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A Study of Thermal Comfort and Ventilation Parameters in Air-Conditioned Architectural Studios in a Hot Humid Abia State University, Uturu Environment

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Abstract

The study presented objective and subjective report of thermal comfort levels and ventilation characteristics of two air-conditioned postgraduate study studios in architecture department of Abia State University Uturu a hot humid environment. Thermal comfort variables were measured while the students responded to survey questions on their sensation of indoor climate. Air exchange rate, age of air and air exchange effectiveness were determined. Though the air conditioners were on, the studios did not condition within the comfort zone, of ASHRAE standard 55, causing occupants to report cold thermal sensations and the objective data analysis revealed that the studios were uncomfortable. The thermal neutralities were significantly higher than that proposed by ASHRAE Standard 55:1992. The monitored air exchange rates indicated that the provisions of outside air for ventilation based on design occupancy are adequate for the two study studios. In addition, questionnaires were completed by the students in order to provide a subjective assessment of thermal comfort and indoor air quality. Finally, the outcomes of 64 survey responses from the study studios to thermal comfort questions were presented and discussed.

Keywords: *Thermal comfort, Air exchange effectiveness, Tracer gas decay method, Air conditioning, Objective study, Subjective and approach*

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Background to the Study

Abia State University Uturu is located in the tropical region with hot and humid climate, where most buildings use air-conditioners. Due to high degree of heat resulting from high temperature and humidity. The humidity form sticky feeling, which creates discomfort Abia State University have continuously increased in number and structural facilities since 1986 it moved into its permanent site in Uturu. The distribution of lecture halls, studios, laboratories and other academic spaces will most certainly undergo changes in the years ahead.

In recent years, Nigerians energy consumption have increased, and is most likely to significantly increase in the next coming years. Therefore, primary concern should be given to making sure that the people inside are happy and comfortable. As observed by Ahmad (2004), through the knowledge of thermal comfort behavior of humans and energy utilization behavior of buildings, the best strategy can be adopted.

The objectives in ventilating buildings are to efficiently distribute air to the occupied zones and to remove or dilute indoor contaminants. The performance of a ventilation system is judged by its local mean age of air, contaminant removal effectiveness, air exchange effectiveness and the thermal conditions. Both thermal comfort and air quality can have important impacts on productivity.

There is need therefore to consider carefully thermal condition in Architecture studios in Abia State University Uturu, because of the high degree of task required from the postgraduate students of architecture, and also because of the negative influences that an unsatisfactory thermal environment could place on learning and performance. In tropical regions, the hot and humid climate may have an adverse impact on occupants comfort indoors.

The significance of maintaining good indoor architecture studio climate is self-evident when one considers the academic stress associated with training architects. In view of the importance of thermal comfort and indoor air quality, the design challenge therefore is to achieve acceptable indoor environmental conditions for studios occupants.

In this study thermal comfort levels and ventilation parameters of two mechanically ventilated architectural studios were evaluated and compared with ASHRAE standard (1989) and ASHRAE55and ISO 7730(1994) respectively. The neutral temperatures were calculated and the students' perceptions of the degree of comfort in postgraduate studios investigated.

Thermal Comfort Studies in Tropical Hot Humid Areas

Based on literature reviews, there are few thermal comfort studies conducted in tropical environments before the 1990s. According to comfort studies the proposed temperature for air-conditioned non-residential buildings is 23-26°C. However, since 1990's with increasing energy usage in commercial sectors, more researches have been conducted in the area of thermal comfort to find ways of providing comfortable indoor environments to reduce energy consumption and costs. Studies have shown that an increase in temperature indoor setting of 1.5°C gave 15.8% energy saving. (Daghigh and Sopian 2009)

