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Climatic Variations and Indoor Environmental Quality Performance of Houses in Selected Cities in Oyo State, Nigeria

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Abstract: *Understanding how climatic variations influence Indoor Environmental Quality (IEQ) becomes crucial for designing sustainable and comfortable living spaces in this specific region. This study therefore investigates the effect of climatic variations on IEQ performance of houses in selected cities within Oyo State, Nigeria. The types of data collected for the study were numeric and ordinal. The numeric data of air temperature, relative humidity, air velocity and noise level, were gotten through objective measurements and IEQ through IEQ Calculator. The ordinal data were gotten through observation and questionnaire. Control Potential Zone technique on psychometric chat was used to analyze climate of Ibadan, Ogbomoso and Kisi. The physical measurements were conducted in the living, bedroom and kitchen spaces of the sampled houses in the low, medium and high residential density zones of the selected cities. A sample size of 581 houses from 3,490 were selected across each of the three residential density zones in the selected cities. The indoor temperature and relative humidity in the three cities were higher during the afternoon period with average thermal stress index of 39.4^{0}C, 36.9^{0}C and 38.4^{0}C respectively for Ibadan, Ogbomoso and Kisi respectively. None of the spaces satisfied the effective indoor ventilation comfort criteria of between 0.5m/s -1.5 m/s. All the spaces except the bedroom space in the compound impluvium house type satisfied the illumination range of between 50 – 60 lux. The maximum indoor noise level during the morning, afternoon and evening periods in study area were 58db, 59db and 58db respectively. Result from the IEQ calculator indicated that majority of the houses (83.6%) were star 2 in the IEQ performance. The implication was that these houses were below average in terms of IEQ performance.*

Keywords: Indoor Environmental Quality (IEQ) Performance, Climatic variations, House types Thermal Stress, Control Potential Zone (CPZ)

INTRODUCTION

Man's comfort is invariably affected by the influence of climate around the earth. Consequently, man builds house to protect himself from harsh weather elements. The indoor environment is a very important dimension of housing. It provides accommodation and safety for people, which can be conducive and well suited for the intended use or otherwise. In Nigeria, housing studies have focused on the optimal use of space, building materials and technology in relation to cost (Amole, 2009). Physiological issues in building are very important; they are the indices of measuring the climatic effects on building, the result of which describe the comfort of indoor environment. The comfort in an indoor environment is indeed a major concern for the occupants of buildings. Indoor environment is therefore a complex setting essential for psychological health, happiness and dignity of the occupants. By experience, people living in residential buildings in warm humid climate like Nigeria experiences indoor discomfort which affects their lifestyle and well-being resulting from high temperature, high relative humidity, high solar radiation and low air velocity associated with the country's climate zone. The comfort or discomfort of an occupant in a house is dependent on the quality of indoor environment, which is in turn predominantly determined by four main ambient parameters: air quality, thermal comfort, acoustical ambience, and visual comfort.

Variations Climatic effects on Indoor comfort in residential buildings has been studied mainly in the context of major urban environment, however, studies of indoor comfort with respect to climate across different urban residential zones are very scanty in literature and especially in Nigeria. This is a critical issue because there are multi-dimensional in the climatic, spatial configuration, housing typology and structural form across the city or cities in addition to variation in density. These intracity and intercity variations in climate may result in a variety of indoor environmental qualities which need to be examined and evaluated in order to help in understanding the IEQ situations across the cities of the study.

The issue of global warming which heat up the outdoor environment especially in warm humid climate have imposed climatic stress on the indoor environment, the residents resulted to the use of active energy strategies to moderate their indoor environment. This action has proven to be uneconomical especially in Nigeria where economic recession has further complicated the issue (Adunola, 2006; Ayinla, 2011). If this study is not conducted now, these climatic variations may exacerbate the IEQ situation as majority of residents would not be able to afford the cost of active energy to create comfortable indoor environment. This study therefore, examined the implications of climatic variations on Indoor Environmental Quality (IEQ) of houses in both intracity and intercity of Ibadan, Ogbomoso and Kisi.

LITERATURE REVIEW

Since the beginning of time, man has been affected by the climate and its influence over the earth. The first humans were not known to have built shelter but evidence indicate that early humans lived in caves to protect themselves from weather elements. The climatic condition of any region depends on a number of geographical factors including the region's latitude, its position with respect to land and water, and its elevation above sea level. For climate there are no political boundaries, but there is always opinions within human societies as to whether a climate is acceptable or good or bad. This variation in judgment according to Adunola (2006) depends upon personal attitudes, past experiences and comfort level. Therefore the scale of good and bad differs from one place to another; for instance the people like the Eskimos find the climate along the fringe of the Arctic Ocean agreeable, whereas nomads of the desert like the desert climate. Many people in the modern world are adapting to the climate of their regions and feel uncomfortable when they are removed from them (Ayinla, 2018).

