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Original Research Article

Ergonomics Impact of Indoor Air Temperature in Thermal Comfort of Tertiary Institutions' Classrooms in Abeokuta, Nigeria

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ABSTRACT

This study presented the results of the impact of indoor air temperature in thermal comfort of tertiary institutions' classrooms in Abeokuta, Nigeria. This was conducted between December 2017 and May 2018 between the hours of 8.00 and 16.00. A total of twenty (20) classrooms were assessed for meteorological indoor conditions: air temperature (T_a), relative humidity (RH), air velocity (V_a). Three thousand five hundred questionnaires were administered to students to determine their thermal condition during lectures. Furthermore, a regression model as a function of the measured air temperature (T_a) was also used to estimate the radiant temperature (T_r) and operative temperature (T_o). The results showed that 34.24±2.5°C, 51.85±5.1%, 0.5±0.12m/s, 33.80±2.5°C and 34.07±2.5°C were recorded respectively for the indoor conditions of T_a, RH, V_a, T_r, and T_o. Moreso, the result showed that 22.6 and 15.1% of the students felt warm and slightly warm with 13.5 and 10.1% experiencing hotness and very hot conditions. Some students (11.5 and 7.6%) felt slightly cool and cool with 1.75% of the students experiencing neutrality with the indoor meteorological conditions. The study established that the human responses to the thermal environment are inherently difficult to predict due to subjective assessment of indoor users. These have a considerable effect on comfort and health of the students during lecture.

1. INTRODUCTION

Thermal comfort (TC) can be defined as the situation in which individual or group of people feel neither extremely cool nor extremely hot in a particular environment. This could be termed as the "condition of mind which expresses satisfaction with the environment" of the individual (ASHRAE 2010). Several parameters could be used to determine thermal comfort of an individual and these includes physiological, psychological or subjective parameters (Musa et al., 2015a). These parameters do depend on many factors which includes air temperature (Ta), radiant temperature (Tr), air velocity (Va), relative humidity (RH) of the environment etc (Musa et al., 2017).

Air movement in a classroom has a great impact on the feelings and thermal preference of the students (Modeste et al., 2014). Thermal comfort is a very important factor for human health and if not properly looked into, it can lead to unforeseen situation or circumstances such as death (Musa et al., 2015b). The international standard (ISO 10551,2001) provided the conditions under which more people in good health will find a given environment comfortable (Modeste al., 2013). The TC condition in a ventilated classroom may be assessed through the air flow pattern and its velocity, the temperature distribution and the air quality (Stamou and Katsiris, 2006).

Good indoor conditions will not only make its occupants comfortable but promote the energy saving and its sustainability (Nicol and Humphreys, 2004). Natural ventilation implies that air is supplied and removed from the indoor space of a classroom by natural means. TC studies in classrooms have been conducted under two methodologies; objectives survey (predicted mean vote (PMV) and predicted percentage dissatisfied (PPD)) and subjective based on thermal sensation votes (TSV) and thermal preference votes (TPV) (Ledisma and Hamza, 2017).

The objective of this study is to determine the impact of the quality indoor air temperature of tertiary institution's naturally ventilated classrooms in Abeokuta, Nigeria.

2. MATERIALS AND METHODS

2.1. Site Selection and Instrumentation

The experimental study was carried out in four tertiary institutions in Abeokuta. The institutions include Moshood Abiola Polytechnic Ojere, Federal University of Agriculture Alabata, Federal College of Education Osiele and Adegbenro ICT Polytechnic Itori. A total of twenty (20) classrooms were assessed for meteorological indoor conditions. Three thousand five hundred (3,500) questionnaires were administered to students to determine their thermal condition during the lecture period across the selected tertiary institutions using random sampling technique between December 2017 and May 2018 at 8:00hrs and 16:00hrs. Three environmental parameters, which include air temperature (Ta), air velocity (Va) and relative humidity (RH), were measured while the students were administered the questionnaire.

