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# An assessment of Users' Satisfaction with the Thermal Comfort of Selected Lecture Theatres in Ahmadu Bello University Zaria, Nigeria

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## Abstract

*Thermal discomfort in lecture theatres can create unsatisfactory conditions for effective learning. Achieving a thermally comfortable indoor environment in any building is of great importance for all building users. However, this has become a complex task in educational buildings. This study assessed the thermal comfort parameters in 6 lecture theatres of the main campus of Ahmadu Bello University, Zaria. The study adopted both the objective and subjective approach of thermal comfort assessment. Checklist was used to characterize lecture theatres while measuring devices were used to collect data on air temperature, relative humidity, and air velocity. A total 510 questionnaire was used to collect data on users' perception on thermal sensation. Findings from the objective assessment for morning and afternoon sessions, showed that the indoor air temperature, relative humidity, and air velocity were in the range of 27.53$^{o}$C to 35.59$^{o}$C, 35.29% to 55.34%, and 0.01 m/s to 1.23 m/s respectively. Findings from the subjective assessment showed the thermal sensation vote to be 28.4% and 18.6% for morning and afternoon votes respectively. Results from the inferential statistical analysis showed significant differences ($p \leq 0.05$) in the mean value of the thermal comfort parameters measured across all the theatres. The study recommended that natural ventilation should be adequately augmented with sufficient mechanical ventilation systems in the lecture theatres to enhance the thermal condition of the indoor spaces. Also, future designs of lecture theatres should comply with accepted standard for achieving optimum thermal comfort.*

**Keywords:** Air velocity; Relative Humidity; Temperature; Thermal Comfort; Lecture Theatre; User's Satisfaction.

## Introduction

The quality of the indoor space of a building affects the comfort, health and productivity of the occupants. Creating a thermally comfortable environment is one of the important factors to be considered when designing buildings. According to López-Pérez, Flores-Prieto and Ríos-Rojas (2019) the educational environment in the humid tropical region is often confronted with the issues of heat gain reduction in the building indoor space. However, this is due to high temperature, relative humidity and low air movement in the building indoor space. Norfadzilah, Rosli, Ahmad and Tanti (2015) asserted that when there is no adequate heat gain reduction mechanism in buildings, the thermal condition becomes inadequate which often results in thermal discomfort affecting the indoor quality of the building. According to Djamila (2017) the thermal condition of the building indoor space affects the quality of indoor space. Therefore, buildings are generally built to conform to the prevailing climate and provide an internal and external surrounding to support the livelihood of its occupants by providing safety, health and comfort (Saliu, Sagada, Abdullahi & Evanero, 2015). More so, the concept of thermal comfort is very important in students' learning environment as it affects the student's health, productivity and wellbeing (Abubakar & Alibaba, 2018). According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE, 2014), the term "thermal comfort" is defined as the condition of mind that expresses satisfaction with the thermal environment.

According to Ibrahim, Ishaq, Muhammad and Maksha (2014) achieving overall thermal comfort in a building is a complex task. However, in deciding what people find thermally comfortable, one must consider a range of environmental and personal elements. The importance of comfort in the blueprint of a building has been widely translated into numerous comfort indices of which the most influential are environmental and personal factors, such as air temperature, air velocity, relative humidity, average radiant temperature, clothing insulation and metabolic rate (Abubakar & Alibaba, 2018). Thermal comfort is therefore a central element of the quality of indoor environments. According to Andersen, Fiero and Kumar (2016), the major academic activity of students in a school building is learning which is often affected by indoor environmental quality (IEQ). Thermal condition in learning environment has to be considered carefully not only because of the high occupant density in lecture theatres, but also the negative influences that an unsatisfactory thermal environment has on learning and performance.

Consequently, the conditions in a building have direct effect on the comfort and productivity of the occupants as people spend about 80–90% of their time indoors and hence this calls for periodic evaluation of the effects of the environment on students' academic activities in schools (De Giuli, Valeria, Pontarollo, Chiara, De Carli, Michele, Di Bella, & Antonino, 2012; Laskari, Carducci, Isidori, Senzacqua, Standardi, & Cristalli, 2017; Berquist, Ouf & O'Brien, 2019). López-Pérez *et al*. (2019) opined that since the learning environment like the lecture theatre is a space where learners and educators congregate for extended periods of time to participate in the activities of teaching and learning, the environment created during these activities is considered as an important part in the teaching and learning process.

Many researchers have considered the human comfort in indoor environments (Rupp, Vásquez, & Lamberts, 2015), thermal comfort sensation (Frontczak & Wargocki, 2011; Albatayneh, Alterman, Page & Moghtaderi, 2016) and different thermal comfort approaches (Laskari *et al*., 2017) with a view to provide occupant comfort in buildings. The learning environment such as the lecture theatre is one of the spaces that demand attention as it relates to student's well-being and learning performance. The need to ensure proper thermal comfort consideration in educational buildings in today's world motivated this study. Additionally, motivation for the study originated from increased concerns raised by previous studies like those of Manzuma and Awesiri (2020), Manzuma and Ufwai (2020), Adekunle, Manzuma and Stanley (2020), Manzuma, Mbamali, Stanley and Sani (2018), Manzuma, Mbamali, Stanley and Sani (2017a) and Manzuma, Mbamali, Stanley and Sani (2017b) about the need to cut down on greenhouse gas emissions. Hence, this study aims at assessing the thermal comfort user's satisfaction with a view to establishing the thermal comfort level and users' satisfaction in lecture theatre Ahmadu Bello University Zaria, Nigeria.