According to Daghigh and Sopian (2009), a study in a controlled climate chamber involving 130 university students aged between 18-24 conducted in 1993,with all the subjects engaged in light activity of 1.0 met and wearing clothes of0.5 Clo value, air velocity 0.1 m s' and relative humidity 50%. The result showed that the neutrality temperature was 28.2°C at 50% relative humidity and this agreed with Sabarinah and Ahmad(2005)'s, study on a factory involving male university students and workers aged between 18 to 40 at three different environmental conditions which tested four different physical levels of work at each condition . Both concluded that majority were more tolerant towards higher air temperatures i.e., 23-29°C, yet Abdul and Kannan (1997) in a survey measured the indoor environmental parameters to study and determine the comfort conditions of college students in their naturally ventilated classrooms. A mean temperature of 29.8°C and mean air movement of 0.27 m s ^{1} were experienced by the subjects at average 65% humidity. The neutrality temperature calculated was 27.4°C which is 1.4°C lower than mean room temperature. The result agreed with Humphreys' adaptive model where the comfort temperature is close to the mean indoor temperature. While Ahmad(2004) explained that a study on 21 year old university students showed the comfort range of 24.5-28°C with 73% humidity, and neutrality temperature of 26.3°C. but, the result was a combination of air-conditioned and naturally ventilated rooms.

In further research by Ahmad (2004), of eleven air-conditioned offices. The results showed a comfort range of 20.8-28.6°C which was wider than the recommended range by,(ASHRAE,1992 and ISO 7730,1994). Another study to compare the results of eight thermal comfort studies done by Ahmad, (2003) in various buildings suggested that ASHRAE 55 and ISO 7730 (1994) has a higher thermal comfort range for tropical environments than present, which indicates that people in tropical environments are acclimatized to higher environmental temperatures.

Ahmad (2004)in determining whether the demonstration low energy office (LEO) is thermally comfortable as an office working space, showed that the office was generally thermally comfortable in the morning with PPD values of 18.19% and became cool in the morning and afternoon with PPD values of 24.12 and 21.56% respectively.

Sabarinah and Ahmad (2005), Zain, Taib and Baki (2007) queried typical strategies to naturally improve comfort in hot and humid climates without air conditioning. The result revealed that the prospect of not using air conditioning in rural area where good design strategies were adopted.

According to Busch (1992), a preliminary study of thermal comfort in a Malaysia's single storey terraced houses using field measurement and CFD technique and carried out Validation of CFD Fluent through the comparison of field measurements indicated that the design of single storey terraced houses is not effective in providing natural ventilation, hence could not attain thermal comfort.

Previous IAQ and Ventilation Effectiveness Researches in Tropical Environments

According to Busch (1992), Rhasbudin, Xusof, Leman and Hussain (2005) in a research of industrial buildings took measurements of concentration levels of main indoor contaminants and air exchange rate. Air exchange rate (ACH) ranged from 0.1-0.3. An IAQ audit methodology was developed and adopted to establish the IAQ profile of the building. A case-study was used to demonstrate the application of the IAQ audit and evaluate its comprehensiveness and usefulness to the building owners or facility managers. This audit was conducted for the development and application of an IAQ audit methodology for the tertiary institutional buildings. The IAQ audit consists of monitoring of thermal comfort parameters, microbial counts, dust particles and concentrations of carbon dioxide (Co_2), carbon monoxide (CO), formaldehyde (HCHO) and total volatile organic compounds (TVOCs). Air exchange rate, ventilation effectiveness and age of air were also investigated The IAQ results collected in this study was used to develop an IAQ database for institutional buildings. This is beneficial for development of guidelines for good indoor air quality in institutional buildings.

According to Sekhar, Tham and Cheong (2003), Air exchange effectiveness values in a seven-storey office building was calculated, Tracer gas analysis, based on concentration decay method, was employed to determine these values. The results indicated air flow patterns in the occupied zones with approximate perfect mixing. The measured concentration levels of indoor air pollutants were also found to be within reasonable limits.

Sekhar et al (2003) in further a comprehensive indoor air quality (IAQ) and energy studies in a hot and humid climate concluded that performance indices, such as ventilation index, energy index and the newly introduced indoor pollutant standard index (IPSI) are envisaged as practical tools for quick assessment in exploring the integrated issues of IAQ and energy in buildings.

Materials and Methods

In order to determine thermal comfort, in the two architectural studios objective and subjective approaches were carried out. Environmental variables were measured using, data loggers, which took simultaneous measurements of the following variables, air velocity, relative humidity, dry bulb temperature and mean radiant temperature. Objective physical measurements were carried out at points inside the studios and all measurements were taken at a height of 1.2 meters above the floor, which represented the average height of occupants at seated level.