Climate plays a very important part in affecting people's daily life as well as the whole environment. Climate affects human behaviour, human health, human energy, national energy consumption. Climate is a very complex concept, consisting of five different factors, each one of which depends on the other. The different climatic factors are solar radiation, air temperature, relative humidity, wind and precipitation. Architects are usually interested in the factors of the climate which directly affect human comfort and building usage. These factors according to Ayinla (2018) are expressed in the form of averages, changes and extremes of temperature, the temperature differences between day and night, relative humidity, wind speed and direction, incoming and outgoing radiation, and rainfall and its distribution. The records of the climatic factors can be collected from different sources such as airports and meteorological stations.

The first architectural design with climate consideration in history is dated to the fourth century B.C in Greece with Vitruvius quoted as saying we must at the outset take note of the countries and climates in which buildings are built. He stressed the need to adjust buildings to the actual environmental and physical conditions that is climate responsive. Climate responsive architecture takes advantage of free energy in the form of heat and light. Each region of the world employs its own techniques and designs in its buildings that are best suited to that particular region and that encompass the region's cultural pattern.

The concept of bioclimatic architecture was first defined by the architect Victor Olgyay, when in 1963, published the results of his studies in the book "Design with Climate: Bioclimatic Approach to Architectural Regionalism" The essence of bioclimatic design from the book is to create a favourable microclimate both inside the building and outdoors through the application of architectural techniques. The studies produced comprehensive theoretical information about designing of the human-friendly spatial environment in different climatic regions and a design method, which employed a bioclimatic chart and determined comfort zones. According to Olgyay (1963), the design process of bioclimatic architecture is linear and consists of four successive stages (Figure 1).

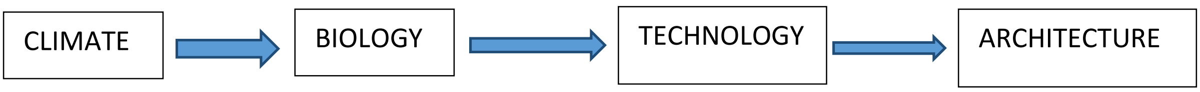

Figure 1: Olgyay bioclimatic design as a linear process.
Source: Olgyay (1963) .

Olgyay (1963), synthesized elements of human physiology, climatology and building physics, an architectural regionalism concept and designing with regards to the environment. The building envelope is essentially a modifier of the microclimate; a space isolated from excessive climate temperature and humidity, space isolated from excessive prevailing winds and precipitation, that excludes unwanted influences like excessive radiation but admits the desirable and useful, appropriate daylighting.

Later a number of other researchers undertook further study of bioclimatic design concept, among them Mahoney (1971) in Koenigsberger (1978), Givoni in 1976, Lippsmeier in 1980, Szokolay in 1986 and Ajibola in 2001. In 1971, Mahoney took a slightly different approach proposing a design methodology that followed three stages of design elaboration (the idea-sketching phase, development of the design and detail drawings). His method was based on a successive climate analysis. There were altogether six charts, where the first four of them were intended for the input of climate data to make a comparison with the comfort zone, and the last two were used for reading the recommended design principles as regards the layout, orientation and shape of the building respecting the local climate conditions. These studies formed an important basis for development of climate-appropriate and environmentally-balanced architectural design. Unfortunately, the methodology so thoroughly developed in the theory defied successful implementation in practice. The study of Givoni (1976) focused on the principles for determining comfort zones based on the average monthly climatic data (wind, humidity and temperature), using psychrometric charts as a methodological aid in designing.

Lippsmeier, in 1980, added cloudiness and precipitation to the list of elements that affect the climate requirements and asserted that the local climatic conditions should be taken into consideration when designing a building to ensure appropriate planning and construction. The author lists the consequences of ignoring these conditions as follows:

a. Human comfort, mental and physical capacities of the occupants can be impaired in case there are extreme conditions of solar radiation, glare, temperature and temperature change, precipitation, humidity, air movement or air pollution.
b. The safety of buildings can be endangered due to earthquakes, windstorms, flooding, tidal waves or biological agents.
c. Building can be damaged due to premature fatigue of building materials by intense solar radiation, high humidity and condensation, dust and sandstorms or salt content of the air.

Szokolay, in 1986, shared common features with Givoni (1976) and introduced the use of psychrometric chart and Control Potential Zone (CPZ) techniques to the analysis of climate for building design. According to him, control potential zone techniques are set of outdoor condition within which indoor comfort can be achieved by one of the passive control techniques.
A lot of research efforts have gone into the determination of the relationship between climate and architecture but the notable one conducted in warm humid climate of Nigeria was that of Ajibola in 2001 and Ayinla in 2015. In the two studies, they towed the line of Szokolay (1986), and described climate responsive design as a way a building form and structure moderate the outdoor climate to provide comfortable indoor climate for human good and well-being. Ayinla (2015) further suggested ways of moderating the indoor climate in buildings which includes sitting of buildings, shape and size of buildings, provision of cross ventilation, orientation, night ventilation, daylighting and choice of appropriate materials to prevent and minimize heat gain. Buildings should respond to passive energy and have minimal use of active energy for economic viability.