Air temperature (Ta) and Relative Humidity (RH) were measured with GM013-Thermo-Hygro indoor/outdoor, Max/Min Thermometer-Hygrometer with external sensor (Shenzhen Kai Heng Jie Technology Ltd, China) (Figure 1). The Am-4201 microprocessor digital anemometer (Lutron Electronics Enterprise co Ltd, Taiwan.) was used to record the air velocity (V_a) at sixty minutes intervals. This meter was placed 1.2m from the ground for measuring directly to avoid obstacle (Figure 2).

Figure 1: GM013-Thermo-Hygro Indoor / outdoor, Max/Min thermometer-Hygrometer with external sensor (Musa et al., 2018)

Figure 2: Am-4201 Vane probe digital anemometer (Musa et al., 2018)

The mean radian temperature (T_r) was estimated using the following regression model as a function of the measured air temperature (T_a) (Nagano and Mochida, 2004).

$$T_r = 0.99Ta - 1 \quad (1)$$

The operative temperature (T_o) was also determined from the measured air temperature (T_a) and the mean radiant temperature (T_r) with Equation 2 (ASHRAE/ANSI 55R, 2004).

$$T_o = AT_a + (1 - A)T_r \quad (2)$$

Where the weighting factor (A) depends on air velocity (V_a), A = 0.5 for $V_a < 0.2$m/s; A = 0.6 for $0.2 < w < 0.6$m/s; A = 0.7 for $0.6 < w < 1$m/s (ASHRAE/ANSI 55R, 2004).

2.2. Questionnaire Survey

A questionnaire administered was to obtain the necessary information on the subjective responses of thermal sensation, thermal comfort, acceptance and satisfaction. The thermal sensation votes (TSV) was on 11-point scale from extremely hot to extremely cold. Thermal comfort votes (TCV) consists of a 4-point scale from comfortable to not-comfortable while thermal acceptability votes (TAV) and satisfaction votes (TSatV) were on a 2-point scale of acceptable, unacceptable, satisfied and dissatisfied respectively. The students were interviewed every hour to capture their thermal behaviour of the environment during the activities. The data collected was subjected to descriptive statistics and multi-linear regression analysis using SPSS software version 23 and Microsoft Excel 2013.

3. RESULTS AND DISCUSSION

The measured meteorological parameters were used to calculate the predicted mean vote (PMV) and predicted percentage dissatisfaction (PPD) as presented by the UNI EN ISO 7730 (2006). The classroom has its function as both theoretical class and practical hours that needs concentration and the relaxed mind for their performance thus highlighting the need of a thermally comfortable indoor environment.

Table 1 to Table 3 show the recorded average hourly values of air temperature (T_a), Air Velocity (V_a) and relative humidity (RH) respectively. Table 4 below shows the calculated operative and radiant temperature (T_o and T_r) and also showed the monthly cumulative hourly value of the meteorological parameters recorded. Table 5 shows the average descriptive statistics (Mean, Min, Max, and Standard Deviation) values of the meteorological conditions which were recorded around the classrooms of the selected institutions respectively.

Table 1: Average hourly T_a (°C)

Time	December 2017	January 2018	February 2018	March 2018	April 2018	May 2018
8:00hrs	26.3	28.1	31.7	33.4	30.9	28.1
9:00hrs	28.9	30.1	33.3	35.4	33.5	29.3
10:00hrs	31.6	33.1	34.5	37.2	33.7	31.7
11:00hrs	32.6	34.6	36.3	38.5	37.0	33.6
12:00hrs	34.8	37.0	37.6	39.5	36.8	35.5
13:00hrs	36.5	38.2	37.4	39.2	37.1	34.7
14:00hrs	37.1	36.8	36.0	37.7	35.6	33.4
15:00hrs	35.8	36.0	35.1	34.8	34.1	31.9
16:00hrs	33.8	34.4	33.0	33.3	32.1	31.0

Table 2: Average hourly V_a (m/s)

