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A COMPARATIVE ANALYSIS OF SUBJECTIVE THERMAL COMFORT PERCEPTION IN SELECTED RESIDENTIAL BUILDING TYPOLOGIES IN JOS-NIGERIA

Ahmed Umar Audu[1], Pontip Stephen Nimlyat[2], Ademola Olatunji Jimoh[2], Auwalu Nasiru Umaru[2], Muhammed Murtala Bello[3]

[1 &2] Department of Architecture, Faculty of Environmental Sciences, University of Jos, Nigeria
[3] Department of Architecture, Faculty of Environmental Technology, Abubakar Tafawa Balewa University, Bauchi, Bauchi State, Nigeria
Email: bmmurtala@atbu.edu.ng

Abstract

The principle applied in the design and construction of the residential building's envelope influences its thermal performance and occupants' thermal satisfaction level. This study examined the design and material ensemble of existing residential buildings in Jos and assessed the level of thermal satisfaction of their occupants. The study was carried out in two seasons that is dry season and rainy season. The study involved post occupancy thermal comfort survey of households and physical measurement of thermal parameters, with subjective and objective data obtained respectively. Two building typologies were selected for the thermal comfort survey and 80 respondents who were occupants of these two building types, (a 3-bedroom bungalow and 4-bedroom duplex at the University of Jos Senior Staff Quarters) responded to the questionnaire administered. ASHRAE's Standard 55 and European Standard EN 15251 which adopted the thermal comfort model by Fanger were used as voting scales. The subjective data obtained from the occupant survey were analysed using SPSS Statistics version 21, while the subjective data were analysed using tables. Findings reveal that the main determinants of Occupants' thermal comfort are air temperature, relative humidity, radiant temperature, and construction material/ensemble. The replies from the occupants revealed that the building's design, materials, and overall composition have an impact on these parameters, as seen by the marginal variations in heat perception between the occupants of the four-bedroom duplex and the three-bedroom cottage. This situation is clearly due to the differences in the design and material ensemble of the two building types. However, by using thoughtful design techniques and selecting and applying materials carefully, it is possible to improve the thermal conditions in the two types of buildings.

Keywords: Building Envelope, Building Typologies, Passive Design Techniques, Thermal Comfort

INTRODUCTION

The level of thermal comfort experienced by occupants of a given building is a function of the thermal performance of the building envelope ensemble. Thermal comfort as defined by the ASHRAE standard is "the condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ASHRAE, 2013). Hensen (1990) defined thermal comfort as "a state in which there are no driving impulses to correct the environment by the behaviour. Thermal comfort is also defined by the International Standards Organization ISO 7730 (2005) as the state of mind that expresses satisfaction with the surrounding environment, implying that comfort is a physiological and psychological condition. Environment is a key factor in the definition of thermal comfort as can be seen from the three definitions above. The building environment that determines the thermal comfort of occupants is both indoor and outdoor environment. The indoor environment is defined by the building envelope and thermal comfort within the indoor environment is a function of the thermal quality and performance of the envelope. According to Saleh (2007), the building envelope acts as a thermal barrier, increases thermal performance and hence plays an important role in regulating indoor temperatures and helps to determine the amount of energy required for the desired thermal comfort for occupants. The outdoor environment on the other hand is characterized by several microclimatic elements such as prevailing wind, precipitation, temperature, solar radiation and relative humidity which directly or indirectly affect the indoor environment and hence affect the thermal comfort of occupants of buildings, therefore the building envelopes must serve as essential modifiers of these microclimatic elements (Olanipekun, 2002).

Thermal comfort and microclimate consideration have become an essential aspect of building design in Nigeria today because of the obvious energy shortage in the last two and half decades, before this period much considerations were not given to passive design principles for the thermal efficiency of our buildings as thermal comfort was achieved through active mechanical means. Active mechanical means of achieving thermal comfort are no longer sustainable due to the obvious shortage in domestic power supply to the populace by the Nigerian government. For a sustainable solution to be achieved the building envelope needs to be optimized to reduce cooling loads by passive cooling design strategies. Ogunsote, Prucnal-Ogunsote and Adebgie (2011) defined passive cooling design as a “design techniques or design features used to cool buildings naturally without energy consumption that is without the use of active mechanical driven devices”.

The degree of building envelope optimization for passive cooling can best be determined by first understanding the thermal feelings of occupants of existing residential buildings. Akande (2010), in line with this, noted that residential apartments in Nigeria in general are not responsive to the requirements of the tropical climate, as their envelopes were not designed with passive design principles. Hence, they are not thermally efficient enough to provide the required thermal comfort to occupants without much dependency on energy-dependent mechanical means. The objective of this study is to investigate the thermal comfort perception of occupants of residential buildings in Jos under passive natural means to propose modifications to the envelope design of residential buildings to achieve the desired thermal comfort through passive strategies.

LITERATURE REVIEW

By the definition of Thermal comfort, it is obvious that individual subjective feelings and conditions are key in determining the state or level of their comfort. The comfort of individuals is influenced not only by the thermal environmental factors alone but also by personal differences in mood, culture, and other individual organisational and social factors (Nicol, 2010). Based on the above, comfort is a state of mind rather than a state condition. The definition of thermal comfort has been thrown open as to what is meant by condition of mind or satisfaction. However, it correctly stressed that the judgment of comfort is a cognitive process which involves a lot of inputs influenced by physical, physiological and other factors (Djongyang, Tchinda & Njomo, 2010). There are several factors which affect thermal comfort, they are air temperature, mean radiant temperature, air velocity, relative humidity, intrinsic clothing and level of clothing (Darby & White, 2005). The first four are factors of the thermal environment while the other two are concerned with the individual. Aside from these major factors, several others may affect the sensation of comfort. However, Air Temperature and air humidity are the most common factors that are usually addressed in the conventional design process, though they affect only 6% and 18% of the thermal comfort respectively (Ahmed, Khan, Maung, Than, & Rasul-Mohammad, 2014). Other factors such as the temperature of surrounding surfaces and the air velocity account for 50% and 26% of thermal comfort perception, respectively (Abed 2012).