## Thermal Comfort in Buildings

The International Organization for Standardization (ISO) (2006) and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) (2017) define thermal comfort as that condition of mind that expresses satisfaction with thermal environment. According to Lança, Coelho and Viegas (2019) the primary criteria for thermal comfort of the human body as a whole can be summed up into environmental parameters such as air temperature, radiant temperature, humidity and air speed and personal parameters such as clothing and activity.

The accuracy of any thermal comfort assessment in buildings requires that many variables that affect the thermal performance of a building are taken into consideration. According to Alterman, Page, Moghtaderi and Zhang (2015) these variables are constantly changing due Phyto the dynamic nature of weather conditions which becomes difficult to accurately predict the thermal comfort performance. Therefore, to conduct an accurate assessment of thermal performance of a building, an account must therefore be taken of the building as a complete system under the variable external conditions such as outdoor temperature, outdoor relative humidity and air flow (Alterman, Moffiet, Hands, Page, Luo & Moghtaderi, 2012). Moreso, Rupp, Vásquez and Lamberts (2015) asserted that air temperature and air humidity are the most common factors considered as indicators in the conventional design process for thermal comfort. Moreso, Rupp, Vásquez and Lamberts (2015) asserted that air temperature and relativehumidity are the most common factors considered as indicators in the conventional design process for thermal comfort. The most commonly used index of thermal comfort are air temperature, relative humidity and air velocity (Health and Safety Executive, 2014). Arif, Katafygiotou, Mazroei, Kaushik and Elsarrag (2016) asserted that thermal comfort consistently came as the number one complaint by building occupants over other indoor environmental attributes namely; air cleanliness, odour, and noise especially in the tropics.

## Factors affecting Thermal Comfort in Buildings

Thermal comfort is achieved through the combination of several variables which could be environmental such as temperature, mean radiant temperature, relative humidity, air velocity, and personal factors which are metabolism and clothing.

## Air Temperature

According to ASHRAE (2017) air temperature is the temperature surrounding the body; it can be in degree Celsius or Fahrenheit. Air temperature is reckoned as the most effective thermal parameter among the entire environmental factors (Andersen, Fiero & Kumar, 2016). This is imputable to the fact that the human physical structure is sensitive to temperature (ANSI/ASHRAE Standard 55; 2013). Results from many researches indicate the relationship between air temperature, indoor thermal comfort, and productivity. Furthermore, Tammy and Oweikeye (2016) asserted that high temperatures in lecture theatres may affect the learning activities. As far as the optimum indoor temperature is concerned, Fanger (1973) has recommended an optimal indoor temperature for human thermal comfort to be 25.6 °C in Northern temperate zone. On the other hand, in relation to air temperature, ASHRAE (2017) also proposed $22.8\ ^oC \leq SET \leq 26.1\ ^oC$ and $20.0\ ^oC \leq SET \leq 23.9\ ^oC$ for summer and winter (for typical indoor and seated person), respectively, within 5 to 16 mm Hg water vapour pressure.

## Relative Humidity (RH)

According to Djamila, Chu and Kumaresan (2014) RH is the quantity of water vapour a unit volume of air holds at any given time and it could be referred to in different terms such as dew point temperature, humidity ratio and relative humidity. When water is heated and it evaporates into the surrounding environment, the resultant water in the air is the humidity. A highly humidified environment has a lot of water vapour in the air, impairing the evaporation of sweat from the skin. According to Tammy and Oweikeye (2016) high relative humidity can inhibit effective evaporative cooling by loss of moisture through the skin which leads to uncomfortable 'sticky' feeling characteristics to hot and humid climates. If water is heated and had evaporated to the surrounding region, it will increase the percentage of humidity in the gentle wind. According to Liu, Liao, Yang, Du and Hu (2014) relative humidity is the part between the current amount of evaporative water and the actual quantity of water that the air can contain at a given temperature. When the relative humidity is between 40-70% it would not cause a considerable effect on human comfort (Liu *et al*., 2014). However, it has been pointed out that there is no established lower humidity for thermal comfort (ASHRAE, ANSI/ASHRAE Standard 55; 2013), but high humidity in hot regions is a major problem since it will prevent skin sweating to cool off.

## Air Velocity

Air velocity is the speed of air running across the building and may help cool the building g if it is cooler than the environment (Liu *et al*., 2014). Air velocity could lead to cooling or heating the space based on the given indoor condition such as indoor temperature and relative humidity. These two elements and air velocity have the most influence on human thermal comfort indoors (Zhang, Arens & Zhai, 2015). Even though ASHRAE 55 (2013) standard has not fixed any number as a limit, it has suggested highest indoor air velocity of 0.2 m $sec^{-1}$. Indoor air velocity greater than 0.2 m $sec^{-1}$ could lead to indoor discomfort even at high indoor air temperature. Furthermore, ISO 7730 (2006) has stated that there is no specified minimum air velocity indoors, because this will rely strongly on other variables.

### Thermal Comfort Evaluation Criteria

Table 1 presents the acceptance criteria for thermal comfort evaluation. The criteria are those of ASHRAE.

**Table 1**: ASHRAE Harmonized Standard for Thermal Comfort Evaluation

| S/N | Parameter | Acceptance Criteria |
|---|---|---|
| 1 | Air temperature (°C) | 20-26 |
| 2 | Relative humidity (%) | 30 – 70 |
| 3 | Air Velocity (m/s) | 0.001-0.2 |

**Source**: ASHRAE (2013; 2014; 2017)

### Study Area

The study was carried out in Ahmadu Bello University (ABU) Main Campus, Zaria, Kaduna State, Nigeria. Zaria is located in the Northern part of Nigeria, with geographical coordinates between longitudes 7° 36' 00E" and 7° 46' 00E" and latitudes 11° 02' 00N" and 11° 12' 00N", with an altitude of 500–700 meters above sea level and a total area of $300km^2$. Two distinct seasons are identifiable in the Zaria area, and these include the dry and rainy seasons. The wet season lasts from April to October, with the maximum rainfall in August. Zaria has a mean annual rainfall of 1082 mm. The institution is the largest and the most extensive of universities in sub-Saharan Africa. Currently, it covers a land area of 7,000 hectares and encompasses 12 Faculties, a Postgraduate school and over 90 academic Departments.

