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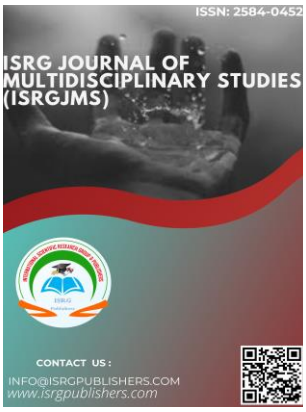

Evaluation of Thermal Comfort Conditions in Traditional Mud Buildings of South-Eastern Nigeria

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Abstract

The issue of occupant thermal comfort is paramount in the discussion of sustainable housing. In the case of Sub-Saharan Africa where majority of the population live in Low-cost houses, identifying the best solutions to indoor thermal comfort is of significant value. This study was conducted in order to gather information on the thermal and climatic conditions as well as the thermal preferences of occupants of traditional mud houses in the South-Eastern part of Nigeria. The data collected through physical measurement and surveys were subjected to descriptive analysis. Graphs and normal distribution tables were used to determine the comfort temperature, thermal sensation and thermal preference of the occupants. The result of the study showed that thermal comfort has significant value as well as indicated that more research is required in some of the aspects of the study, especially in the area of design, performance of traditional building materials and other variables that determine thermal comfort in the traditional mud residential buildings in the study area.

Keywords: *Thermal comfort, traditional buildings, mud houses, thermal sensation, thermal preferences, south-eastern Nigeria*

1. Introduction

Thermal comfort is defined by experts as “that condition of mind which expresses satisfaction with the thermal environment” American Society of Heating, Refrigerating and Air Conditioning Engineers (Goodchild, 1974). Thermal comfort depends on the mean radiant temperature and air temperature. Overheating would be experienced when either or both of these rise to an unacceptable level (ASHRAE, 2020).

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Human body is often exposed to a series of heat production, both from internal metabolism of company and that of surrounding elements. As these happen, the human body tries to maintain a thermal balance with its environment (Heerwagen, 2004). These heat exchanges through the ambient environment can be controlled so that the occupants of building will be thermally comfortable through architectural designs options aimed at providing optimal conditions for livability (Olgyay, 1958). Parameters that are effective in thermal comfort analyses are often categorized into personal and environmental parameters. While, air temperature, relative humidity, air velocity and radiant temperature are considered as environmental parameters; factors considered as personal parameters consists of the human metabolic activity level and clothing (Özdamar, et al. 2018). Another major parameters for thermal comfort studies is the element of sensation and perception. Different Models exist for the study and analysis of thermal comfort amongst which is thermoneutrality (Hoof, 2010). One of the mosrt common models is the PMV-model, which suggests that the most comfortable thermal sensation is neutral. However, other than thermal sensations, there exists other measures associated with perception of the thermal environment, which includes thermal satisfaction, thermal comfort, thermal acceptability and thermal preferences. These conditions are believed to impact on the appropriateness of any thermal condition (Humphreys, 2007). It is believed that thermoneutrality does not essentially correspond to the preferred thermal sensation. A typical instance, may refer to a condition that is very warm outside, whereas people prefer somewhat cool conditions over thermoneutrality or slightly warm feeling. On the other hand, when it is very cold outside, people often prefer slightly warm conditions instead, thus thermoneutrality is not always often the ideal preference (Butala, 2007), (Fountain, 1996). As stated earlier, the human body maintains thermal balance with the environment through varieties of autonomous activities. Other than these activities, people often employ strategies to assist in adapting to indoor or outdoor thermal conditions Study has it that people in hot climate zones prefer higher indoor temperatures than people living in the colder climatic regions. This contrasts with the fundamental assumptions for comfort standards based on PMV-model (de Dear, 1997). Hence, the element of adaptation becomes a gradual reduction of the human reactions to repeated environmental stimulation, which can be behavioral with regards to clothing, physiological with regards to acclimatization or psychological with regards to expectations (de Dear, 2002), (de Dear, 1998).

It is common knowledge that thermal discomfort is a challenge to poor regions like the tropical regions of Sub-Saharan Africa due to heat and humidity stress, as buildings in this region are constantly exposed to solar radiation daily (Olufowobi, 1998).

Study shows that a large number of thermal comfort studies have been conducted in buildings for all types of climate. Most of these were carried out in tropical, sub-tropical and temperate climate zones (Ajibola, 2001). Indication suggests that thermal comfort in traditional mud residential buildings are way higher than those of conventional ones. This present study is mainly concerned with traditional mud residential buildings as characterized by mud walls and thatch roofs used to fully envelope the indoor space without considerations for windows (Al-ajim, 2010).