Time	December 2017	January 2018	February 2018	March 2018	April 2018	May 2018
8:00hrs	0.5	0.3	0.3	0.3	0.4	0.3
9:00hrs	0.4	0.4	0.4	0.4	0.3	0.4
10:00hrs	0.5	0.4	0.4	0.4	0.4	0.5
11:00hrs	0.4	0.4	0.4	0.4	0.4	0.5
12:00hrs	0.6	0.6	0.7	0.6	0.5	0.6
13:00hrs	0.5	0.4	0.5	0.5	0.5	0.5
14:00hrs	0.5	0.7	0.8	0.7	0.7	0.6
15:00hrs	0.6	0.6	0.7	0.7	0.7	0.6
16:00hrs	0.5	0.6	0.5	0.6	0.6	0.7

Table 3: Average hourly RH (%)

Time	December 2017	January 2018	February 2018	March 2018	April 2018	May 2018
8:00hrs	58.70	67.25	55.75	65.65	60.00	69.50
9:00hrs	52.95	60.90	50.65	60.05	55.00	64.15
10:00hrs	46.15	53.00	47.20	55.80	51.00	58.50
11:00hrs	44.90	48.20	41.20	50.10	43.00	51.40
12:00hrs	53.45	53.15	39.60	49.40	45.00	49.05
13:00hrs	59.65	58.40	37.90	50.45	44.00	50.30
14:00hrs	62.90	61.50	37.55	51.50	45.00	51.55
15:00hrs	53.90	55.35	37.55	47.60	44.00	54.60
16:00hrs	49.50	54.55	37.95	50.35	46.00	57.05

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Table 4: Average meteorological and calculated values of T_r and T_o conditions for the experiment

Time	T_a (°C)	T_r (°C)	T_o (°C)	RH	V_a	A
8:00hrs	29.65	29.25	29.49	62.80	0.35	0.6
9:00hrs	31.75	31.33	31.58	57.28	0.38	0.6
10:00hrs	33.63	33.19	33.45	51.94	0.43	0.6
11:00hrs	35.43	34.98	35.25	46.47	0.42	0.6
12:00hrs	36.87	36.40	36.68	48.28	0.60	0.6
13:00hrs	37.18	36.71	36.99	50.12	0.48	0.6
14:00hrs	36.10	35.64	35.96	51.67	0.67	0.7
15:00hrs	34.62	34.17	34.49	48.83	0.65	0.7
16:00hrs	32.93	32.50	32.77	49.23	0.58	0.6

Table 5: Descriptive statistics for meteorological conditions

	N	Minimum	Maximum	Mean	Std. Deviation
Air Temperature (°C)	9	29.65	37.18	34.2400	2.49842
Air Velocity (m/s)	9	0.35	0.67	0.5067	0.12042
Relative Humidity (RH)	9	46.47	62.80	51.8467	5.12463
Radiant temperature (°C)	9	29.25	36.71	33.7967	2.47509
Operative Temperature (°C)	9	29.49	36.99	34.0722	2.49230

The air temperature was at its peak value of 37.18 °C at 13.00 hrs. The temperature variation in the indoor environment varies according to the movement of sun and the heat penetration through window opening (Modeste et al., 2014). The air velocity was also at its peak of 0.67 m/s at 13.00 hrs. Similarly, the result shows the relative humidity - time graph with highest humidity of 62.80% recorded in the morning around 08.00hrs. This is due to the moisture air content at that period and it varies as the. In the afternoon as the sun moves towards west and due to the surface cooling of the ground floor, the ambient temperature is less. The elevated air temperature reduced the humidity in the noon (Musa et al., 2018).

The concept of adaptation has been introduced in the thermo-hygrometric comfort evaluation (UNI EN ISO 7730, 2006). De Dear and brager (1998) model used the percentage dissatisfaction (PD) calculation with objective to compare the results with other approaches. The present empirical equation 1 and 2 above allow calculating the radiate and operative temperature as a function of the indoor air temperature (T_a). The difference between the calculated value and the experimental value was less than 0.1°C.

3.1. Subjective Approach

The subjective questionnaire was completed by interviewing each student every hour to determine the level of acceptability of the environmental conditions during the lecture period. The ISO extended 11-point of the thermal sensation scale was used (ISO 10551, 2001). Each student gave ratings of thermal sensation, comfort, acceptance and satisfaction (Figures 3 to 6).

