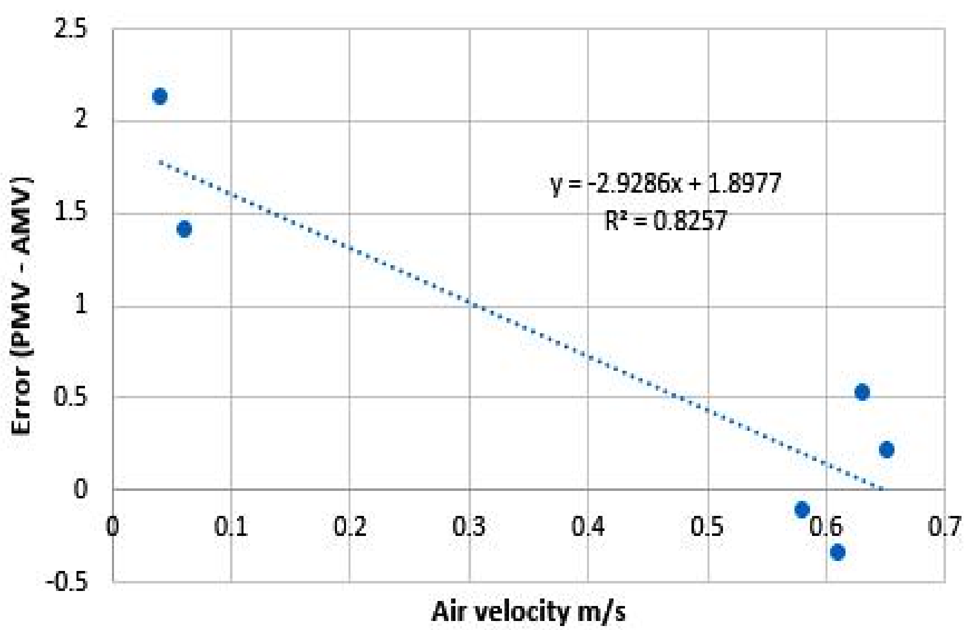


Figure 9: Air velocity versus thermal mean votes (PMV – AMV)

The summer PMV model results from the spaces (1.56 and 2.02 for FEES and AKTH respectively) clearly show that the spaces were uncomfortably warm, while the AMV results show they were slightly warm. On the other hand, the requirements of the adaptive thermal comfort approach of CEN 15251 (2007) for buildings type II stated that the operative temperatures (T_{op}) in indoor spaces should lie within the upper and lower boundaries (T_{max} and T_{min}) of the calculated comfort range temperatures. From the same Table 6 above, it can be seen that the calculated T_{op} in the spaces across all the seasons, with exception of AKTH during the summer, fell within the said boundaries. However, when the $T_{max\text{-}fan}$ was introduced as a result of fan action, the thermal conditions in AKTH also become acceptable. The lowest boundary of the comfort range during the winter was 23.7 ˚C, while the upper boundary during the summer was 33.8 ˚C. This adequately contained the highest point reached by the T_{op} and therefore signifies that EN 15251 could therefore be used in predicting thermal conditions in Kano region.

Nevertheless, it seems that the provisions made by international comfort standards were done with less consideration of the sub-Saharan Africa in mind. For example, using these standards' recommendations, the data presented in Table 6 and Figures 6, 7 and 8 indicate that the spaces were overheated during the summer, and although the ceiling fans had greatly enhanced their thermal qualities and became acceptable to most of the occupants, the spaces still did not satisfy all the three overheating criteria recommended by CIBSE TM52. This could be explained by the fact that this comfort standard considered only the UK situations when compiling the thresholds. Similarly, one of the acceptability conditions imposed by ASHRAE 55 on prevailing mean outdoor temperature limit is a range of between 10 °C and 33.5 °C, and in this study all the mean summer temperatures recorded were found to be above this limit.

CONCLUSION

The study investigated the possibility of overheating in two lecture theatres in Bayero University, Kano, and how ceiling fans raised the levels of their thermal acceptability. Various physical parameters were measured which culminated in calculating comfort indices and concurrently the occupants were subjected to a survey to determine their actual comfort perceptions. The physical measurements and surveys were conducted from August 2016 to May 2017 and comparisons were made between the experimental and surveyed data obtained from the theatres as well as against thresholds of relevant international comfort standards. In line with the results obtained by previous thermal comfort studies, this study also found discrepancies between the measured indices and the perceived results, as well as with the comfort standards' thresholds. The PMV/PPD model overestimated the thermal perceptions of the respondents in both summer and winter. This divergence may not be unconnected with the situations of the dominant climatic conditions of the region under study, which were found to be outside the acceptability limits of the comfort standards. The theatres were found to be hot based on the results of the thermal indices recommended by the standards, however the use of ceiling fans (though operated at 0.65 m/s and below) was found to be very productive, it raised the T_{max} by 2 °C and thereby enhanced the thermal conditions of the theatres. It is however believed that higher air velocity than what this study obtained can further enhance the thermal qualities of buildings in Kano region.

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