There are several models for measuring thermal comfort. The most commonly used models are the heat-balance approach (the Fanger model) and the adaptive models. The Heat-Balance approach combines the theory of heat transfer with the physiology of thermoregulation to determine a narrow range of comfort which building occupants will find comfortable. The range which is determined by a 'PMV' (Predicted Mean Vote) defines comfort in terms of air temperature, radiant temperature; air velocity and humidity, hence is easily measured physically by the use of specific instruments.

The adaptive thermal comfort approach on the other hand is expressed by the adaptive principle as defined as: 'if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort' (Humphery, Nicol & Roaf, 2015). The adaptive thermal comfort model is the most suitable approach to passive solar buildings as it defines comfort with a wider range of thermal parameters and correlates variable outdoor conditions with indoor conditions. The combination of the two models that is the heat-balance approach and the adaptive approach gave rise to two groups of data which are the objective and subjective data upon which this research is based. The heat-balance approach which involved the measurement of air temperature, relative humidity and radiant temperature, with the use of instruments constituted the objective data while the subjective data was based on a carefully structured questionnaire guided by the human thermal adaptation interrelated processes. De Dear and Brager, (1998) suggested that this could be behavioural, physiological and psychological.

Study Area

Jos is located in North Central Nigeria at latitude 9^{o} 55^{1} 48^{11}N and longitude 8^{o} 53^{1} 24^{11}E on the plateau at about 1,238 metres or 4,062 feet high above sea level as shown in Figure 1. The climate of Jos falls within the tropical savannah climatic zone with average monthly temperature ranging between 21 ^{o} C and 25 ^{o} C. Typical of tropical climate, Jos has two major seasons, dry and wet or rainy seasons. The dry season is usually between the months of October and April when rainfall is less and temperature is high with low humidity. The wet or rainy season is within the period between May and September and is usually characterized by low average temperature but high humidity with average rainfall and humidity of 1,400mm and 60% respectively. The climate of Jos can be said to be moderate as compared to other cities within the same zone. This is because of its position above sea level which affects its micro-climate making the city enjoy relatively low average temperature the year round. A maximum monthly temperature of 34 ^{o} C is usually recorded between the months of March and April, and a maximum of 27.1 ^{o} C in August which is the middle of the rainy season. The minimum lowest monthly temperature of 13.1 ^{o} C usually occurs between December and January a period of dry cold harmattan season, while the highest minimum of 18 ^{o} C occurs in August which is also the middle of the rainy season.

Jos City has witnessed a high level of urbanization in the last two and a half decades with large-scale housing development. The effect of urbanization and global warming has effects on the unique microclimate of Jos city which was hitherto acclaimed as a cold city as temperature is observed to be on the increase in the city lately.

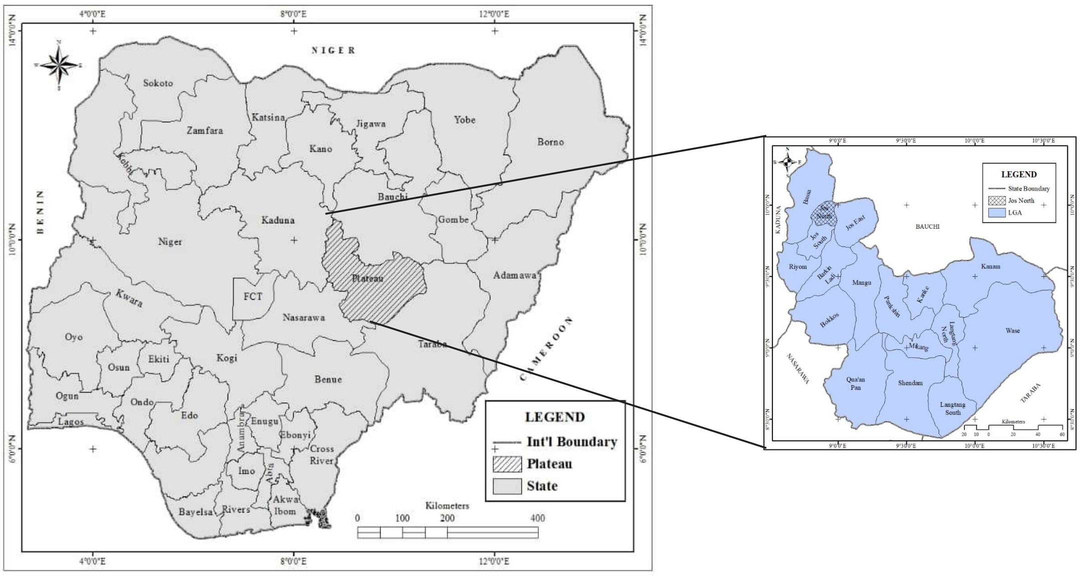


Figure 1: Map of Nigeria Showing Plateau State and Study Area
Source: University of Jos GIS Laboratory (Accessed 15/09/2023).

METHODOLOGY

Thermal comfort research requires a combination of two important groups of data which are the subjective and objective data. This is so because of the complex nature of thermal comfort where a combination of human and environmental factors are involved in varying proportions. While the human factors are subjective and involve the occupant's subjective perception of thermal comfort, the environmental factors are objective and involve physical measurement of thermal comfort parameters.