### Materials and Methods

This study adopted a field survey approach. The survey involved the collection of data on thermal comfort parameters in lecture theatres through the use of checklists. The measurements were taken under two different conditions namely artificial ventilation and natural ventilation. In the context of this study, artificial ventilation actually means a combination of natural and artificial ventilation while natural ventilation implies that no artificial means of air movement, circulation and conditioning were in operation at the time the measurements were done. Data from field measurement were obtained using a Tekcoplus Carbon dioxide meter (Figure 1a) and Pyle Anemometer (Figure 1b).

**Figure 1a**: Tekcoplus $CO_2$ Meter


**Figure 1b**: Pyle Anemometer

The Tekcoplus $CO_2$ Meter (Figure 1a) is a portable device equipped with many functions. It was used to measure the air temperature and relative humidity. The Pyle Anemometer (Figure 1b) is a suitable tool for determining environmental situations. It was used to measure the air velocity in the study area. The Pyle Anemometer measures air velocity in the range 0.40-30.00 m/s with an accuracy of ± (3%+0.20m/s). The Tekcoplus Carbon dioxide meter (Figure 1a) and Pyle Anemometer (Figure 1b) were held at a height 1.2m above the floor level at the various sampling points of the theatre for 5 minutes' average sample. The results were displayed on the screen of the instrument. Data were collected and recorded 3 times in the record sheet for each lecture theater at three sampling points.

The population of the study composed of lecture theatres within the university main campus. There were twenty-nine (29) functional lecture theatres at the time of the study. Purposive sampling technique was used to select six (6) theatres out of the population based on the following criteria:

i. Lecture theatres with different designs were selected
ii. Lecture theatres with larger capacity were selected from those of the same design
iii. Lecture theatres must be purpose-built structure
iv. Theatres must not be undergoing any form of maintenance at the time of the study

For the subjective approach, a questionnaire was use to collect data on user's perception. The administration of the questionnaire was based on samples drawn from the selected lecture theatres. Below is the breakdown of the selected lecture theatres in Table 2.

**Table 2**: Selected lecture theatres for the study

| S/N | Lecture Theatre | Seating Capacity |
|---|---|---|
| 1 | A | 272 |
| 2 | B | 309 |
| 3 | C | 327 |
| 4 | D | 214 |
| 5 | E | 276 |
| 6 | F | 296 |
| **Total** | | **1694** |

For the purpose of anonymity, the selected lecture theatres are represented with labels A, B, C, D, E and F as shown in Table 2. The questionnaire was distributed to users of selected theatres during lecture periods. However, to establish the sample size, the equation given by Cochran (1963) for sample size determination was used.

The sample size for the respondents is 234. However, 30% was added to the sample to cater for non-return of questionnaires, therefore, the total sample size of 304 was adopted for the study. The same number of questionnaires was distributed for both morning (8.00am-11.00am) and afternoon sessions (12.00am-3.00pm). This was done to compare the responses of the respondents for both morning and afternoon responses across all the theatres. Altogether, the sum of 608 questionnaire was distributed of which 510 questionnaire was completed and returned by the respondents. Convenient sampling technique was used to select the respondents. This technique was adopted because it involves drawing samples that are both easily accessible and willing to participate in the study.

Descriptive statistics (percentages, frequency distribution, mean, and standard deviation) was used to analyse the data using SPSS software version 22. Parametric test in the form of Two-way analysis of variance (ANOVA) was used to establish the differences between thermal comfort parameters in the morning and afternoon sessions. The Duncan multiple comparison post-hoc test was performed on ANOVA findings to identify significant pair wise differences between the thermal comfort parameters across the selected lecture theatres. This was used because the data collected from objective measurement was found to be normally distributed after a normality test.

## Results and Discussion

This section presents the result and discussion of major findings from the study.

### Characteristics of the Lecture Theatres

The information on the general and artificial features of the buildings includes floor area, material and number of seats, size and number of doors, size and number of windows and the data is presented in Tables 3 and 4.

**Table 3**: General Features of the Theatres

| T | FA ($m^2$) | SM | DS ($m^2$) | NoD | WS ($m^2$) | NoW | TWA ($m^2$) |
|---|---|---|---|---|---|---|---|
| A | 256 | Plastic | 2.5 | 4 | 0.72 | 22 | 15.84 |
| B | 290 | Wood/plastic | 3.78 | 4 | 2.88 | 7 | 20.16 |
| C | 257 | Wood/plastic | 3.78 | 2 | 0.72 | 24 | 17.28 |
| D | 201 | Plastic | 3.36 | 2 | 0.62 | 39 | 24.18 |
| E | 259 | Plastic | 3.78 | 4 | 2.88 | 8 | 23.04 |
| F | 278 | Plastic | 3.78 | 2 | 0.72 | 10 | 7.2 |

T – Theatre; FA – Floor area; SM – Seat material; DS – Door size; NoD – Number of doors; WS – Window size; NoW – number of windows; TWA – Total window area

It can be observed in Table 3 that theatre B has the largest floor area (290 $m^2$). The seat material for theatres A, D, E and F is plastic while theatres B and C are made up of combination of wooden and plastic materials. Theatres A, B and E have the highest number of doors (4 doors each) and theatres C, D and F have 2 doors each. Theatre D has the highest number of windows with total area of 24.18$m^2$ followed by theatres E, B, C, A, and F respectively. Table 4 gives the details of artificial ventilation features of the buildings.