The samples were recorded at every five minute interval. This method is similar to Busch (1992)'s thermal measurement in air conditioned studios. The two personal parameters of metabolic rate and clothing insulation were estimated in accordance with ISO 7730.the metabolic rate was set to be 1.2 met which was for sedentary activities (office, dwelling, school, laboratory), whereas the Clo-value (thermal resistance)was set to be 0.5. The males wore shirts with short sleeves, light cotton trousers, light socks and shoes. While females wore, skirts, cotton trousers, and blouses or silk. Measurements of thermal comfort parameters was conducted between October 1stto December 31stof 2016.

The tracer gas concentration decay technique was used to experimentally study air exchange rate, age of air and air exchange effectiveness. The age of air concept was used to evaluate the air exchange effectiveness. The first step in obtaining a method for field measurement of Air Exchange Rate (ACH).

Age of Air and Air Exchange Effectiveness (AEE) were to select a tracer gas that is relatively harmless and is easily detectable. Carbon Dioxide (Co_2) is the tracer gas that best fulfills the toxicity requirement and can be detected accurately and economically using direct reading instrument. It was chosen because its density is almost similar to density of air. Co_2 is also a gas recommended as an index of global room ventilation by international standards, in view of these advantages,Co_2 was identified as the best tracer gas for this research. The source is the Co_2 type fire extinguisher; the 12.51 kg in designated cylinders were used during the tests.

The next step was the selection of an appropriate injection scheme for the source of Co_2. An intermittent injection scheme was preferred over a continuous injection scheme. With this scheme, the source was activated for only a short period of time for 20mins to avoid disturbing the background Co_2 concentrations in the studios. This was made by injecting the gas946until room concentrations have become uniform using a desk fan. The concentration decay of tracer gas was measured using four indoor air quality (IAQ) meters. Furthermore, occupants input during experiment phase was essential for evaluating thermal conditions of space and the effectiveness of implemented solutions. People input was directly obtained through interviews and questionnaire surveys, therefore, assessment of the thermal comfort in the two studios was based on responses to questionnaire survey, which was administered simultaneously with the physical measurements in each studios, A total of 65 respondents participated in the survey for the two studios.

The dominant gender distribution sampled was male (64.3%), The total response rate was 100%. Before the survey, the subjects were seated for approximately 30minutes as recommend by Feridi, and Wong (2004)'sedentary activities. Sufficient time for body pre-condition in each survey was respondent's metabolic rate (M) at the same level throughout the study estimated to be equal to 1.2 Met.

Results and Discussion

Thermal comfort assessment: From the thermal comfort parameters, Predicted mean vote (PMV) and percentage people dissatisfied (PPD) for the two air- conditioned postgraduate studios by using Info Gap together with Microsoft Excel were calculated. The ranges of PMV for postgraduate studios 1 and 2 were between (-1.5)-(-1.2) and (-1.1)-(-l.5) and PPD were in the ranged between 56-62% and 36-47%, respectively as shown in Fig.1 Based on ISO 7730, the comfort range was taken to be the conditions when the PMV has the values between -1 and +1. These analysis's resulted from the measurement in October-December,2016 from 9.00 a.m. to 4.00 p.m. when the air-conditioner were on all the time, These results shows that more than half of the occupants felt thermally uncomfortable in the studio 1 during sedentary activities with an average temperature of 21.5°C and relative humidity of 53%. The studio 2 is thermally uncomfortable with an average temperature of 22.6°C and relative humidity of 59%.