Urban climate and the building indoor climate are both parts of a climatological continuum. There is however an operational regional natural climate modified at the urban scale by the structure of the town or city; this is further modified at the site scale by the individual building. There are varieties of climatic influences and effects on individual buildings and communities as a result of mutual influence that exist between architecture and climate. Architecture intentionally modifies the climate of an immediate area. The architectural design is traditionally shaped by the challenges and opportunities of the regional climate. The analysis of the local climatic conditions is the starting point in formulating building and urban design principles aimed at maximizing indoor comfort.

The concept of comfort represents the state of a building occupants' satisfaction in relation indoor environment. Early research in this area dates from the first century AD, the notion being enunciated by Vitruvius Pollio in the ten famous books about architecture, *De architectura*, a treatise of Greek and Roman architecture dedicated to Emperor Augustus. In his work Vitruvius established performance criteria starting from how to choose the proper site of a city or a building, to compliance criteria of space, lighting, ventilation, acoustics and orientation, solutions to preventing excessive moisture or mutual shading of buildings, and to economic criteria for construction of a building. Considering these criteria enunciated since antiquity, now has been laid the groundwork to scientifically developing criteria of study the environmental effects on buildings and their users. Interior comfort is made up of several components, studying the interaction between them, and how they affect the building and people. Therefore, interior comfort components are:

a) Thermal comfort relative to temperature, humidity, air velocity.
b) Acoustic comfort: noise from outside, inside, vibrations, and so on.

c) Visual comfort and lighting quality: vision, lighting, indicator of brightness, reflection, and more.
d) The quality of indoor air pollution, odour, fresh air supply, and more.

Some authors have attempted to define what Indoor Environmental Quality (IEQ) is. IEQ connotes the satisfaction of building occupants with all the components of indoor environment. Most people spend their time indoors in offices, schools and homes, and as such, indoor environment (thermal, ventilation, visual and acoustic environments) could have beneficial effects for the occupants when appropriately designed and implemented. Improved indoor environment affects human health, well-being, and performance positively (Kuo, Chang and Chiang, 2008; Di Giulio, Grande, Campili, di Bartolomeo and Cellini, 2010). In 1997, Clement-Croome in the book titled "Naturally Ventilated Building" comprehensively defined comfort as the overall comfort of a building interior and health of its occupants, according to him, comfort is an interaction between not just the ambient physical dimension of indoor environment but also of social and spatial ones.

The Study Area.

The study was carried out in Three (3) selected cities in Oyo State, Nigeria. These cities are Ibadan, Ogbomoso, and Kisi. Oyo State falls entirely within the warm humid climate, there are however variations in the micro climatic conditions in these selected cities. Each of these cities is socially and geographically unique because of the differences in their level of urbanization and micro climate respectively.

Ibadan is located on latitude $7^{0}23^{I}$N, longitude $3^{0}55^{I}$E, it is however within the rain forest region of Nigeria. Ogbomoso on the other hand, lies on $8^{0}10^{1}$ North of the equator and longitude $4^{0}10^{1}$ East of the Greenwich Meridian, within the derived savannah region of Nigeria, while Kisi is located on latitude $9^{0}05^{I}$N and longitude $3^{0}51^{I}$E, and falls within the real savannah with alternating wet and dry seasons. These peculiarities portends possible implications on their indoor environmental quality. The location and site features of these cities are shown in figure 2.