From Table 4, it can be seen that all the selected theatres have installed fans and some air conditioning systems (ACs). Theatre A has the highest number of installed fans (17) followed by theatres B, C, F, E and D with 16, 14, 14, 11 and 8 fans respectively, but only 7, 5, 12, 8, 1, and 13 were functioning in theatres A, B, C, D, E and F respectively. In terms of installed ACs, only theatres D and F have installed ACs with 4 and 2 numbers respectively. All the available ACs in theatre D were functioning while non was functioning at the theatre F. Theatres A, B and E have large numbers of faulty fans and this may greatly affect the artificial ventilation systems for those spaces. The artificial ventilation system of theatres C, D, and F on the other hand are considered to be much better as most of its fans and ACs were in proper working condition. The installation of adequate artificial ventilation systems is a key measure to improving the thermal comfort of indoor spaces.

**Table 4**: Fans and Air conditioners in the Theatres

| Theatres | Number of Fans | Functional Fans | Number of ACs | Functional ACs |
|---|---|---|---|---|
| A | 17 | 7 | - | - |
| B | 16 | 5 | - | - |
| C | 14 | 12 | - | - |
| D | 8 | 8 | 4 | 4 |
| E | 11 | 1 | - | - |
| F | 14 | 13 | 2 | - |

**Assessment of Environmental Thermal Comfort Parameters**

The measurement basically captured three (3) parameters which include indoor air temperature, indoor relative humidity, and air velocity which are required for evaluating the thermal comfort of an indoor environment. Table 5 shows the result of the statistical test of these parameters in the different lecture theatres for artificial ventilation condition.

**Table 5**: Thermal Comfort Parameters under Artificial Ventilation Condition

| **Theatre** | **Indoor Temperature** | | | **Indoor Relative Humidity** | | | **Air velocity** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Morning Mean ± SD | Afternoon Mean ± SD | P-value | Morning Mean ± SD | Afternoon Mean ± SD | P-value | Morning Mean ± SD | Afternoon Mean ± SD | P-value |
| A | 32.70 ± 1.06[d] | 33.84 ± 1.13[d] | 0.041 | 46.40 ± 2.59[a] | 41.19 ± 3.42[ab] | 0.002 | 0.18 ± 0.15 | 0.14 ± 0.05 | 0.65 |
| B | 31.62 ± 1.35[cd] | 31.46 ± 0.73[b] | 0.759 | 50.82 ± 2.07[b] | 49.12 ± 2.93[c] | 0.175 | 0.13 ± 0.14 | 0.24 ± 0.17 | 0.17 |
| C | 27.67 ± 2.95[a] | 32.41 ± 0.95[c] | 0.000 | 55.34 ± 2.46[c] | 47.34 ± 2.19[bc] | 0.000 | 0.15 ± 0.12 | 1.03 ± 1.39 | 0.078 |
| D | 29.20 ± 0.93[ab] | 27.42 ± 1.15[a] | 0.002 | 47.73 ± 0.98[ab] | 43.60 ± 3.30[bc] | 0.002 | 0.54 ± 0.60 | 0.71 ± 0.63 | 0.556 |
| E | 31.47 ± 0.94[bcd] | 35.59 ± 0.87[e] | 0.000 | 47.19 ± 3.21[a] | 35.29 ± 1.80[a] | 0.000 | 0.07 ± 0.05 | 0.09 ± 0.04 | 0.498 |
| F | 30.02 ± 1.62[bc] | 33.72 ± 1.08[cd] | 0.000 | 49.07 ± 2.06[ab] | 44.82 ± 6.81[bc] | 0.093 | 0.28 ± 0.13 | 1.23 ± 0.53 | 0.094 |
| F | 11.401 | 71.782 | | 17.922 | 11.960 | | 3.394 | 2.574 | |
| **P-Value** | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.010 | 0.038 | |

n=6; data analyzed using two-way Analysis of Variance followed by Duncan multiple comparison post hoc test. Values along the same column with different superscripts [a], [b], and [c] are significantly different ($p \leq 0.05$). **ASHRAE-55 Standard Limits: Air velocity** ≤ 0.2 m/s, **Air temperature** 20 °C to 26 °C, **RH=** 30% to 70%.

P-values along the column shows the difference in the mean indoor temperature, relative humidity and air velocity among the various lecture theatres while p-values along the row shows differences in the morning and afternoon measurements. For the indoor temperature, a significant decrease ($p \leq 0.05$) was observed in theatre C and D with the value of 0.002 and 0.000 respectively when compared with other theatres in the morning session. For the afternoon session, a significant decrease was seen in theatre D. A significant increase was observed in the afternoon session when compared with the morning session in theatres A, C, E and F while in theatres B and D, the temperatures recorded in the afternoon were surprisingly lower than in the morning and no obvious reasons could be seen for this anomaly.

A significant decrease was observed in theatres A, C, D and E with the values 0.002, 0.000, 0.002 and 0.000 respectively in both morning and afternoon sessions. Furthermore, a significant decrease in relative humidity was observed in the afternoon session when compare with that of the morning in all the theatres except theatre B. In the case of air velocity, no significant difference ($p>0.05$) was observed in all the lecture theatres, likewise between the morning session and the afternoon session.