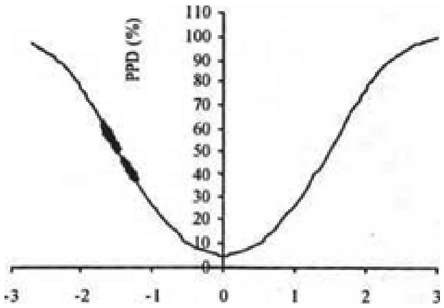


Fig. 1: Two air-conditioner studios Predicted Percentage of Dissatisfied (PPD) as a function of predicted mean vote (PMV)

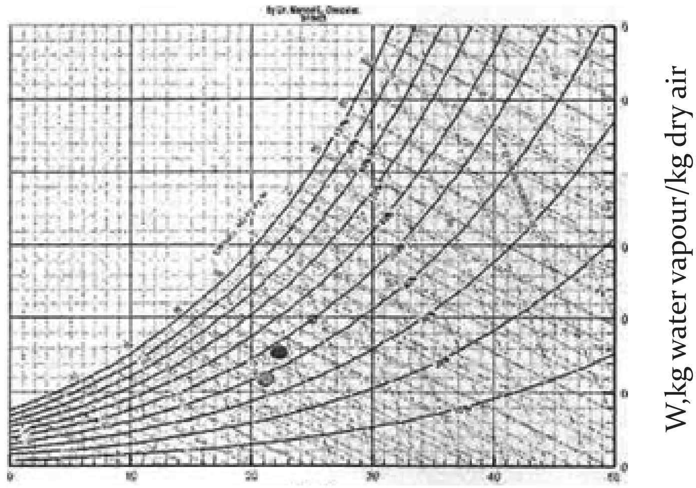


Fig 2:

The ASHRAE Standard 55-1992 states that the comfort zone for summer conditions, air temperature to be between 23-26°C and relative humidity between 20- 60%. Figure 2 shows that the studios did not fall within the comfort range during studying hours. It was observed that the state of temperature for studios is far from the recommended indoor thermal comfort design temperature range of23-26°C.

Surveys of the human thermal response produced the following equation Auliciems (1981)'s equation for estimating thermal neutrality in both on the mean monthly dry bulb temperature Tm.

Table 1: Measurements of ACH and Outside Air Quantities for Naturally and mechanically ventilated study office

Middle of study office

Study Office	ACH (h^{-1})	Fresh air (l/s)[a] D = 0.9AC/3.6	Design occupancy No. of persons (Occ)	Design occupancy l/s/Occ F=D/E	Actual occupancy No. of persons (Occ) E'	Actual occupancy l/s/Occ F=D/E'
1	1.7	33	3	11	5	6.6
2	2.5	109	7	15.6	10	10.9

a Based on an effective space volume of 90% (total volume less furnitures in the office)

$T n = 17.6 + 0.31 Trn$

It applies to both naturally ventilated and air- conditioned buildings.
Regarding this equation the thermal neutrality for two studios were, 26.1°C. The neutrality temperatures (24.6°C, 26.1°C and 27.4°C) for Ngani corresponds well to 27.4°C ET*

The proposed neutral temperatures are higher than 24.5°C recommended by ASHRAE Standard 55. This finding is similar to the finding of other studies n tropical hot humid environment.

Evaluation of Air Exchange Rate (ACH)
Figures 3 and 4 shows the concentration decay profiles in postgraduate studios from which the ACH were determined. The measurements for two offices were carried out when the outside air velocity was 0.3 m/s; hence air infiltration could be neglected as the external wind pressure was low. The ACH and the fresh air quantities are computed and tabulated in Table 1.

From Table 1, the air exchange rates are 1.7 and 2.5 and the amount of fresh air provisions are 11 and 15.6 1/s/person on the basis of design occupant density (10 m2/person) and 6.6 and 10.9 1/s/person on the basis of actual occupancy for postgraduate studios 1 and 2, respectively.

It is to be noted that these provisions except studios 1 in actual occupancy are generally adequate based on current ASHRAE Standard 62 requirements of 10 1/s/person and. It is worth of note that based on design occupancy, outside air provision in comparison to actual occupancy is higher and in accordance to ASHRAE requirement for the two studios.

Evaluation of age of air and Air Exchange Effectiveness (AEE): The AEE parameters are obtained from the fundamental data of age of air measurements recorded by the IAQ meter, which are presented in Table 2. The local age of air for studios 1 and 2 was between, about 35 and 30 minutes, respectively. It means that the length of the time for fresh air to remain in the studios is about 35 and 30 minutes respectively.