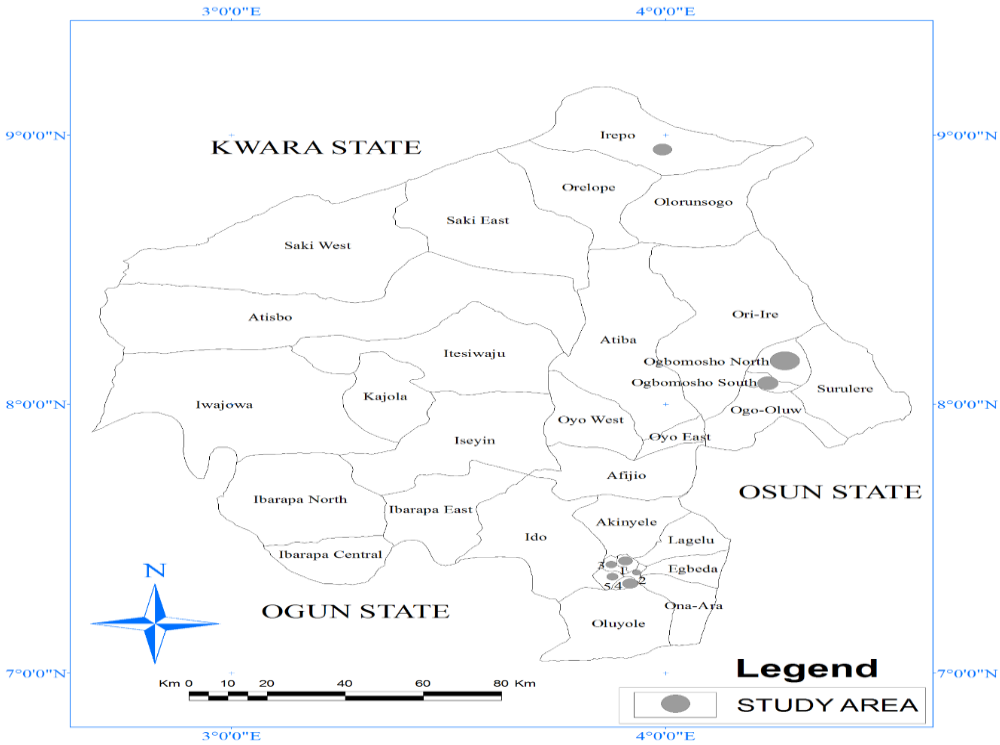

Figure 2: Location of Ibadan, Ogbomoso and Kisi on Oyo State Map
Source: Urban and Regional Planning Department, LAUTECH, Ogbomoso.

METHODOLOGY

The types of data collected were numeric and ordinal. The numeric data were gotten using technical instruments of objective measurements and relevant software. The ordinal data were gotten through observation and questionnaire. The technical instruments involved the use of three equipment and one software to physically measure indoor climatic elements such as temperature, relative humidity, air velocity and noise. The physical measurements of these ambient parameters were conducted in the living, bedroom and kitchen within the sampled residential buildings in the low, medium and high residential density zones.

Kestrel 4500 Pocket Weather and Environmental Meter was used to measure indoor temperature, relative humidity, air velocity as well as heat stress which is the perceived temperature resulting from the combined effects of temperature and relative humidity It has a maximum range of operation for various elements, the range is from -29^{0}C to 70^{0}C for temperature, 5% to 95% for relative humidity and 0.01m/s to 60m/s for air velocity. Noise Dosimeter was used to measure noise exposure. The second-by-second measurements provided by dosimeter is ideal for performing detailed analysis of daily pattern of noise or sound level exposure measured in decibel. The intensity of light source, as perceived by the human eye was measured with Lux Meter which has provision for saving minimum and maximum lux values, the equipment also has calibration multiplier and supports both lux and foot candles. The illumination level was measured in in lumen. Complementing the equipment was the IEQ Calculator (Apartment) Software, the software was used to rate the indoor environmental quality of the studied spaces, it was adopted for the measurement because it provided an easier alternative to estimate the indoor environmental quality (IEQ) in residential environment. Several values of indoor ambient parameters derived from objective physical measurement were taken and imputed on IEQ calculator. The parameter included air temperature, relative humidity, room floor area, room density, air velocity, illumination level, as well as acoustic level. The Indoor Environmental Quality (IEQ) of the apartment was therefore expressed via a 5-star bench marking scale (5 – star Best Apartment, 1-star Worst apartment. A sample of 581 houses were selected from a total population of 3.490 houses proportionately distributed across each of the three residential density zones in the three selected cities of Ibadan, Ogbomoso and Kisi for the study.

Climatic data were obtained from the Metrological stations in Ibadan, Ogbomoso and Kisi as secondary data. The data obtained includes values for air temperature, relative humidity, air velocity and solar radiation were subjected psychrometric chat for climate analysis.

RESULTS AND DISCUSSION

Interaction of climate and building provide an indoor climate within which man experiences a comfort peculiar to the occupied space. Indoor comfort sensation is much related to the prevailing outdoor or environmental condition at any particular time (Markus and Morris, 1980). It is therefore necessary to have a good understanding of the climate of the study area and its implications for the quality of the indoor environment within the occupied spaces.

The Climatic Conditions of, and Patterns in, Ibadan, Ogbomoso and Kisi.

The relevant climatic data from meteorological stations at International Institute for Tropical Agriculture, Ibadan (IITA) and Nigerian Metrological Agency (NMA) Old Airport, Samonda, Ibadan, for Ibadan, Oyo State Water Corporation, Ogbomoso Water Works for Ogbomoso and Oyo State Agricultural Development (OSADEP) Saki for Kisi for a period of five years were obtained in line with the recommendations of Mash (2001) and Liu Yang (2003) that averages of climatic data for a period of between five and ten years are adequate for building design purpose. The data obtained included values of maximum and minimum temperature, maximum and minimum relative humidity, solar radiation, rainfall and wind speed on a monthly basis from January to December for the years 2015, 2016, 2017, 2018 and 2019. Averages of these data for the five years period were presented in Tables 4.1, 4.2 and 4.3 for Ibadan, Ogbomoso and Kisi respectively.