2. Background of the Study

The South-Eastern Nigerian regions comprises of the mainly Igbo tribe, who occupy the area of six geopolitical states in Nigeria (Dmochowoski, 1990). It lies within the warm-humid zone of the tropics and characterized by high temperature and high humidity. Dominating winds in this region are South-West trade winds from March to October and North-East trade winds from November to March. The wind direction at various times of the year plays a domineering role in determining the climate of the country (Aniakor, 2002).

The sun is one of the most abundant resources in the South East zone of Nigeria which is within the warm humid zone of the tropics. The zone is characterized by high temperature and high humidity. The effect of these therefore results in thermal discomfort associated with the zone. Contemporary and traditional buildings in the zone are constantly exposed to solar radiation every day. Despite this, a casual observation reveals that there is thermal comfort in the indoor space of the traditional mud residential buildings, even during the daytime when solar radiation is much felt at the outdoor of the buildings. Probably, the thermal sensation expressed by the observer might be as a result of the design of such buildings. A review of available literature reveals that there is no verification to validate the opinion surrounding the comfort conditions in mud houses, as most of these speculations are devoid of any empirical analyses. Owing to this, there is need for empirical study on effectiveness of thermal comfort in these traditional mud residential buildings in the South East zone of Nigeria. This study therefore aims to investigate the effectiveness of thermal comfort in the traditional residential buildings in the South East Zone of Nigeria, with a view to contributing towards measures to improve the thermal comfort in the indoor space of the buildings, in the case the existing ones are found inadequate.

2.1. Description of study site

The study in this work was conducted around the Enugu region which is located in the Southeastern part of Nigeria with geo-location as 6.26° North and 7.29° East. The predominant human activity in the study area is characterized as farming community. The regional climate is classified as a tropical rain forest with a derived savannah. Set on an altitude of 304.7m above sea level, its climate is characteristically humid and this humidity is oppressive between March and November as indicated in figure 1, (Anyadike, 2002). The average maximum temperature is 34.9°C, with average low of 22.3°C the annual mean temperature is 26.7°C. Typical with the rest of West Africa, the rainy and dry seasons are the only weather periods in this location. The hottest months of the year are February to April, a period in which isolation increases with the apparent north ward movement of the sun and the cloud cover is sparse. Temperatures for February-April are typically above 27°C, while those of September, October and November are typically above 26°C. The coolest month is usually August, middle of rainy seasons, high cloud cover, temperatures are typically around 24°C. Annual temperature in south east are fairly high generally around 26°C.The average hourly wind speed experiences significant seasonal variation over the course of the year. The windier part of the year lasts for 7 months, between March to September, with average wind speed of 5.5m/s. The windiest month of the year is August, with an average wind speed of 7.1m/s. The wind direction comes relatively from the west for 10 months (monsoon season), from January to November, with a peak percentage of 75% in July. Additionally the wind direction comes from the north for 2 months (Harmattan season) through November to January, with a peak percentage of 41% in January. The surroundings of the measurement sites can be characterized as typical rural land-use, with residential housing. The ground in the study zone is firm with

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abundance of building earth for traditional earthen architecture. Forest products provide materials for construction ranging from post (to hold the roof) to sticks for wattle-and-daub construction, and thatch and raffia mats for covering the roof. Conversely, with the rise of modern agriculture, the South east area shed most of its thick forests giving way to open cultivated lands. Also, the growth of towns and modern institutions has equally contributed to a transformation of the vegetation and physical features of the area.

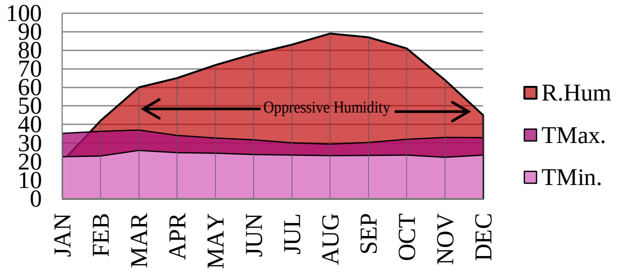

Figure 1. Average climatic data of Enugu city

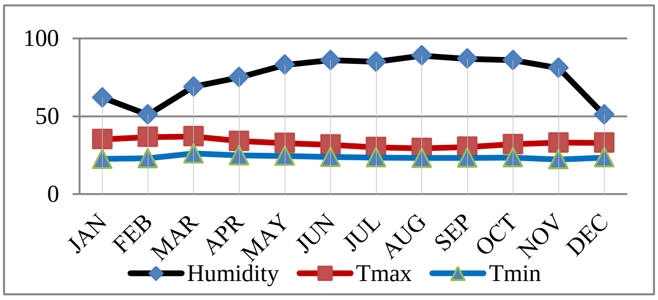

Figure 2. Average monthly temperature and relative humidity of Enugu city during the year of study