Based on the data presented in Table 5, inferences were drawn for artificial ventilation condition as follows; that the mean indoor air temperature was between 27.67 $^{o}$C and 35.59 $^{o}$C for both morning and afternoon sessions. However, it can be observed that all the values for the mean indoor temperature exceeded the ASHRAE standard (20 $^{o}$C to 26 $^{o}$C), with up to 10%. Therefore, the air temperature is considered to be above the expected temperature for occupants' thermal comfort. The increased temperature values were observed across all the lecture theatres during lectures and may be attributed to the inadequate ventilation from the ventilation system such as fans and air conditioners that were observed not to be functional. This increased temperature may cause users of the lecture theatres to experience tiredness, dizziness as well as physical and mental fatigue during lectures (Liu *et al*., 2014; Rupp *et al*., 2015; Andersen *et al*., 2016).

Furthermore, the indoor relative humidity measured was within the acceptable range of the ASHRAE standard. The standard specifies that relative humidity should be between 30% to 70% and the highest value recorded in the morning was 55.34% and the least 35.29% in the afternoon. High humidity levels often result in inefficient evaporative cooling of the skin which leads to discomfort while low level of humidity may cause occupants to experience dry and irritated skin (Frontczak & Wargocki, 2011; Vireen *et al*., 2012). The air velocity for theatres A, B, C and E for morning are within the threshold of < 0.2 m/s while in theatres D and F, the threshold was exceeded. The exception of theatres D and F may be due to the presence of functional fans and ACs in operation during lectures. Whereas, for the afternoon session, the air velocity for theatres A and E are within the threshold of < 0.2 m/s except for theatres B, C, D and F which exceeds the threshold. Therefore, the wind speed for afternoon period in the theatres C and F is quite higher when compared with other lecture theatres, and this may be as a result of installed fans within the indoor space and the air flow into the theatres in the afternoon.

Table 6 shows the result of the statistical test on the environmental parameters in the lecture theatres under natural ventilation. A significant decrease in temperature was observed in the morning and afternoon sessions in theatre C, D and F (F is an exception in the afternoon) when compared with theatres A, B and E. For indoor relative humidity, no significant difference ($p>0.05$) between the morning and afternoon sessions were observed in all the theatres. For the air velocity, a significant increase ($p \leq 0.05$) in theatre C in the morning session was recorded above the others while for the afternoon session, the significant increase was observed only in theatre E. No significant difference was recorded between the morning and the afternoon sessions.

Based on the data presented in the Table 6, the mean indoor air temperatures in the occupied zones were between 27.53 $^{o}$C - 35.23 $^{o}$C for both morning and afternoon sessions. However, it can be observed that all the values for the mean indoor temperature exceeded the standard values with a percentage not up to 10%. Therefore, the air temperature is considered to be above the expected temperature for occupants' thermal comfort. This may be as a result of windows in the theatres being closed, and also some of the windows were not fully opened. In addition, some of the doors in the theatres were found to be closed due to security reason. The users of the lecture theatres may experience tiredness, dizziness as well as physical and mental fatigue. Furthermore, the relative humidity measured was within the acceptable range of the ASHRAE standard. The lowest values for relative humidity were recorded in the afternoon (39.13%) and the highest in the

**Table 6**: Assessment of thermal Comfort Parameters under Natural Ventilation Condition

| **Theatre** | **Indoor Temperature** | | | **Indoor Relative Humidity** | | | **Air velocity** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Morning Mean ± SD | Afternoon Mean ± SD | P-value | Morning Mean ± SD | Afternoon Mean ± SD | P-value | Morning Mean ± SD | Afternoon Mean ± SD | P-value |
| A | 32.50 ±1.07[d] | 34.07 ±1.20[b] | 0.01 | 44.52 ± 3.27[b] | 46.04 ±1.56[c] | 0.226 | 0.12 ± 0.04[ab] | 0.03 ± 0.01[ab] | 0.055 |
| B | 33.90 ±1.22[d] | 35.23 ± 1.55[b] | 0.060 | 45.86 ± 3.67[b] | 44.17 ± 2.11[bc] | 0.250 | 0.05 ± 0.03[ab] | 0.08 ± 0.03[ab] | 0.486 |
| C | 30.38 ±1.72[bc] | 33.27 ±1.55[ab] | 0.002 | 40.53 ± 2.36[a] | 39.98 ± 2.13[a] | 0.608 | 0.19 ± 0.06[b] | 0.001 ±0.00[a] | 0.012 |
| D | 27.53 ± 1.46[a] | 31.58 ± 2.39[a] | 0.001 | 42.76 ±1.43[ab] | 41.93 ± 1.30[ab] | 0.222 | 0.01 ± 0.01[a] | 0.09 ± 0.04[ab] | 0.066 |
| E | 32.10 ±1.13[cd] | 34.22 ± 1.61[b] | 0.005 | 39.13 ± 3.79[a] | 39.62 ± 4.23[a] | 0.800 | 0.01 ± 0.01[a] | 0.16 ± 0.04[b] | 0.003 |
| F | 29.73 ± 1.54[b] | 35.16 ±1.81[b] | 0.000 | 39.22 ± 1.52[a] | 39.63 ± 1.96[a] | 0.627 | 0.04 ± 0.02[ab] | 0.08 ± 0.04[ab] | 0.395 |
| F | 24.472 | 5.595 | | 8.869 | 11.226 | | 3.761 | 2.677 | |
| P-Value | 0.000 | 0.000 | | 0.000 | 0.000 | | 0.06 | 0.033 | |

n = 6; data analyzed using two-way ANOVA followed by Duncan multiple comparison post hoc test. Values along the same column with different superscripts [a, b], and [c] are significantly different (p ≤ 0.05). **ASHRAE-55 Standard Limits: Air velocity ≤** 0.2 m/s, **Air temperature** 20 ºC to 26 ºC, **RH=** 30% to 70%.

morning (46.04%). The air velocity for all the theatres for both morning and afternoon sessions are within the threshold of < 0.2 m/s even though they were lower in natural ventilation than in artificial.