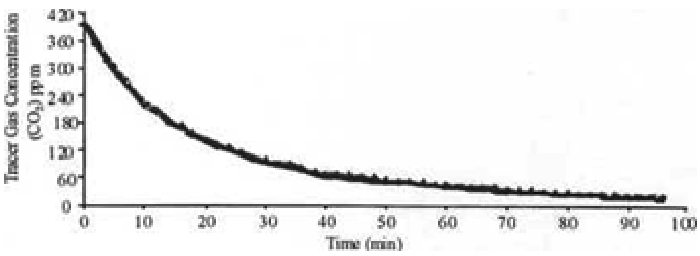


Fig. 3Variationof local tracer gas concentration vs. time for postgraduate studio 1

Table 2: Measurements of age of air and air exchange effectiveness for offices

Middle of Main Office Room			
Study office	Exhaust, τ_E (s) G	Local, τ_L (s) H	Local ε_L G/H
1	2158	2224	0.97
2	1738	1755	0.99

Fig. 4Variation of local tracer gas concentration vs. time for postgraduate studio2

When there is a uniform distribution of air over the office air-space $\Sigma_{L=}1$.

$$\frac{B = A}{H}$$

Where: A is the volume of space and H is the height of studio. In the present study, the volume of the studios 1 and 2 are A = 286 and 352 m^3 and their surface areas are B = 86.6m^2 and 106.3 m^2, respectively.

However, when there is a non-uniform distribution of air over the studio air-space or in other words, some stagnant zones within studio air-space, values of ELare significantly less than 1. A value less than 1.0 shows less than perfect mixing with some degree of,

Fig 5:

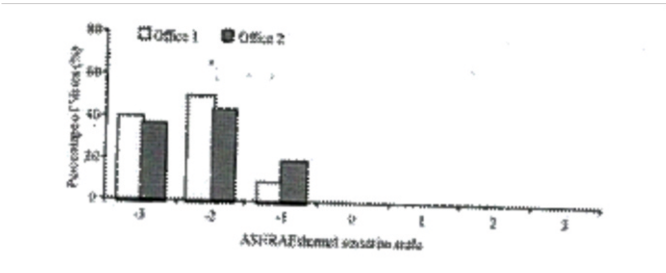
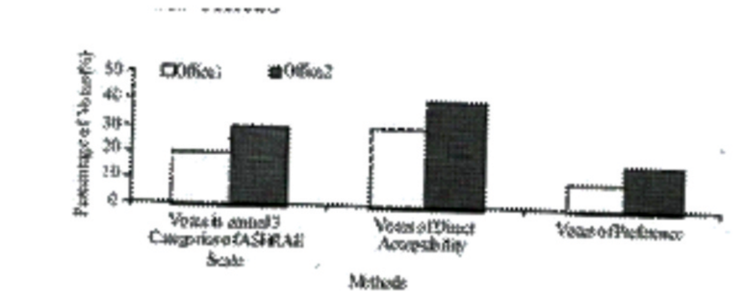


Fig 6:



Comparisons of various methods of assessing thermal acceptability for two studios stagnation. A value of $\{_L>1$ suggests that a degree of plug or displacement flow is present. The local air change effectiveness at location for postgraduate studio1 and 2 was found to be 0.97, 0.99, respectively and this implies that there was no short-circuiting of ventilation air on a global scale. The local air change effectiveness indicated a reasonably perfect mixed air in those conditions.

Evaluation of Questionnaire

Figure 5, shows the profile of Thermal Vote cast on the ASHRAE scale for the two studios. From the relative frequency of votes in each category. It can be seen that the thermal vote for studios centered on -2 to -3. On the other hand, Fig. 6 gives a comparison of the various methods of assessing acceptability. By equating the central three categories of the ASHRAE 55 scale with the notion of acceptability, 10 and 20% of the occupants for studios 1 and 2, respectively are assumed to be satisfied with the thermal condition in their studios. The direct vote of acceptability for studios are 75 and 89% for two conditions. In contrast, the thermal preference scale appears to be only 40 and 56 % of the respondents. Therefore, it is clear that there are people who voted beyond the center three category and yet find their environment acceptable. Different results can be obtained from different methods of measurements and are similar to other studies.