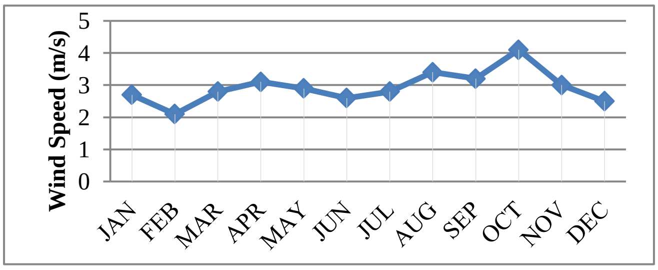

Figure 3. Average monthly wind speed of Enugu city during the year of study

3. STUDY METHODOLOGY

The authors conducted field assessments to gather information on the thermal and climatic conditions as well as the thermal preferences of occupants. The data gathered were supplemented with the experiment process to obtain the result.

All the climate data and other information were analyzed using graphical analysis mode (mathematical graphs and charts) to produce the detailed report for analyzing the effectiveness of thermal comfort in this study.

The following instruments were employed for the experimental studies as shown in Figure 4:

a. Digital thermometer (for air temperature)
b. Thermo-anemometer (for air movement/ or air velocity) indoor and outdoor.
c. Electronic sensor connected to data logger (for relative humidity)
d. A digital still camera (Sony cyber shot) was used to take photographs of some of the selected Igbo traditional residential buildings in the study area.
e. A laptop (computer) was used for Computational Fluid Dynamics (CFD) simulation. It is useful in predicting the indoor thermal environment. The laptop was also used for collation of data generated during the study.

The data collected from the study were subjected to descriptive analysis by describing them in frequency tabulation. Graphs and normal distribution tables were used to determine the comfort temperature, thermal sensation and thermal preference. The input comprised the data collected from the primary and secondary sources. These were data collected through physical measurement and surveys. The information obtained was inputted graphically and in tables. The output from data analysis was utilized in the research. The data from the secondary source and the results from the analysis of primary source were applied to determine the thermal comfort. The result of the application was presented and showed that thermal comfort has value. It also showed that more research is required in some of the aspects of the transposition, especially in the area of design, performance of traditional building materials and other variables that determine thermal comfort in the traditional residential buildings in the study area. The data output formed the basis of subsequent studies and conclusions reached by the study. Data output involved building typologies, graphs and analysis of the results.

	
Raytek, (Raynger ST) Infra-red Sensor temperature monitoring equipment.	Temperature-Velocity-Humidity monitoring equipment

Figure 4. Climate and thermal Data equipment used in the field experiment measurements

4. INVESTIGATIONS AND FIELD MEASUREMENTS

4.1. Experimental Measurement

The field survey recorded the environmental and personal parameters which are important factors affecting thermal comfort. The relatively low mean clothing values of 0.27 clo and 0.34 clo reflect the casual dress codes in their homes. The typical male attire is short pants or and t-shirt, while the common female attire consists of a wrapper and blouse. In some occasions, the male respondents were observed to wear only pants with upper body bared during the hot afternoon survey in their homes and sweaters during the early mornings and late evenings. Relatively equal numbers of male and female respondents participated in the survey. In terms of age distribution, the biggest percentage of respondents (about 50%) was represented by young adult age group (between 21 and 30 years old) and the smallest percentage was from oldest age group (more than 50 years old). The average height and weight

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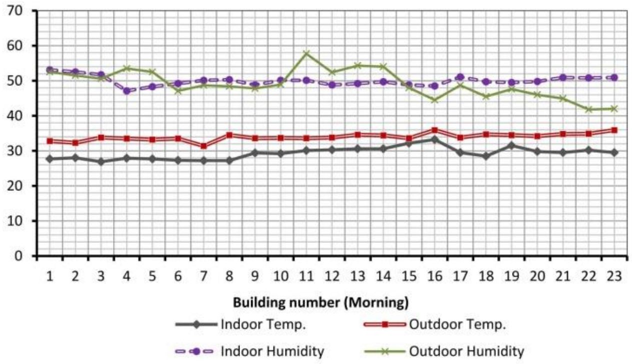
of the respondents indicated that they are within the typical (normal) African human body proportion.