## Assessment of Thermal Comfort Perception of the Respondents

A subjective assessment of the thermal comfort in the theatres was also conducted. The thermal sensation (ranging from very warm to very cold), humidity (ranging from very humid to very dry), level of thermal comfort, level of thermal satisfaction, relative humidity sensation, air movement and thermal acceptability were surveyed and evaluated.

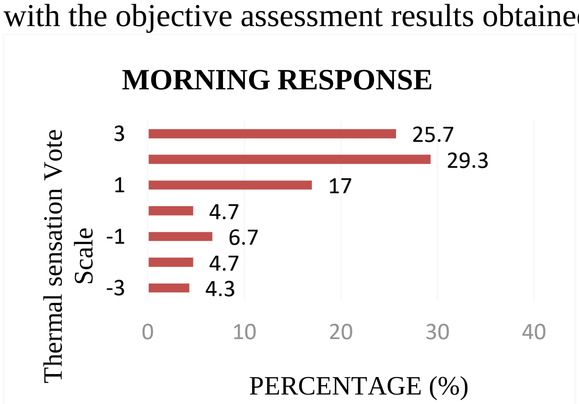
From Table 7, the majority of the respondents are males who are mostly within the age of 21-26 years. Also, the majority of the respondents are in their third year of study in the university.

**Table 7**: Demographic Information of Respondents

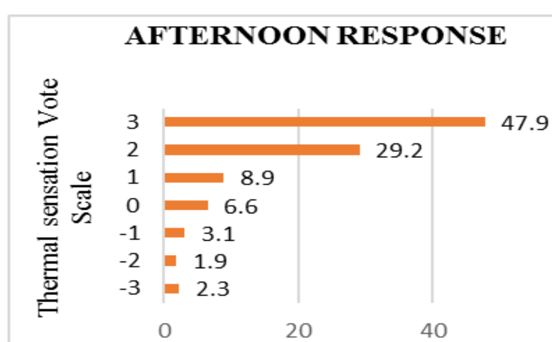
| Information | Morning Respondents | | Afternoon respondents | |
|---|---|---|---|---|
| | **Frequency (no)** | **Percent (%)** | **Frequency (no)** | **Percent (%)** |
| **Gender** | | | | |
| Male | 166 | 64.6 | 177 | 70.0 |
| Female | 91 | 35.4 | 76 | 30.0 |
| **Total** | **257** | **100** | **253** | **100** |
| **Ages** | | | | |
| 16-20Yrs | 17 | 6.6 | 218 | 86.2 |
| 21-26Yrs | 223 | 86.8 | 31 | 12.3 |
| 27-32Yrs | 17 | 6.6 | 4 | 1.6 |
| **Total** | **257** | **100** | **253** | **100** |
| **Academic level** | | | | |
| 300L | 160 | 62.3 | 100 | 39.5 |
| 400L | 88 | 34.2 | 134 | 53.0 |
| 500L | 9 | 3.5 | 19 | 7.5 |
| **Total** | **257** | **100.0** | **253** | **100.0** |

**Thermal Sensation vote of Respondents**

The results of thermal sensation of respondents are presented in Figures 2a and b. The result was obtained using 7-point thermal sensation subjective scale (-3= cool, -2= moderately cool, -1= slightly cool, 0= neutral, +1= slightly warm, +2= moderately warm, +3= warm). Analysis of results shows that majority of respondents voted slightly warm, moderately warm and warm sensation. The ASHRAE standard 55 specified that an acceptable thermal environment should have 80% of the respondents vote for the central categories i.e., -1 (slightly cool), 0 (neutral) and +1 (slightly warm). However, in Figures 2a and b, only 28.4% and 18.6% of respondents voted for morning and afternoon sessions respectively were within the central categories, indicating that the respondents are not comfortable in the theatres.. This finding agrees with the objective assessment results obtained when measurements were carried out.




(a)

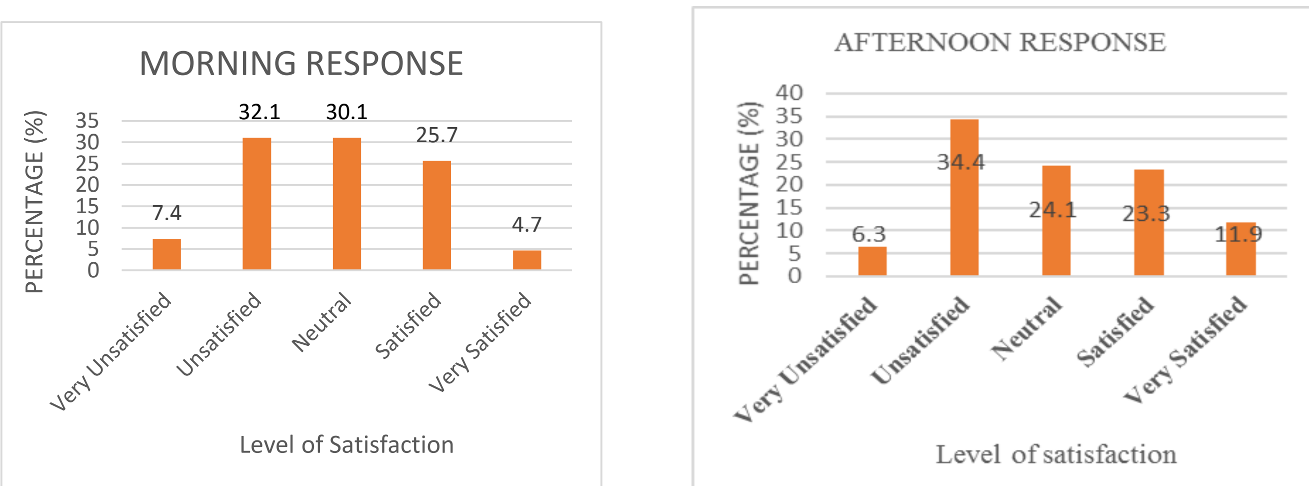



(b)