To determine the subjective thermal sensation votes of occupants in this research therefore, a subjective thermal comfort survey was carried out by the use of a questionnaire which was carefully designed to obtain relevant information bordering on the thermal conditions of respondents. The questionnaire was designed in line with the ASHRAE's Standard 55 (ASHRAE, 2013) and European Standard EN 15251 (EN15251, 2012) which adopted the thermal comfort model of Fanger (1970). These models are based on subjective assessment of the thermal environment given on the 7-point thermal sensation scale (1-cold – 2-cool – 3-slightly cool – 4-neutral – 5-slightly warm – 6-warm – 7-hot).

The objective data involved the measurement of both outdoor and indoor physical environmental variables with the aid of instruments. The environmental variables measured in this research were four, which include (1) air temperature, (2) relative humidity, (3) radiant temperature of the wall and (4) radiant temperature of the glazed window. The equipment used for measuring these variables was the Oregon Professional Weather Center Model: WMR200/WMR200A, a weather station for outdoor environmental variables as shown in Plate 1, while for indoor variables, Digital Data Loggers were used for measuring air temperature, radiant temperatures of (wall & window glass) and relative humidity are shown in Plates 2 and 3. The building typologies selected for measurement were measured simultaneously with equipment stationed at the living room, bedroom and kitchen for each of the selected buildings within the same housing quarters shown in plates 4-7 and their respective floor plans as indicated in Figures 2-3. The outdoor measuring equipment was however stationed in one location within the housing quarters.

To determine the average thermal conditions of the study area for the year, measurement of the physical variables was carried out at different seasons of the year that is hot, wet and cold seasons of the year, with measurements spanning a period of six to eight weeks within each season. For convenience and because of the limited number of equipment, physical parameters for this study

were only recorded at one uniform height above the floor which is 1.2m for air velocity and air temperature and the same height of 1.2m for radiant temperature and humidity. The equipment were stationed at different positions within the living spaces to measure parameters at the north, west and east-facing walls for indoor measurements. The Digital Thermometer and Anemometer were both connected to a laptop computer which recorded all measurements by the equipment on per per-second basis. All the equipment used for measurement in this study were well-calibrated to ensure the accuracy and reliability of the readings before the field measurement. All the equipment used met the ISO 7730 requirements (ISO, 2005).

Plate 1: Weather Station for Measurement of Outdoor Environmental Variables at the University of Jos

Source: Fieldwork (2023)

Plate 2: Digital Equipment Setup for Field Measurement of Data for Indoor Space

Source: Fieldwork (2023)

Plate 3: Digital Thermometer Instrument for Field Measurement of Radiant Temperature
Source: Fieldwork (2023)

Case Study

Two building typologies selected for this study were a 3-bedroom bungalow and a 4-bedroom duplex at the University of Jos Senior Staff Quarters. The two buildings are in the same physical environment under similar microclimatic conditions, the two building typologies are selected from the drawn-up samples of 80 buildings out of a total of 198 buildings of the University of Jos Senior Staff Quarters. These building typologies under investigation are naturally ventilated with all the rooms cross ventilated, their materials of construction are similar with a main vertical envelope of 230mm sandcrete block wall with internal and external plastering as a finish. The windows are glazed with clear glass, the floor of concrete with thermoplastic tiles, and the roof of the two building typologies is a simple timber structured gable roof with a corrugated asbestos roofing sheet. The distinguishing features in the material and method of construction between the two building typologies are the reinforced concrete suspended floor of the four-bedroom duplex, the reinforced concrete ceiling slab also of the four-bedroom duplex, while the bungalow is of the asbestos ceiling and a corrugated iron canopy over windows of the bungalow building.

Figure 2: Case Study1 Floor Plan

Source: Fieldwork (2023)

Plate 4: Case Study1 South Elevation
Source: Fieldwork (2023)

Plate 5: Case Study1 East Elevation
Source: Fieldwork (2023)

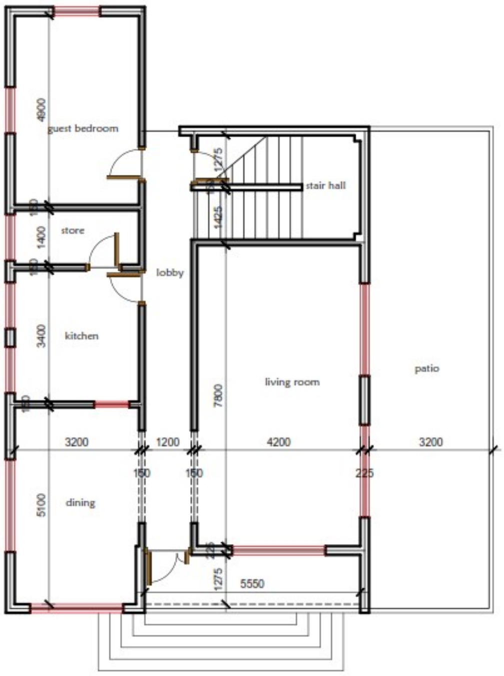


Figure 3a: Case Study2 Ground Floor plan
Source: Fieldwork (2023)