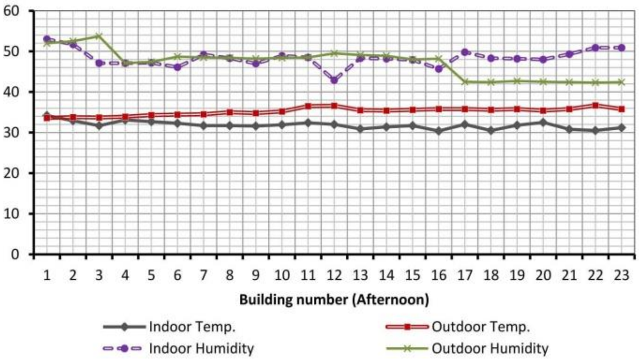
4.1.2. Investigation and Field measurements

The survey was conducted at the traditional residential buildings cluster of Ugwogo -Nike (figure 5). The Figure 6 shows the graphs representing the information gathered from the survey both in the morning and afternoon periods.

Figure 5. Images of the typical traditional mud houses in the study area



(a) Morning period



(b) Afternoon period

Figure 6. Graphs showing the information from survey (morning and afternoon periods)

Using Humphrey's comfort temperature equation for deriving the global expected comfort temperature stated as follows:

$T_c = 0.534T_o + 12.9$ ………………………….…… (equation 1)

Where T_c is the comfort temperature and T_o is the mean outdoor temperature, the derived comfort temperature for this location is presented in Figure 7.

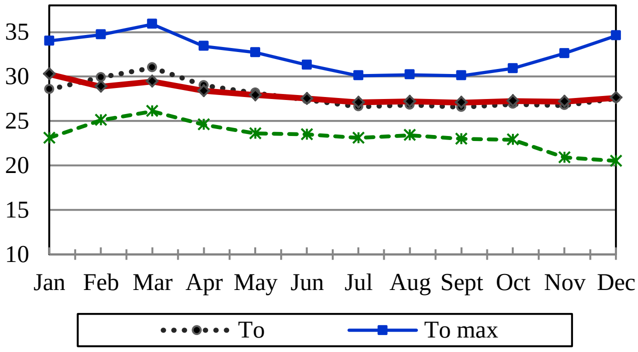


Figure 7. Average comfort temperature T_c indicated in red, as compared to mean outdoor temperature T_o

4.2. Summary of Field Investigation

The following were observations from the field investigation:

a. The mean temperatures recorded indoors in the morning hours as shown in Table 1, ranged from 26.9 ºC to 33.20 ºC, while that of afternoon (indoors) ranged from 30.4 ºC to 34.2ºC. The mean temperature outdoor for morning hours ranged from 31.40 ºC to 33.96ºC, while that of the afternoon periods ranged from 33.6 ºC to 36.70 ºC.

b. The mean relative humidity (RH) recorded indoors in the morning hours ranged from 47.10% to 53.1%. On the other hand, outdoor morning hours relative humidity measurements ranged from 41.80% to 57.70%. The afternoon hours recorded 42.30% to 53.70%. This is due to the dry season when the moisture content of the atmosphere is less because the sky is bright with sunshine.

c. The mean air velocity (m/s) recorded indoors in the morning hours were 0.0m/s. In the afternoon, the same 0.0m/s was recorded. The recorded low air velocities for the dry season indoors were due to the fact that all measurements were taken inside the typical traditional residential buildings in the study area. Secondly, the miniature windows used in the huts where considered to be responsible for lack of air flow and ventilation. At the outdoor in the morning hours as shown in Table 5, the air velocities ranged from 1.08 to 1.80m/s while in the afternoon periods, the air velocities ranged from 1.17 to 1.80m/s.

Table 1. Summary of climatic data as measured

	Morning period (Indoor)	**Afternoon Period (Indoor)**	**Morning period (Outdoor)**	**Afternoon Period (Outdoor)**
Mean air temperature (°C) (Mean, Standard deviation) (Minimum, maximum)	(29.30, 1.69) (26.90, 33.20)	(31.82, 0.91) (30.40, 34.20)	(33.96, 1.02) (31.40, 35.9)	(35.20, 0.92) (33.60, 36.70)
Mean relative humidity (%)	(49.96, 1.38)			

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(Mean, Standard deviation) (Minimum, maximum)	(47.10, 53.10)	(48.37, 2.11) (42.90, 53.00)	(49.08, 4.05) (41.80, 57.70)	(47.14, 3.53) (42.30, 53.70)
Mean air velocity (m/s) (Mean, Standard deviation) (Minimum, maximum)	(0.04, 0.14) (0.0, 0.50)	(0.0, 0.0) (0.0, 0.0)	(1.08, 0.56) (0.0, 1.80)	(1.17, 0.56) (0.0, 1.80)

4.3. Thermal Comfort Measurements

This part of the survey was conducted simultaneously with the field measurements. It involved a survey conducted through questions directed to the occupants of the houses. The questions were intended to identify Thermal Comfort elements based on human body reactions to the environment.