**Figure 2a and b**: Thermal sensation votes of the respondents for morning and afternoon

**Respondents' level of Satisfaction with Air Temperature**

The results of subjective responses on the level of satisfaction with air temperature are presented in Figure 3a and b. The results show that most of the respondents are not satisfied with the air temperature for both sessions. For morning responses, 32.1% of the respondents indicated being unsatisfied with the temperature of air circulating within the indoor space of the theatres whereas 30.1% were neutral. Furthermore, 25.7% of the respondents expressed satisfaction with the air temperature of the theatres and this may be the percentage of respondents seated closed to functional artificial ventilation systems. In the afternoon survey, 6.3% of respondents were very unsatisfied and 34.4 % of the respondent expressed dissatisfaction with the air temperature, while 24.1%, 23.3% and 11.9% were neutral, satisfied, and very satisfied respectively. In both cases, more than 40% of the respondents express their dissatisfaction with the ambient air temperature and this an indication of the need for improvements to the temperature control systems in the theatres.




(a) (b)

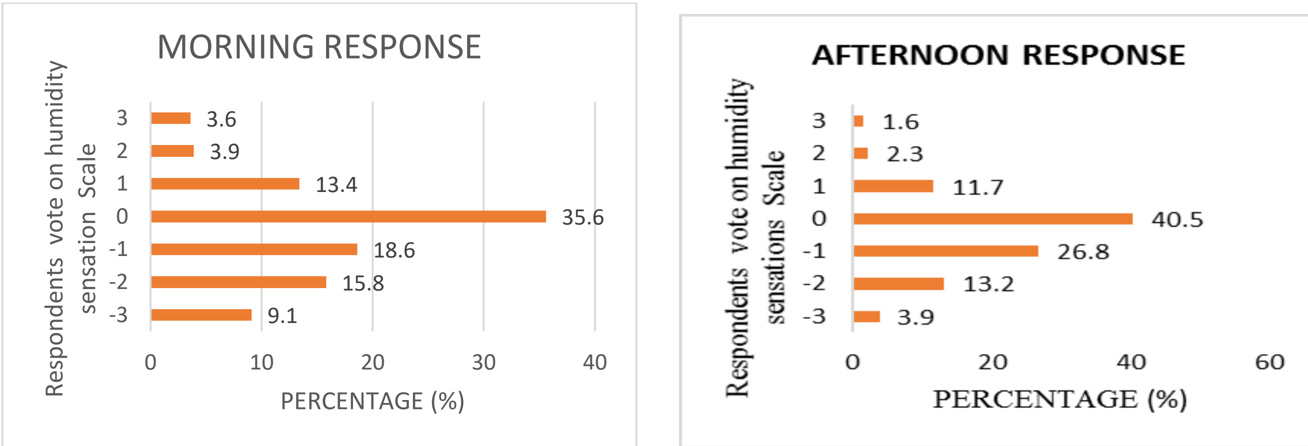
**Figure 3a and b**: Respondents Vote on Level of Satisfaction with Air Temperature

**Respondents' vote on Relative Humidity Sensation**

The humidity assessment uses the 7-point subjective scale of -3 (much too dry), -2 (too dry), -1 (slightly dry), 0 (just right), +1 (slightly humid), +2 (too humid), and +3 (much too humid). The responses on humidity are presented in Figures 4a and b. It is observed that the respondents are comfortable with the relative humidity as 67.6% and 79.0% of the respondents voted within the central categories (-1, 0, +1) for both morning and afternoon respectively. Hence, comfort condition for humidity exist in all the theatres.