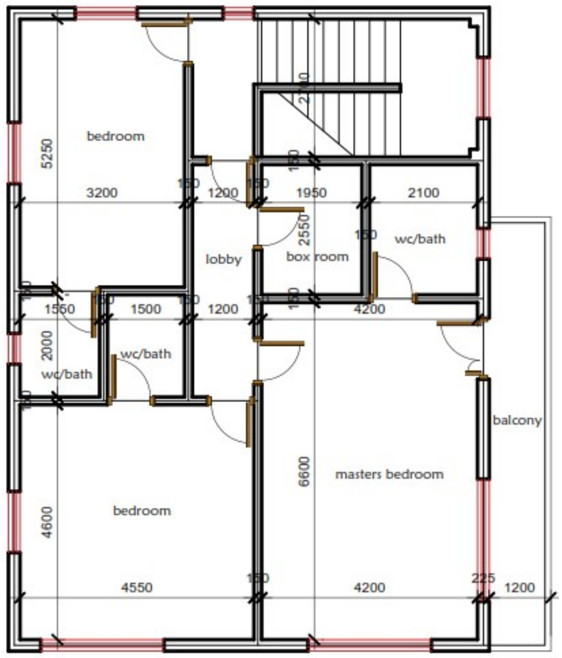


Figure 3b: Case Study2 1st Floor plan
Source: Fieldwork (2023)

Plate 6: Case Study2, North Elevation

Source: Fieldwork (2023)

Plate 7: Case study2, Passive Energy West Elevation

Source: Fieldwork (2023)

Population and Sample Size

A sample size of 80 buildings was selected from a total population of 198 existing housing units of the University of Jos senior staff quarters, using Cochran's sample size equation cited in Fellows and Liu (2008). Based on Cochran's equation one respondent was selected from each building in the entire building population of 198 on which the study was based. For the required sample size of 80 and a return rate of 70%, 104 questionnaires were distributed.

PRESENTATION OF RESULTS AND DISCUSSION

The occupant survey was carried out in two different seasons, first in December 2018/January 2019 and in June/July 2019. Survey participants were drawn from 80 houses which is the sample size selected from a total number of 196 houses which constitute the total housing units of the University of Jos Senior Staff Quarters Housing Estate, Bauchi Road. The survey participants were drawn from residents of a 3-bedroom bungalow and a 4-bedroom duplex. From the total of 80 questionnaires administered in the two seasons 76 and 64 were completed and returned for December/January and June/July respectively. The response rate accounted for 95% and 80% respectively. The reason for the high rate of response may be a result of follow-up by the research assistants who in most cases waited and guided the respondents in answering the questions, particularly the technical questions and in most cases retrieved the questionnaires there and then.

Gender, Age and Marital Status

Results of the questionnaire administered in two seasons of the year indicated that 43% of the 64 respondents in the rainy season were male, and 57% were female. The age distribution of respondents shows that the majority of the respondents were adults with the age distribution of only 10.9% that were below the age of 18 years, 37.5% were between 18 and 25 years old, 23.4% were between 26 and 35 years old, 17.2% were between 36 and 50 years old, while those above 50 years were10.9%. The mean occupant's age of 2.80 indicates that the majority of the occupants/respondents fall within the age of between 18 and 35 years old. The marital status indicates that the majority of the respondents, 64.1% were single and 35.9% were married. In dry season54% of the 74 respondents in rainy season were male, and 46% were female. The age distribution of respondents shows that the majority of the respondents were adults with the age distribution of 2.7% below the age of 18 years, 33.8% between 18 and 25 years old, 31.1% between 26 and 35 years old, 23.0% were between 36 and 50 years old, while those above 50 years were 9.5%. The mean occupant's age of 3.03 indicates that the majority of the occupants/respondents fall within the age of between 26 and 50 years old. The marital status indicates that the majority of the respondents, 54.1% were single and 45.9% were married.

Table 1: Percentage Distribution of Occupants' Demographic Characteristics in the Case Study Buildings

	Seasonal Distribution					
Characteristics	**Rainy Season (n=64)**			**Dry Season (n=74)**		
	%	**Mean**	**SD**	**%**	**Mean**	**SD**
Age of Occupants		2.80	1.184		3.03	1.033
Below 18yrs	10.9			2.7		
18 - 25yrs	37.5			33.8		
26 -35yrs	23.4			31.1		
36 - 50yrs	17.2			23.0		
Above 50yrs	10.9			9.5		
Total	100.0			100.0		

Source: Fieldwork (2023)

Respondents Indoor Thermal Conditions (Bungalow)

The result of the indoor thermal conditions of respondents indicates the feeling of indoor thermal parameters by respondents at the hours of the day when the survey was conducted. The measurement of the parameters is based on a thermal comfort scale of 7 which ranges from cold at one extreme to hot at the other. The 7 scale rating includes; cold, cool, slightly cool, neutral, slightly warm, warm and hot. The responses as presented in Table 2 for the 3-bedroom bungalow show a mean of 4.14 for perceived room temperature in the rainy season which shows that the respondents mostly with the feeling of between being neutral or slightly warm, thermal comfortability is a mean of 3.00 indicating that most respondents were slightly comfortable, however thermal preference as can be seen from the table is a mean of 2.78 which indicate that most respondents thermal preference is between too cool or a little bit cool.

The means of indoor thermal environment control in the rainy season for the 3-bedroom bungalow is a mean of 4.19 and a standard deviation of 2.64, which indicates that most respondents use either a portable room heater or a portable fan, the standard deviation of 2.64 indicates a difference in the thermal feeling of respondents and their means of controlling it. The period of the day when respondents generally feel comfortable between the early morning hours and late evening hours is a mean of 2.73 on a scale of 6 which includes four other periods between the two extreme periods that is mid-morning hours, early afternoon hours, late afternoon hours and early evening hours. The 2.73 mean indicates that most respondents feel most comfortable between mid-morning and early afternoon hours. The tolerance level of the respondents at the period of the survey is a 5 scale rating beginning with perfect tolerance, slightly hard to tolerate, hard to tolerate, very hard to tolerate to intolerable. The room tolerance is a mean of 2.05 which indicates that the majority of the respondents consider the room to be slightly hard to tolerate. The Perceived Relative Humidity is also a scale of 5 like the Room tolerance level, the result is a mean of 1.84 which also indicates that most of the respondents find humidity to be slightly hard to tolerate.