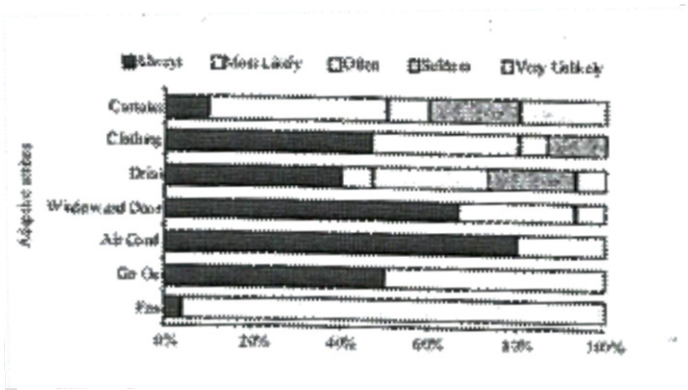


Fig. 7: Adaptive behavior office 1

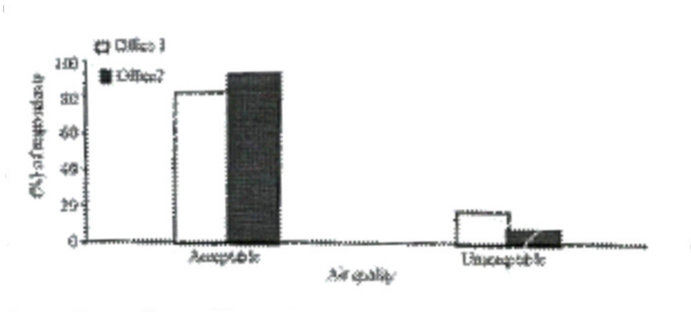


Fig. 8: Distribution of air quality

Figure 7 and 8 explain the list of various adaptive actions that were common in the studios and the percentage of people who choose to employ them. The environmental control by turning off the air-conditioner is highly preferred by students in both studios with the percentages of 78 and 70.3%, respectively. Other favoured adaptive actions were opening the windows and door with the percentage of 60.6 and 58 for studios 1 and 2 respectively, going out to warmer places with the percentage of 51 and 54.3 for studios 1 and 2, respectively was another favorable action. Putting on extra clothes was also a favorable action with 48.8% and 50% respectively.

Figure 8, shows the opinions of students on the air quality in the two studios. Staff were satisfied with the air quality, therefore, air quality in two studios were within tolerable limits for students. ASHRAE Standard 62 defines acceptable air quality as conditions in which more than 80% of people do not express dissatisfaction.

Conclusion

Objective measurement of the two post graduate studies showed that they had their thermal conditions falling within the comfort zone of ASHRAE standard 55 and ISO 7730.

It was seen that the outside air exchange rates values are sufficient based on design and actual occupancy for studio 2 but was not sufficient based on actual occupancy in studio 1.

In the case of air exchange effectiveness, it was observed that the AEE values in the two studios are close, implying that the exist no serious problems of short circuiting of ventilation air in the studios and that the ventilation air is well mixed.

The neutrality temperatures are higher than the ASHRAE Standard 55-(1992). The result of this study like previous studies in tropical hot humid areas suggest a wider thermal comfort range for Nigeria than that proposed by international standards, i.e., ASHRAE Standard 55-92, which indicates that most part of Nigeria and people in hot and humid climate are acclimatized -to much higher environmental temperatures. The thermal votes for the two studios centered around (-2) to (-3).

In terms of the use of climatic control to modify the indoor environment, it was found that turning off the air- conditioners, opening of windows and doors, going out and putting on extra clothes were high in the two studios. The study discussed the occupant's behaviour in utilizing the various environmental and personal controls to make themselves thermally comfortable. Adaptive actions contributed in some positives to the higher level of thermal comfort. When the occupants have the freedom to modify the environment and make necessary adjustment such as: windows- door opening arrangements; they always use them to compensate for the less comfortable thermal conditions.

The information obtained from questionnaires confirm that the air qualities in the two studios were satisfactory. The information obtained from the measurement and questionnaire show that the studios have good air quality.

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