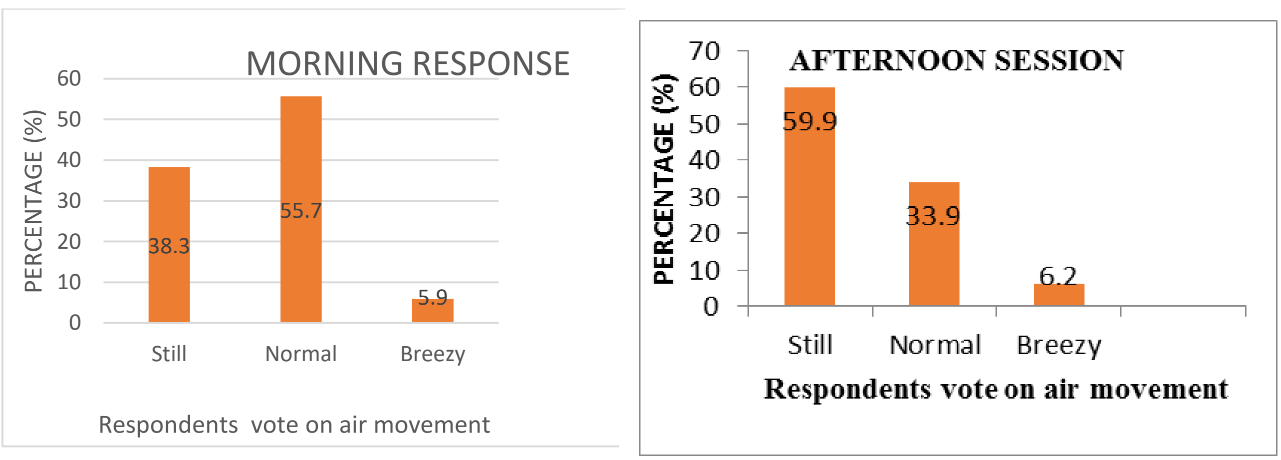
**Respondents' Vote on Air movement**

Figure 5a and b shows the results of the subjective assessment of air movement in the theatres with 55.7% and 33.9% of respondents respectively perceived air circulation as normal for morning and afternoon sessions. However, 38.3% and 59.9% perceives air movement to be still in the morning and afternoon respectively, while 5.9% and 6.2% respectively perceives the air to be breezy for morning and afternoon sessions, it can be concluded that the indoor thermal environment of the selected theatres during the afternoon session was not comfortable because majority (59.9 %) of respondents perceives the air movement to be still.




(a) (b)

**Figure 4a and b**: Respondents vote on humidity sensation




**(a)** (b)

**Figure 5a and b**: Respondents vote on air movement

**Thermal Comfort Acceptability of Respondents**

The distribution of subjective responses on thermal acceptability is presented in Figure 6a and b. The scale ranged from Totally Acceptable to Totally Unacceptable (TA; Totally acceptable, A; acceptable; N; Neutral, U; Unacceptable, TU; Totally unacceptable).

As shown in Figure 6a and 6, majority (51% and 64.2%) of respondents voted the thermal comfort in the theatres as Unacceptable (TU and U) for morning and afternoon respectively. In addition, 32.4% and 25.7% were "Neutral" about the thermal acceptability for morning and afternoon sessions respectively. The thermal comfort in the theatres is acceptable to less than 20% in each of the morning and afternoon sessions. These findings may be as a result of non-installation of air conditioning systems in some of the theatres and the bad state of a large number of installed fans in some of the theatres. Inadequate provision for natural ventilation is another possible cause.

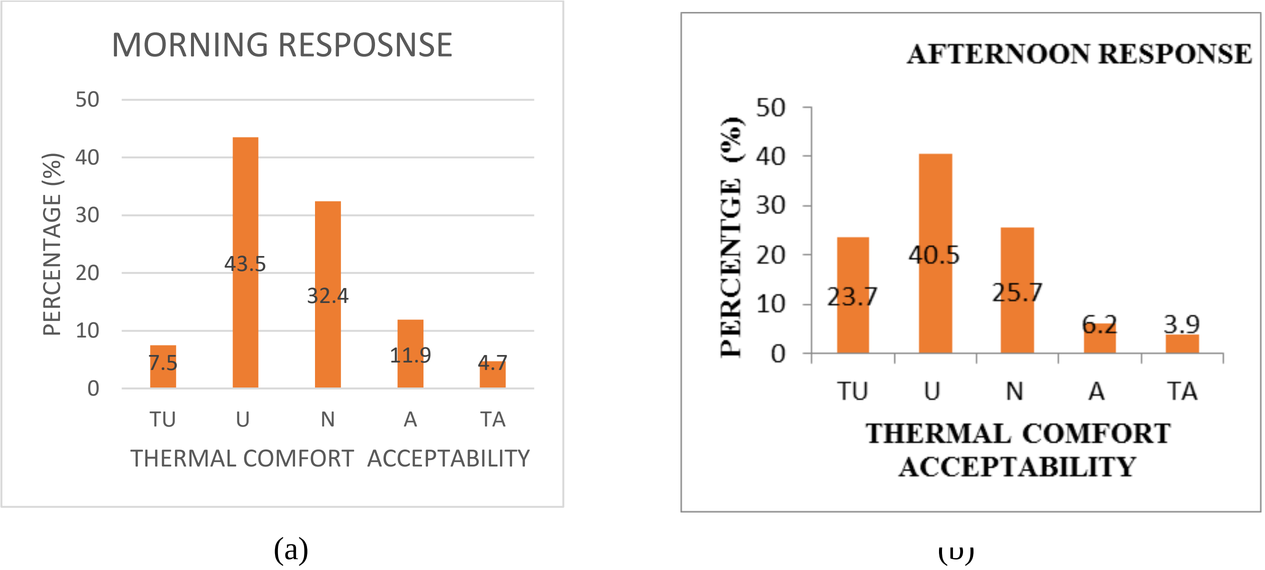



**Figure 6a and b**: Respondents Vote on Thermal Comfort Acceptability

## Conclusion

The mean temperature component of the thermal condition in the theatres were outside the comfort zone as values exceeded the range specified by the ASHRAE standard while both relative humidity and air velocity were within the acceptance range for thermal comfort. Results from the inferential statistics showed significant differences ($p<0.05$) in the mean value of the thermal comfort parameters measured in the morning and afternoon for indoor air temperature, indoor relative humidity, and indoor air velocity across all the theatres. The results of subjective evaluation agree with that of objective assessment as the number of respondents that voted within the central categories (-1, 0, +1) were not up to 80% which is needed for the thermal environment to be described as comfortable and acceptable. The main conclusion from the study is that temperature is the single most important determinant of thermal comfort in the surveyed buildings as it is the only variable whose values were above the recommended range for comfort in all the theatres while the other parameters were mostly within the specified range. The significant differences observed in the mean values of the variables between morning and afternoon periods is an indication of the difference in requirements for comfort between the two periods. It is recommended that adequate measures be taken to ensure that conditions that will guarantee a comfortable temperature in the indoor environment throughout the day and at all seasons are implemented in all the theatres on campus so as to ensure the comfort of the students and consequently promote effective and efficient learning.

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