In the dry season, the results obtained were slightly different from those of the rainy season for the same 3-bedroom bungalow as the mean for perceived room temperature was 3.91 indicating that most of the respondents were mostly feeling either slightly cool or neutral, thermal comfort level in dry season had a mean of 2.34 indicating that most respondents were moderately or slightly comfortable, thermal preference of most respondents in dry season is a mean of 3.46 which indicative of a preference of a little bit cool or no change by most respondents.

The means of indoor thermal environment control in dry season is a mean of 5.15 which indicates that most respondents use portable fans, the period of the day when respondents generally feel comfortable is a mean of 3.36 which is indicative of early afternoon and late afternoon from the scale of 6 like in the rainy season. The tolerance level of the respondents in the dry season on a 5 scale rating like in the rainy season is a mean of 1.56 which indicates that the majority of the respondents consider the room to be either perfectly tolerable or slightly hard to tolerate. The Perceived Relative Humidity in the dry season is however without a significant difference from that of the rainy season as the result shows a mean of 1.83 which also indicates that most of the respondents find humidity to be slightly hard to tolerate.

Table 2: Respondents Indoor Thermal Conditions (Three-Bedroom Bungalow)

	Rainy Season (n=37)		Dry Season (n=41)		Overall (n=78)	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Perceived Room Temperature	4.14	1.70	3.71	1.05	3.91	1.41
Thermal Comfort Level	3.00	1.67	2.34	1.17	2.65	1.46
Thermal Comfort Preference	2.78	1.42	3.46	1.12	3.14	1.31

Means of Indoor Environment Control	4.19	2.64	5.15	2.04	4.69	2.38
Period of the Day Most Comfortable	2.73	1.95	3.63	1.91	3.21	1.97
Room Tolerance	2.05	0.74	1.56	0.63	1.79	0.73
Perceived Relative Humidity	1.84	0.83	1.83	0.70	1.83	0.76

Source: Fieldwork (2023)

Air Temperature

Air temperature values as shown in Table 3 recorded average values for the following indoor living spaces for the bungalow, the living room recorded an average value of 23.6^{o} C in the rainy season, bedroom and kitchen recorded average temperatures of 24.3^{o} C and 23.9^{o} C respectively in the same rainy season. The value of outdoor average air temperature recorded in the season was 23.55^{o} C. Dry season values for air temperature range from 25.2^{o} C for the living room, 27.8^{o} C for the bedroom to 25.0^{o} C for the kitchen while the outdoor average temperature recorded for the season was 28.8^{o} C. The value recorded for air temperature as can be seen from the table is highest for the bedroom in the two seasons this may be a result of the orientation of the bedroom which is to the west and the west orientation is most exposed to the hottest part of the day as the sun directly faces the bedroom from the west from mid-day to sunset.

Relative humidity

Relative humidity as recorded in the rainy and dry seasons as shown in Table 30 shows high values in the rainy season and relatively low values in the dry season. The daily hourly average relative humidity values in the rainy season were 73.4% for the living room, 71.3% for the bedroom and 74.0% for the kitchen. From the recorded values for relative humidity, the kitchen had the highest value followed by the living room and the lowest value was recorded in the bedroom. The corresponding outdoor daily hourly average value recorded for relative humidity for the same season as can be seen from the table was 70.1%. The relative humidity values recorded in the dry season for the living room were 28.9%, the bedroom recorded 27.4% and 26.4% for the kitchen. The highest value of 28.9% recorded in the dry season was in the living room followed by the bedroom, while the lowest value of 26.4% was recorded for the kitchen. The corresponding outdoor daily hourly average value recorded for relative humidity in the same dry season was 32.3%.

Radiant temperature (Wall)

The average daily hourly values recorded for the radiant temperature of the wall which is one of the main enveloping components show no significant difference in the dry season when compared with values obtained in the rainy season. The highest average is recorded in the rainy season. The daily hourly radiant temperature values for the wall in the rainy season were 22.0^{o} C for the living room, 23.6^{o} C for the bedroom and 21.8^{o} C was recorded for the kitchen, similarly, the values recorded in the dry season for the radiant temperature of the wall shows the higher value for the spaces measured. The value recorded for the living room was 22.2° C, the bedroom recorded 24.2° C and 22.8° C was recorded for the kitchen.

Radiant temperature (Glass)

Average daily hourly values were also taken for the radiant temperature of window glass as a part of the external envelope through which heat is transferred into the interior of the building. The values recorded in the rainy season show the highest value of 23.5°C recorded for the window glass of the bedroom and the kitchen, while 23.3°C was recorded for the living room. In the dry season, the living room also recorded the lowest value of 23.2°C radiant temperature for the window glass. The highest value recorded in this season was in the bedroom which was 26.8°C followed by the kitchen which recorded a radiant temperature of window glass of 24.5°C. Table 3 shows the recorded values for the measured thermal variables in the measured living spaces for the three-bedroom bungalow for the rainy and dry seasons. Average indoor values were obtained for air temperature, relative humidity, and radiant temperature for wall and window glass for the measured living indoor spaces which include the living room, bedroom and kitchen for the two building typologies measured in the two seasons that is Rainy season and dry season.