The study revealed that the air temperature was the room temperature and the level of the air infiltration into the classroom was normal according to the ASHRAE standard of the air comfort in a natural ventilated building. The human physiological and subjective responses were observed with 3500 participants in various meteorological conditions over 6 months. It is very difficult to determine the constant relationship between the human responses and indoor conditions.

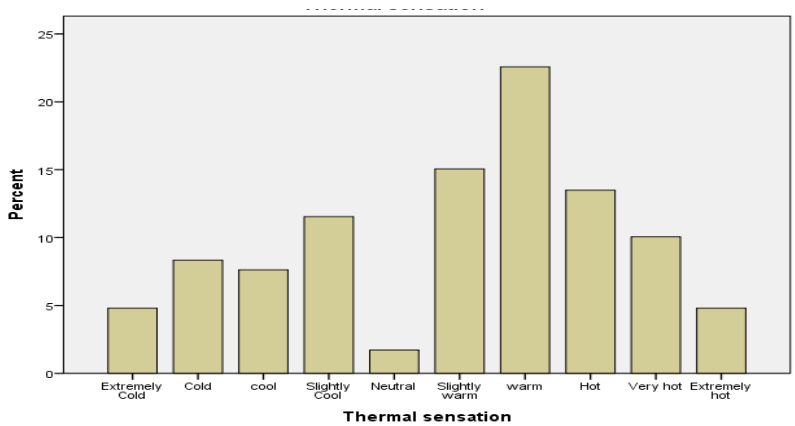

Figure 3: Thermal sensation votes (TSV)

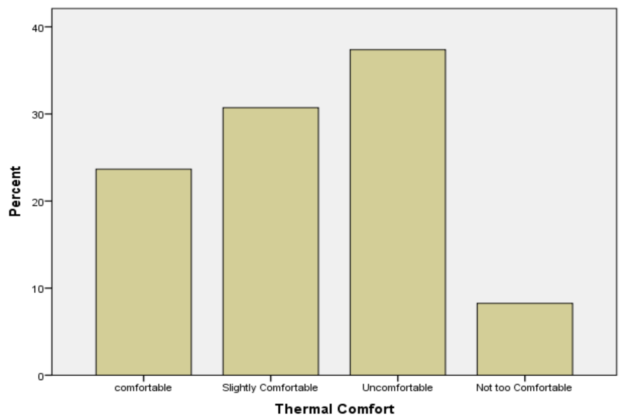

Figure 4: Thermal comfort votes (TCV)

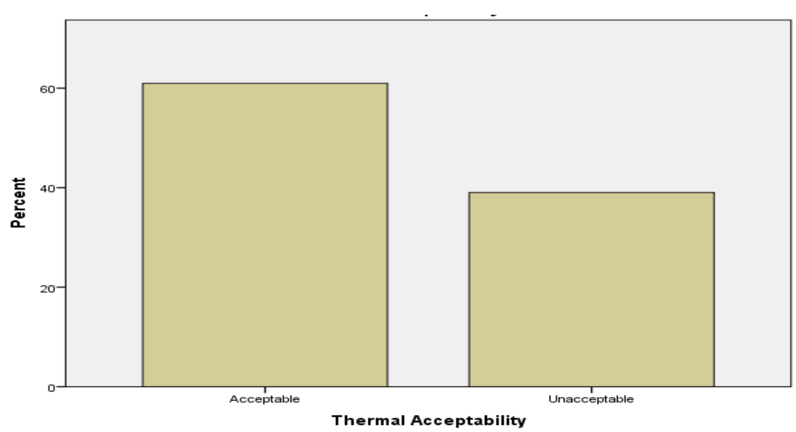

Figure 5: Thermal acceptability votes (TAV)

Figure 6: Thermal satisfaction votes (TSatV)