Table 1: Average climatic data for Ibadan (2015–2019)

Month	Temp ^{0}C (max.)	Temp ^{0}C (min.)	Temp ^{0}C (average.)	RH (am) %	RH (pm) %	Rainfall (mm)	Radiation MJ/m^2/day	Wind speed (m/s)
January	35.5	19.6	26.6	66.3	41.3	0.3	12.1	1.47
February	34.8	20.5	27.7	68.2	35.9	10.8	12.8	1.45
March	34.6	22.6	28.6	62.6	46	47.7	13.6	1.44
April	33.1	22.2	27.7	77.2	61	103.2	13.1	1.42
May	32.0	22.2	27.1	80.8	65.6	149.5	12.3	1.51
June	30.9	21.8	26.4	84.7	69.1	180.1	10.9	1.51
July	29.3	21.5	25.4	89.1	71.6	181.6	9.7	1.49
August	28.9	20.8	24.9	84.8	73.6	141.3	8.9	1.47
September	29.4	20.8	25.1	87.3	71.6	222.6	9.5	1.5
October	31.3	19.6	25.5	85.3	66.3	185.2	10.6	1.47
November	33.0	20.5	26.8	83.5	54.9	79.7	11.9	1.47
December	33.2	18.7	26.0	73.9	44.5	12.2	11.8	1.43
Average	31.9	20.9	26.4	78.6	58.	Total = 1314.2	11.4	1.47

Source: Author's computation from field data, 2020.

Table 2: Average climatic data for Ogbomoso (2015–2019)

Month	Temp ^{0}C (max.)	Temp ^{0}C (min.)	Temp ^{0}C (average.)	RH (am) %	RH (pm) %	Rainfall (mm)	Radiation MJ/m^2/day	Wind speed (m/s)
January	33.6	19.7	26.7	78.8	28.0	1.3	14.2	0.98
February	35.0	21.8	28.4	93.7	30.2	12.8	15	1.16
March	34.6	23.1	28.9	96.4	38.0	66.9	17.3	1.28
April	33.1	23.2	28.2	97.2	51.1	131.1	17.2	1.27
May	31.6	22.3	27.0	98.1	59.5	174.3	16.2	0.99
June	30.0	21.8	25.9	98.8	63.8	233.6	13.9	0.96
July	28.1	21.5	24.8	99.0	67.7	195.7	11.7	0.92
August	27.6	21.3	24.5	99.6	72.4	109.7	9.7	0.87
September	29.2	21.5	25.4	98.2	68.2	197.7	12.8	0.87
October	20.1	21.7	26.0	98.1	60.8	187.9	13.3	0.83
November	31,9	22.6	27.3	98.2	49.6	28.9	15.2	0.81
December	32.5	20.9	26.7	95.6	35.4	1.2	13.5	0.78
Average	31.4	21.8	26.6	96.0	52	Total 1327.2	14.2	0.98

Source: Author's computation from field data, 2020

Table 3: Average climatic data for Kisi (2015–2019)

Month	Temp ^{0}C (max.)	Temp ^{0}C (min.)	Temp ^{0}C (average.)	RH (am) %	RH (pm) %	Rainfall (mm)	Radiation MJ/m^2/day	Wind speed (m/s)
January	33.9	20.4	27.2	63.4	25.1	0.0	12.9	1.44
February	35.1	21.3	28.2	68.3	25.5	0.5	13.3	1.51
March	35.6	23.2	29.4	72.1	34.1	24.1	13.1	1.49
April	33.7	23.1	28.4	74.2	40.0	69.7	12.9	1.51
May	32.1	22.5	27.3	78.9	47.9	138.1	112.2	1.54
June	31.4	22.0	26.7	82.0	55.7	172.0	12.3	1.49
July	30.8	21.0	25.9	84.1	57.5	174.5	12.1	1.41
August	29.2	22.0	25.6	81.0	60.4	122.8	11.4	1.36
September	30.3	22.0	26.2	87.2	60.3	159.4	12.4	1.52
October	31.8	22.0	26.9	90.0	59.5	192.2	12.5	1,53
November	33.0	22.0	27.5	84.2	47.5	65.9	13.3	1.56
December	33.5	21.0	27.3	74.4	44.4	9.5	13.1	1.43
Average	32.5	21.9	27.2	78.3	46.5	Total = 1128.7	12.6	1.48

Source: Author's computation from field data, 2020

Climatic Analysis of the Study Area using Psychometric Chart.

Climate of Ibadan, Ogbomoso and Kisi were analysed using Psychrometric climate analysis, the climatic data for Ibadan, Ogbomoso and Kisi were analysed by the use of control potential zone (CPZ) techniques which according to Szokolay (1992) is the range of outdoor condition within which indoor comfort can be achieved by one of the passive control techniques. The values of monthly minimum and maximum temperatures; and the corresponding values of monthly minimum and maximum relative humidity were plotted on a separated psychrometric chart for each of the three cities (Ibadan, Ogbomoso and Kisi) as climate plots as indicated in Figure 3, Figure 4 and figure 5 respectively for Ibadan, Ogbomoso and Kisi. These data were then superimposed on the comfort zone chart for Ibadan, Ogbomoso and Kisi on the psychrometric chart and various passive cooling techniques that were applicable to each of the city were also plotted on the chart. The climate plots were then compared with the comfort zones in the three cities (Figure 3, Figure 4 and Figure 5). The extent of the climate plot lines in relation to the comfort zone, that is, the aggregate length either below (to the left), or within or even above (to the right of) the zone of comforts for Ibadan, Ogbomoso and Kisi were observed from the graphic in Figure 3, Figure 4 and Figure.5 respectively.