Table 3: Daily Hourly Average for Measured Variables/Parameters for Rainy and Dry Seasons (Bungalow)

Measured Variables	**Measured Spaces**					
	Rainy Season			**Dry Season**		
	Living Room	**Bedroom**	**Kitchen**	**Living Room**	**Bedroom**	**Kitchen**
Air Temperature in °C	23.6	24.3	23.9	25.2	27.8	25.0
Relative Humidity in %	73.4	71.3	74.0	28.9	27.4	26.4
Radiant Temperature (Wall) in °C	22.0	23.6	21.8	22.2	24.2	22.8
Radiant Temperature (Window Glass) in %	23.3	23.5	23.5	23.2	26.8	24.5
Outdoor Air Temperature in °C	23.55	23.55	23.55	28.8	28.8	28.8
Outdoor Relative Humidity in %	70.1	70.1	70.1	32.3	32.3	32.3

Source: Fieldwork (2023)

Respondents Indoor Thermal Conditions (Duplex)

Table 4 is the result of the indoor thermal conditions of respondents for the 4-bedroom duplex. The result shows a mean of 3.48 for perceived room temperature at the hours of the day in the rainy season when the survey was conducted, this indicated that most of the respondents perceived the temperature to be either slightly cool or neutral, a mean of 3.26 was recorded for thermal comfortability, indicating that most respondents were slightly comfortable, thermal preference is a mean of 2.81 which indicate that most respondents thermal preference is for a little bit cool. The means of indoor thermal environment control in rainy season for the 4-bedroom duplex which is a mean of 5.00is indicative of the use of a portable fan by most respondents. The result of the period of the day when respondents generally feel comfortable is a mean of 3.22 indicating that most respondents in the 4-bedroom duplex feel most comfortable in the early afternoon hours of the day. The tolerance level of the respondents at the period of the survey with a 5 scale rating beginning from perfectly tolerance, slightly hard to tolerate, hard to tolerate, very hard to tolerate to intolerable recorded a mean of 1.78 which shows most of the respondents considered their rooms to be slightly hard to tolerate. The Perceived Relative Humidity which is also a scale of 5 like the room tolerance level, recorded a mean of 2.07 which also indicates that most of the respondents find relative humidity to be slightly hard to tolerate.

There were no significant differences between the results obtained in the dry season and that of the rainy season for the 4-bedroom duplex as the mean for perceived room temperature was 3.68 indicating that most of the respondents were mostly feeling either slightly cool or neutral, thermal comfortability in dry season had a mean of 2.57 indicating that most respondents were moderately or slightly comfortable, thermal preference of most respondents in dry season is also without significant difference with a mean of 2.90 which is indicative of a preference of a little bit cool by most respondents.

The means of indoor thermal environment control in dry season for the 4-bedroom duplex is a mean of 4.78 which indicates that most respondents use a portable fan, the period of the day when respondents generally feel comfortable is a mean of 2.95 which is indicative of early afternoon from the scale of 6 like in the rainy season. The tolerance level of the respondents in the dry season on a 5 scale rating like in the rainy season is a mean of 1.58 which indicates that the majority of the respondents consider the room to be either perfectly tolerable or slightly hard to tolerate. The Perceived Relative Humidity in the dry season is also without a significant difference from that of the rainy season as the result shows a mean of 1.80 which also indicates that most of the respondents find humidity to be slightly hard to tolerate.

Table 4: Respondents Indoor Thermal Conditions (Four-Bedroom Duplex)

	Rainy Season (n=27)		Dry Season (n=33)		Overall (n=60)	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**

Perceived Room Temperature	3.48	1.42	3.67	1.55	3.58	1.49
Thermal Comfortability	3.26	1.35	2.00	1.37	2.57	1.49
Thermal Comfort Preference	2.81	1.24	2.97	1.05	2.90	1.13
Means of Indoor Environment Control	5.00	2.02	4.61	2.57	4.78	2.33
Period of the Day Most Comfortable	3.22	2.10	2.73	1.94	2.95	2.01
Room Tolerance	1.78	0.80	1.42	0.61	1.58	0.72
Perceived Relative Humidity	2.07	1.04	1.58	0.79	1.80	0.94

Source: Fieldwork (2023)

Air temperature

Air temperature values as presented in table 5 are average values for the indoor living spaces measured for the duplex. The Air temperature value recorded for the living room was an average of 24.0°C in the rainy season, in the bedroom and kitchen average temperature values of 24.3°C and 25.2°C were recorded respectively in the same rainy season while the value of outdoor average air temperature recorded in the season was 23.55°C. The values for air temperature recorded in the dry season range from 24.4°C for the living room, 24.6°C for the bedroom to 24.8°C for the kitchen while the outdoor average temperature recorded for the season was 28.8°C. The value recorded for air temperature as presented in the table is highest in the kitchen in both rainy and dry seasons this may be a result of both the orientation and size of the kitchen of the duplex. The orientation of the kitchen is to the east which is exposed to the rising sun and receives direct heat from the sun from morning hours to afternoon of the day, and the size/headroom of the duplex is less than in the bungalow.

Relative humidity

Table 5 also shows the relative humidity as recorded in the rainy and dry seasons for the duplex. The values recorded were higher in the rainy season as compared to values recorded in the dry season, as shown in the table the values in the rainy season were almost three times the values recorded in the dry season. The daily hourly average relative humidity values in the rainy season were 66.5% for the living room, 55.6% for the bedroom and 60.9% for the kitchen while the corresponding outdoor average value recorded for relative humidity for the season was 70.1%. From the recorded values for relative humidity, the living room recorded the highest value followed by the kitchen while the bedroom recorded the lowest in the rainy season. The relative humidity values recorded in the dry season for the living room were 20.8%, the bedroom recorded 23.5% while 22.4% was recorded for the kitchen. The highest value of 23.5% recorded in the dry season was in the bedroom followed by the kitchen, while the lowest value of 20.8% was recorded for the living room. However, the corresponding outdoor daily hourly average value of relative humidity in the dry season was 32.3%.