The questions were made up of the following:

a. ASHRAE 7-point scales for thermal sensation vote (TSV). These involve subjective thermal sensation vote in the following manner: (-3) cold, (-2) cool,(-1) slightly cool, (0) neutral, (1)slightly warm, (2) warm, (3) hot.

b. McIntyre (preference) 3-point scales, such as (-2) much cool, (-1) bit cool, (0) no change, (1) bit warm, (2) much warmer.

The data generated from the experiments conducted in this location were put through a Thermal Comfort evaluation system using standard evaluation parameters in order to significantly identify the levels of comfort and its effects within the selected study regions. The ASHRAE 7-Point scale (Table 2) and the Thermal Comfort Scale (Table 3) were adopted for the thermal comfort assessment as analysis in order to determine the Thermal Sensation factor (*TS*) and the Thermal Preference factor (*TP*).

Table 2. ASHREA 7 point scales

Cold	**Cool**	**Slightly cool**	**Neutral**	**Slightly warm**	**Warm**	**Hot**
-3	-2	-1	0	1	2	3

Table 3. Thermal comfort Scale (Preference scale)

Cooler	**Slightly cooler**	**Neutral (No change)**	**Slightly warmer**	**Warmer**
-2	-1	0	1	2

5. ANALYSIS AND DISCUSSION OF RESULTS

The study further applied the thermal feeling measuring scale ASHRAE 7-Point scales and Thermal Comfort Scale for the measurements of the feelings of occupants. The comfort temperature (Tc) using M. Humphrey's equations were calculated. The summary of thermal sensation and thermal preferences is shown in Table 4. This demonstrated the general conditions of the occupants in terms of their acceptability of the indoor conditions. The conditions gave a mean regional comfort temperature value of 29.0 °C with mean indoor temperatures of 29.3 °C (morning) and 31.82 °C (afternoon). Relative humidity values were 49.96% for the morning and 48.37% for the afternoon period. Actual Mean Vote (AMV) of the occupants for the surveyed traditional buildings in the morning and afternoon periods indicated that none of the respondents felt neutral (0). On the other hand, the TSV (thermal Sensation vote) for the morning period recorded a mean Sensation value of -2.4 with SD 1.2 (indicating a cool condition) and 1.0 with SD 0 for the afternoon period (indicating a warm condition). The mean TPV (thermal Preference vote) for the morning gave a 0.7 value with SD 0.6 (indicating the preference for slightly cool condition) which accounted for 37.8% of the vote ,while the afternoon period gave a mean preference value of -1.1 with SD 0 (preference for slightly cooler conditions) with 0%.

Table 4. Summary of thermal sensation and thermal preferences

Time	**Sample size**	**Thermal sensation (-3 to +3) TSV AMV**			**Thermal preference (-2 to +2) TPV**			***T_g* *(when voting)***		***T_{gnv}* *(voting neutral)***	
		Mean	**SD**	**Frequency of neutral%**	**mean**	**SD**	**Frequency of no change%**	**mean**	**SD**	**mean**	**SD**
Morning	37	-2.4	1.2	Nil	0.7	0.6	37.8	29.2	2.9	nil	Nil
Afternoon	nil	Nil 1.0	nil	Nil	Nil -1.1	nil	Nil	nil	nil	nil	Nil

6. CONCLUSION

In this study, the indoor conditions of mud traditional buildings were studied within the South-Eastern part of Nigeria. The study reveals that the traditional mud buildings were at least more adaptable to warm and cold conditions. The traditional building materials are actually more suitable and adaptable to warm humid climate. The occupants of these traditional mud buildings in the study area voted in a unique way between thermal sensation and thermal preference agreeing with the common logical assumption of thermal comfort standard which assumed that under neutral conditions the occupants should prefer to feel neither cooler nor warmer meaning that their conditions were neutral in overall preference. However to further improve the comfort conditions of occupants, the miniature window openings observed in the buildings need to be modified in other to further improve the indoor natural ventilation conditions.

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