Observation from the psychrometric chart indicated that all the climate plotted lines for the three cities were outside the comfort zones.

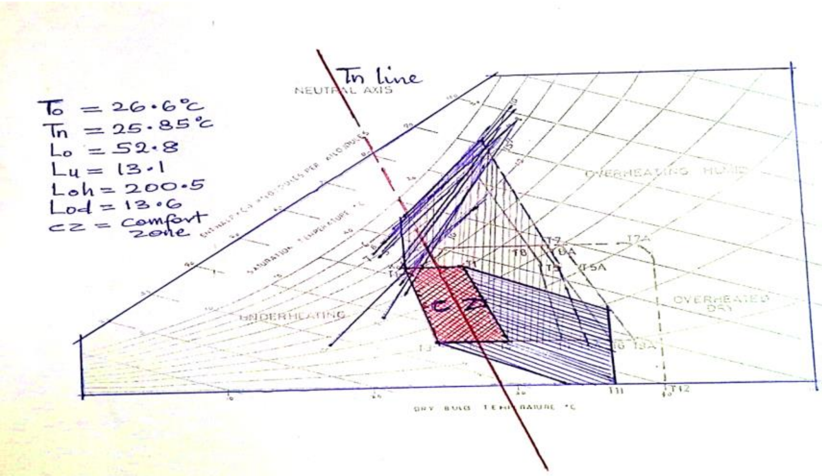

Figure 3: Bio-climatic Chat for Ibadan (2015 – 2019)
Source: Author's analysis from field data, 2020

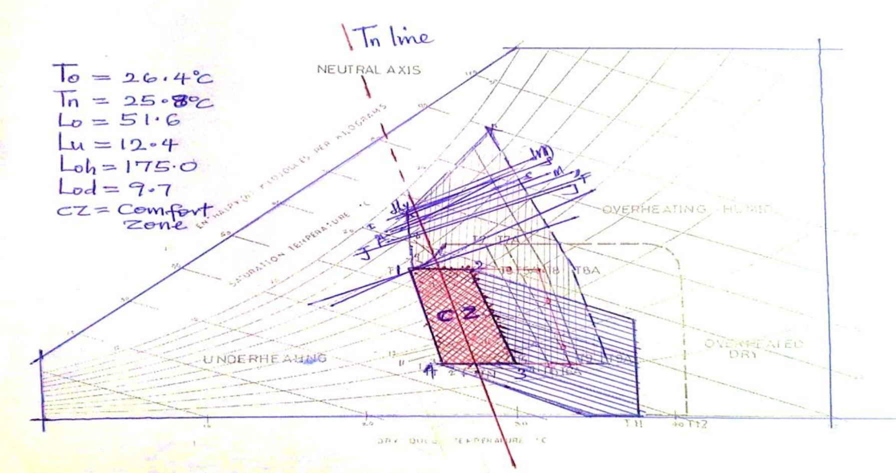

Figure 4: Bio-climatic Chat for Ogbomoso (2015 – 2019)
Source: Author's analysis from field data, 2020

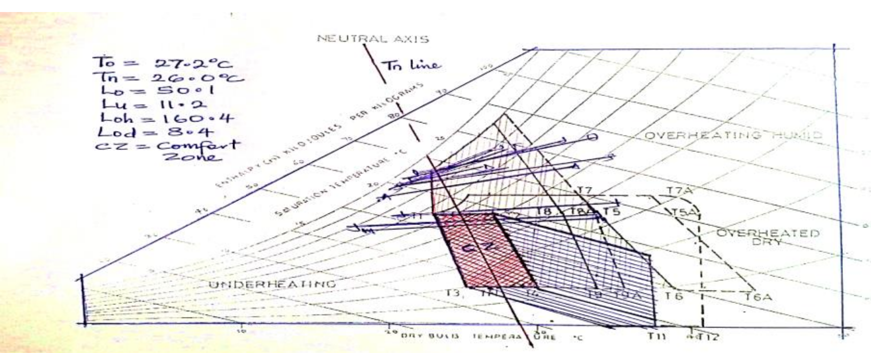

Figure 5: Bio-climatic chat of Kisi (2015-2019)
Source: Author's analysis from field data, 2020