The meteorological conditions of Ogun State, Nigeria were mild from December, 2017 to May, 2018. Table 5 showed that the average mean air temperature was 34.24±2.5^{0}C and the average mean relative humidity was 51.85±5.1%. At high humidity levels, skin moisture tends to increase discomfort, particularly skin moisture that is physiological in origin (water diffusion and perspiration) (Berglund, 1998). As a matter of fact, relative humidity affects the evaporation from the skin, which is the prevailing way of heat loss at high air temperatures, normally from 26°C (Musa et al., 2017). At lower relative humidity, more sweat is allowed to evaporate from the body, while at higher values it is harder for this process to happen, because the air's moisture content is already elevated (La Roche, 2011). Therefore, very humid environments (relative humidity > 70-80%) are usually uncomfortable because the air is close to the saturation level, thus strongly reducing the possibility of heat loss through evaporation (Wolkoff and Kjaergaard, 2007). On the other hand, very dry environments (relative humidity< 20-30%) are also uncomfortable because of their effect on the mucous membranes (Wolkoff and Kjaergaard, 2007). At high humidity levels, thermal sensation alone is not a reliable predictor of thermal comfort (Tanabe et al., 2002). The discomfort appears to be due to the feeling of the moisture itself, increased friction between skin and clothing with skin moisture (Gwosdow et al., 1986). To prevent warm discomfort, ASHRAE (2001) recommended that on the warm side of the comfort zone, the relative humidity should not exceed 60%. The air velocity seems to have a tendency of cutting across the two seasons (dry and wet). The fluctuation between the highest mean air velocity, 0.7 m/sec and the lowest 0.4 m/sec was very minimal and it may be considered that particular tendencies existed. The average mean air velocity throughout the research period was 0.5±0.12 m/s. Furthermore, these students were interviewed to capture the thermal behaviour of the environment while attending lectures. The ISO 11-point extended thermal sensation votes (TSV) was used (ISO10551, 2001) and extended between extremely cold and extremely hot. The students noted their thermal comfort, acceptance and satisfaction. The TSV showed that 22.6% and 15.1% of the students showed felt warmed and slightly warmed. It also showed that 13.5% and 10.1% of the students experienced hotness and very hot meteorological conditions respectively. Modeste et al. (2013) reported that 41.7% of students in his research voted for warm while 15.4% agreed on the cooler environment and 37.5% preferred neutrality in the weather conditions. Similarly, 11.5% and 7.6% felt slightly cool and coolness with 1.7% experienced neutrality of the indoor conditions of the classroom. The results showed that 23.7%, 30.7%, 37.4% and 8.3% of the students were comfortable with the meteorological conditions while others were slightly comfortable, uncomfortable and not too-comfortable. Similarly, the study also showed that 61.0% of the students accepted the classroom meteorological condition while 39.0% respectively were considered unacceptable. Modeste et al. (2013) observed in his research that 75.17% of students found their environment acceptable while 24.83% find the environment not acceptable. While comparing with present study, it was discovered that the result indicated that the subjective judgment on the thermal acceptance is influenced not only by the thermal environment but also by other factors. Poor air quality could be considered as such factor (Musa et al., 2015a). In addition, 61.1% of the students were satisfied with the indoor condition of the classroom while 38.9% were unsatisfied respectively and this could affect the performance of the students. Cornaro et al. (2011) reported that occupants can recognizes the discomfort caused by poor air quality while they seem to related their thermal dissatisfaction to some other effect most probably to poor air quality. Students appear less satisfied about the environment during lecture. This is essentially due to the higher class occupancy and ventilation. Lower occupancy was also responsible for a better air quality (Cornaro et al., 2011)

4. CONCLUSION

The study on TC was conducted in the classroom for understanding the acceptability conditions of the occupants. The study established that the comfort of the students and lecturers during lecture is affected by meteorological condition and could provide a guide on those conditions required for student performance. Human responses to the thermal environment are inherently difficult to predict due to subjective assessment of indoor users. These responses have a considerable effect on comfort, health and behaviour. Some architectural recommendations through building materials can be adopted to improve the indoor thermal comfort along with passive techniques. Future research could also be conducted and considered in a wider range of meteorological conditions. So, more data collection would also be needed for quantifying human responses to indoor thermal condition. Air temperatures and air velocity seems to be fluctuated by meteorological conditions and the set point of temperatures could be different depending on the season and hot or cold environment.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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