Radiant temperature (wall)

The recorded values for radiant temperature for the wall show daily hourly average values that were slightly higher in the rainy season as compared to values recorded in the dry season. In the rainy season, daily hourly radiant temperature values for the wall were 20.8°C for the living room, 30.3°C for the bedroom and 22.6°C was recorded for the kitchen. Values recorded in the dry season for the radiant temperature of the wall were 20.0°C for the living room, 29.5°C for the bedroom while the kitchen recorded 23.0°c. The recorded value of radiant temperature for the kitchen wall is however slightly higher in the dry season compared to the value in the wet season. The reason for lower values for radiant temperature in the dry season may be as a result of harmattan which occurs in the middle of the dry season and is usually characterised by low temperature and humidity.

Radiant temperature (glass)

Average daily hourly radiant temper values recorded for window glass for the duplex in the rainy season show the highest value of 29.6°C recorded for the window glass of the bedroom, the value recorded for the kitchen was 24.0°cwhile the lowest value of 22.5°C was recorded for the living room. In the dry season, the living room also recorded the lowest value of 21.3°C radiant temperature for the window glass, the highest value recorded in this season was also in the bedroom which was 29.8°C followed by the kitchen which recorded a radiant temperature of window glass of 24.0°C. The relatively low value recorded for the radiant temperature of the window glass of the living room in the duplex in the two seasons even though the measured external wall was with west orientation may not be unconnected with the large trees which shaded the west wall from direct sun rays.

Table 5: Daily Hourly Average for Measured Thermal Variables for Rainy and Dry Seasons (Duplex)

Measured Variables	Measured Spaces					
	Rainy Season			Dry Season		
	Living Room	Bedroom	kitchen	Living Room	Bedroom	kitchen

Air Temperature in ^oC	24.0	24.3	25.2	24.4	24.6	24.8
Relative Humidity in %	66.5	55.6	60.9	20.8	23.5	22.4
Radiant Temperature (Wall) in ^oC	20.8	30.3	22.6	20.0	29.5	23.0
Radiant Temperature (Window Glass) in ^oC	22.5	29.6	24.0	21.3	29.8	24.0
Outdoor Air Temperature	23.55	23.55	23.55	28.8	28.8	28.8
Outdoor Relative Humidity in %	70.1	70.1	70.1	32.3	32.3	32.3

Source: Fieldwork (2023)

Table 5 shows the recorded values for the measured thermal variables in the assessed living spaces for the four-bedroom duplex for the rainy and dry seasons. Just like in the three-bedroom bungalow, average indoor values were obtained for air temperature, relative humidity, and radiant temperature for wall and window glass for the measured living indoor spaces that is living room, bedroom and kitchen.

Typical Construction Materials of Surveyed Residences (Bungalow)

Table 6 is the result of the building envelope construction materials for the bungalows surveyed. Building materials were broken into (Wall, Roof and Floor) materials, Finishes for Floor and Ceiling as well as Fixtures for doors and windows. The survey shows that for the three-bedroom bungalow the roof covering material recorded a mean of 1.68 in the rainy season which indicates that the majority of the three-bedroom bungalow had long-span aluminium roofing sheets as roof covering material, walling material recorded a mean of 2.54 in the rainy season which indicated that majority of the building enveloping element were of 225mm hollow sandcrete blocks, floors/floor finishes is a mean of 3.24 which indicate that the three-bedroom bungalows were mainly of the concrete floor slab with screed and terrazzo finish, ceiling material recorded a mean of 2.81 which indicate that ceiling material for most of the three-bedroom bungalow surveyed in the rainy season was of hardboard ceiling, windows material recorded a mean of 2.84 which indicated awning windows with glass while door material recorded a mean 1.89 which is indicative of wooden panel doors as the major type of doors recorded for three bedroom bungalows in the rainy season.

The result of the survey in the dry season as shown in the same table 8 is just slightly different from that of the rainy season as the buildings selected for the survey in the two seasons were not the same. The survey in dry season shows that for the three bedroom bungalow the roof covering material recorded a mean of 1.54 which indicate that majority of the three bedroom bungalows like in rainy season had long span aluminum roofing sheets as roof covering material, walling material recorded a mean of 2.85 in dry season indicating a majority of the building enveloping element were of 225mm hollow sandcrete blocks as in rainy season, floors/floor finishes is a mean of 2.90 indicated no significant change from the result recorded in rainy season when the three bedroom bungalows were mainly of concrete floor slab with screed and terrazzo finish, ceiling material recorded a mean of 2.73 which indicate that ceiling material for most of the three bedroom bungalow surveyed in dry season were of hard board ceiling as well, windows material recorded a mean of 2.39 which indicated aluminum sliding windows with glass as against awning windows with glass recorded during the rainy season, door material as recorded in dry season is a mean 1.34 which is indicative of steel panel door as the major type of doors as recorded for three bedroom bungalows as against wooden panel doors recorded in rainy season.