Table 4: Interpretation of Psychrometric Chat result for the study area

Symbol	Interpretation	Cities					
		Ibadan		Ogbomoso		Kisi	
		Value	Ref.	Value	Ref.	Value	Ref.
To	Annual mean temperature (^{0}C)	26.6		26.4		27.2	
Tn	Thermal neutrality (^{0}C)	25.85	Fig. 4.13	25.78	Fig. 4.14	26.03	Fig. 4.15
Lo	Length of overheated	52.8	Fig. 4.13	51.6	Fig. 4.14	50.10	Fig. 4.15
Lu	Length of under heated	13.1	Fig. 4.13	12.4	Fig. 4.14	11.2	Fig. 4.15
Loh	Length of overheated humid	200.5	Fig. 4.13	175.0	Fig. 4.14	160.4	Fig. 4.15
Lod	Length of under heated dry	13.6	Fig. 4.13	9.65	Fig. 4.14	8.40	Fig. 4.15

Source: Author's analysis from field data, 2020

Table 4 revealed the results of observation from the charts, for Ibadan, the table revealed that the length of overheated Lo (52.8) was greater than the length of under heated Lu (13.1). Similarly, for Ogbomoso and Kisi, the length of overheated (51.6) and (50.10) respectively were greater than lengths of under heated (12.4) and (11.2) respectively for Ogbomoso and Kisi. Generally, for the three cities, the greatest length of overheated period occurred in Ibadan (52.8%) followed by Ogbomoso (51.6) and the lowest overheated period was in Kisi (50.10). This follows the order of urbanization level of the cities.

These results had climatic implication of thermal stress for indoor spaces in the three cities for the period under investigation (i.e. 2015–2019). Also from the charts, the lengths of overheated humid (Loh) for Ibadan, Ogbomoso and Kisi were 200.50, 175.0 and 160.4 respectively were found to be greater than the lengths of overheated dry (Lod) 13.6, 9.65 and 8.40 for Ibadan Ogbomoso and Kisi respectively. The inference from the result was that Ibadan was more humid than Ogbomoso and Kisi in that order. Table 4 Thermal neutrality (Tn) for Ibadan, Ogbomoso and Kisi respectively were 25.85^{0}C, 25.78^{0}C and 26.03^{0}C. The implication and inference of this is that Ogbomoso is more thermally comfortable than Ibadan and Kisi in that order. Climatic implication of indoor thermal stress in the three cities with Ibadan having more stress than Ogbomoso and Kisi in that order.

Variations of Measured Microclimatic Elements in the Study Area

For thermal comfort analysis, the values of micro climatic elements such as temperature, relative humidity and air velocity were measured in all the living room, bedroom, and corridor/kitchen spaces in selected number of buildings in Ibadan, Ogbomoso and Kisi to provide information about variations in temperature, relative humidity and air velocity within the respective buildings. The measurements were taken during the afternoon period because afternoon period offers the worst indoor comfort (Adunola, 2006 and Ayinla, 2011). The results as shown in Table 5 revealed that the differences in temperature was between 0.1^{0}C to 0.5^{0}C, the differences in relative humidity was between 0.1 to 2% while that of air velocity was 0.0 to 0.1m/s. The inferences drawn from this was that similar buildings within the same residential density in the three cities of Ibadan, Ogbomoso and Kisi would also have about the same variation values ranges of 0.1^{0}C to 0.5^{0}C, 0.1% to 2% and 0m/s – 0.1m/s for temperature, relative humidity and air velocity respectively. It was also inferred that the differences in temperatures, relative humidity and air velocity from building to building would be in the same order or less and therefore minimal for similar building within the same residential densities in the study area. The implication would be that error would be minimal when using measured micro climatic data of a building for another similar buildings in the same residential density zone and in the same cities.

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Table 5: Variations in Measured Climatic values in the spaces of the Residential Building types in Ibadan, Ogbomoso and Kisi