Table 6: Typical Construction Materials of Surveyed Residences (Bungalow)

Roofing material	1.68	0.91	1.54	0.81	1.60	0.86
Walling material	2.54	1.32	2.85	0.96	2.71	1.15
Floors/floor finishes material	3.24	1.88	2.90	1.34	3.06	1.61
Ceiling material	2.81	1.60	2.73	1.55	2.77	1.56
Windows material	2.84	1.38	2.39	1.56	2.60	1.49
Doors material	1.89	0.81	1.34	0.88	1.60	0.89

Source: Fieldwork (2023)

Typical Construction Materials of Surveyed Residences (Duplex)

Table 7 is the result of the building envelope construction materials for duplexes surveyed. Building materials were broken into (Wall, Roof and Floor) materials, Finishes for Floor and Ceiling as well as Fixtures for doors and windows. The results obtained for the four bedroom duplexes shows that roof covering material recorded a mean of 2.26 in rainy season which indicate that majority of the four bedroom duplexes had long span aluminum roofing sheets as roof covering material, walling material recorded a mean of 3.37 in rainy season which indicate that the enveloping element of the four bedroom duplexes were mainly of 225mm hollow sandcrete blocks, floors/floor finishes is a mean of 3.56 which indicate that the four bedroom duplexes were mainly of concrete floor slab with screed and ceramic tiles as floor finish, ceiling material recorded a mean of 3.63 which indicate that ceiling material for most of the four bedroom duplexes surveyed in rainy season were of gypsum board ceiling, windows material recorded a mean of 2.33 which indicated aluminum sliding windows with glass while door material recorded a mean 1.70 which is indicative of wooden panel doors as the major type of doors recorded for four bedroom duplexes in rainy season.

The result of the survey in the dry season as shown in the same table 7 is only slightly different from that of the rainy season as the set of buildings selected for the survey in the dry season were different from those surveyed in the rainy season. The survey in dry season shows that for the four bedroom duplexes the roof covering material recorded a mean of 2.46 which indicate that roof covering material for the four bedroom duplexes like in rainy season were mainly of long span aluminum roofing sheets, walling material recorded a mean of 3.12 in dry season indicating that for majority of the buildings, enveloping element were made of 225mm hollow sandcrete blocks like it was in rainy season, floors/floor finishes recorded a mean of 3.21 which indicate that majority of the four bedroom duplexes surveyed in dry season were of concrete floor slab with screed and terrazzo finish, this is different from the result recorded in rainy season when the four bedroom duplexes were mainly of concrete floor slab with screed and ceramic tiles, the reason for this difference may be as a result of renovation works that have taken place over the years when new finishing materials may have been introduced as it appears that the common finishes for floors were originally concrete floor slab with screed and terrazzo finish for all the duplexes. Ceiling material recorded a mean of 4.09 which indicates that ceiling material for most of the four-bedroom duplexes surveyed in the dry season was of gypsum board ceiling as was recorded in raining season, windows material recorded a mean of 2.52 which indicated awning windows with glass as against aluminium sliding windows with glass recorded during the rainy season, door material as recorded in dry season is a mean 1.70 which is indicative of wooden panel door as the major type of doors same as recorded in rainy season.

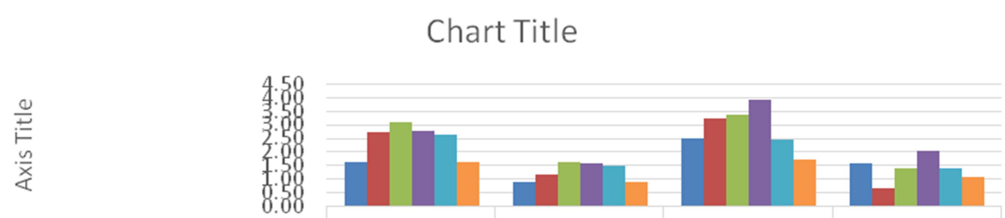
Table 7: Typical Construction Materials of Surveyed Residences (Four-Bedroom Duplex)

	Rainy Season (n=27)		**Dry Season (n=33)**		**Overall (n=60)**	
Variable	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Roofing material	2.26	1.38	2.64	1.67	2.47	1.55
Walling material	3.37	0.84	3.12	0.42	3.23	0.65
Floors/floor finishes material	3.56	1.40	3.21	1.34	3.37	1.37
Ceiling material	3.63	1.96	4.09	2.10	3.88	2.03
Windows material	2.33	1.39	2.52	1.39	2.43	1.38
Doors material	1.70	0.67	1.70	1.33	1.70	1.08

Source: Fieldwork (2023)

Correlation between Typical Construction Materials of Surveyed Residences of Three Bedroom Bungalows and Four Bedroom Duplexes

As can be seen from the chart there are differences in Typical Construction Materials of Surveyed Residences of Three Bedroom Bungalows and Four Bedroom Duplexes, though the differences were not too significant.



	Three-Bedroom Bungalow		Four-Bedroom Duplex	
	Mean	SD	Mean	SD
Roofing material	1.60	0.86	2.47	1.55
Walling material	2.71	1.15	3.23	0.65
Floors/floor finishes material	3.06	1.61	3.37	1.37
Ceiling material	2.77	1.56	3.88	2.03
Winows material	2.60	1.49	2.43	1.38
Doors material	1.60	0.89	1.70	1.08

Figure 4: Chart showing the Correlation between Typical Construction Materials of Surveyed Residences of Three Bedroom Bungalows and Four Bedroom Duplexes

Source: Fieldwork (2023)

CONCLUSION

This research work was carried out in other to assess the thermal comfort perception of occupants of residential housing typologies that are naturally ventilated in Jos, Nigeria. From the result of the thermal perception survey that was conducted, and the measured physical thermal parameters, it is obvious that the main determinants of Occupants' thermal comfort are air temperature, relative humidity, radiant temperature, and construction material/ensemble. The responses of the Occupants indicated that these parameters are influenced by the building design, the building material and its ensemble, as can be seen from the slight differences in the thermal perception between Occupants of the three-bedroom bungalow and that of the four-bedroom duplex. While Occupant's thermal comfort perception indicates that they were generally just okay with the thermal conditions in the two housing typologies, Occupants of the four-bedroom duplex were more satisfied with the thermal conditions as compared to those of the three-bedroom bungalow, this situation is obviously as a result of the differences in the design and material ensemble of the two building types. The thermal conditions in the two building typologies can however be improved by design strategies and careful choice and application of materials.

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