Residential Density Zone	Residential Building Types	Climatic Elements	Ibadan					Ogbomoso					Kisi				
			Outdoor Value	Indoor Values				Outdoor Value	Indoor Values				Outdoor Value	Indoor Values			
				Living	Bedroom	Kit.	Var.		Living	Bedroom	Kit.	Var.		Living	Bedroom	Kitchen	Var.
High Residential Density	Compound impluvium house	Air Temp. (^{0}C)	-	-	-	-	-	33.1	31.4	31.3	31.8	0.5	34.4	32.6	32.6	32.6	0.00
		Rel. Humidity (%)	-	-	-	-	-	60.1	61.9	62.0	60.2	0.2	61.7	62.5	62.5	62.5	0.00
		Air Velocity (m/s)	-	-	-	-	-	0.44	0.02	0.02	0.00	0.02	0.43	0.03	0.03	0.03	0.00
	Brazilian rooming house storey	Air Temp. (^{0}C)	35.0	33.7	33.6	33.9	0.3	33.1	31.1	31.0	31.6	0.6	34.4	32.5	32.5	0.1	30.3
		Rel. Humidity (%)	61.4	63.4	63.8	62.1	1.7	60.1	61.9	61.0	61.2	0.7	61.7	62.4	62.0	0.4	65.3
		Air Velocity (m/s)	0.60	0.01	0.01	0.0	0.01	0.44	0.02	0.02	0.00	0.02	0.43	0.04	0.01	0.3	0.95
	Brazilian rooming house Bungalow	Air Temp. (^{0}C)	35.0	33.4	33.4	33.8	0.4	33.1	31.6	31.50	31.8	0.3	34.4	32.5	32.5	32.8	0.3
		Rel. Humidity (%)	61.4	63.6	63.7	61.8	1.9	60.1	61.9	61.8	61.3	0.6	61.7	62.1	62.0	61.9	0.2
		Air Velocity (m/s)	0.60	0.01	0.01	0.00	0.01	0.44	0.04	0.03	0.00	0.04	0.43	0.04	0.04	0.01	0.03
	Storey Flats	Air Temp. (^{0}C)	36.0	33.2	33.2	33.8	0.6	33.1	31.2	31.2	31.5	0.3	34.4	32.0	32.1	32.1	0.1
		Rel. Humidity (%)	61.4	64.2	64.0	62.0	2.0	60.1	62.0	62.1	60.1	2.0	61.7	62.4	62.3	62.0	0.4
		Air Velocity (m/s)	0.60	0.01	0.01	0.01	0.00	0.44	0.05	0.04	0.01	0.04	0.43	0.05	0.05	0.02	0.03
	Bungalow Flats	Air Temp. (^{0}C)	35.0	32.0	32.1	32.7	0.7	33.1	31.1	31.2	31.3	0.2	34.4	32.0	32.1	32.1	0.1
		Rel. Humidity (%)	61.4	65.4	65.3	63.7	1.7	60.1	62.4	62.2	61.0	1.4	61.7	63.0	62.3	62.1	0.9
		Air Velocity (m/s)	0.60	0.02	0.02	0.01	0.01	0.44	0.06	0.06	0.02	0.04	0.43	0.08	0.08	0.02	0.06
	Duplex (DUP)	Air Temp. (^{0}C)	36.0	36.4	30.6	32.0	1.6	33.1	30.2	30.1	30.6	0.5	34.4	31.0	31.0	31.0	0.6
		Rel. Humidity (%)	61.4	65.7	65.7	63.8	1.9	60.1	62.8	62.7	61.4	1.4	61.7	62.0	62.0	62.0	0.00
		Air Velocity (m/s)	0.60	0.08	0.08	0.05	0.03	0.44	0.07	0.06	0.02	0.05	0.43	0.12	0.12	0.03	0.09
Medium Residential Density	Compound impluvium house	Air Temp. (^{0}C)	-	-	-	-	-	32.5	31.6	31.5	31.8	0.3	24.6	29.3	29.3	29.7	0.4
		Rel. Humidity (%)	-	-	-	-	-	60.5	62.1	62.2	60.0	2.20	62.3	62.8	62.8	62.1	0.7
		Air Velocity (m/s	-	-	-	-	-	0.48	0.01	0.01	0.00	0.01	0.57	0.04	0.04	0.01	0.03
	Brazilian rooming house storey	Air Temp. (^{0}C)	35.6	33.7	33.8	33.9	0.2	32.5	32.4	32.3	32.8	0.5	34.6	32.4	32.4	30.7	0.3
		Rel. Humidity (%)	62.2	65.8	65.9	64.0	1.9	60.5	62.3	62.3	61.9	0.4	62.3	61.0	61.0	59.0	2.0
		Air Velocity (m/s	0.90	0.01	0.01	0.0	0.01	0.48	0.01	0.01	0.01	0.00	0.57	0.03	0.03	0.03	0.02
	Brazilian rooming house Bungalow	Air Temp. (^{0}C)	35.6	32.4	32.4	33.6	1.2	32.5	32.2	32.2	32.4	0.2	39.6	32.2	32.2	32.6	0.4
		Rel. Humidity (%)	62.2	66.2	66.1	64.0	2.2	60.5	62.3	62.4	61.8	0.6	62.3	62.7	62.8	60.9	1.9
		Air Velocity (m/s	0.90	0.02	0.02	0.0	0.02	0.48	0.02	0.02	0.01	0.01	0.57	0.04	0.04	0.08	0.02
	Storey Flats	Air Temp. (^{0}C)	35.6	32.1	32.2	32.4	0.3	32.5	32.2	32.2	32.4	0.2	34.6	32.0	32.0	32.4	0.4
		Rel. Humidity (%)	62.2	67.0	67.2	64.6	2.6	60.5	62.3	62.4	61.8	0.6	62.3	62.9	62.9	62.0	0.9
		Air Velocity (m/s	0.90	0.82	0.02	0.01	0.01	0.48	0.04	0.04	0.01	0.03	0.57	0.05	0.05	0.02	0.03
	Bungalow Flats	Air Temp. (^{0}C)	35.6	30.6	30.8	31.6	1.0	32.5	32.1	321.0	32.6	0.5	34.6	30.0	30.0	31.8	1.8
		Rel. Humidity (%)	62.2	67.8	67.8	66.8	1.0	60.5	62.4	63.0	61.1	1.9	62.3	63.0	63.0	62.1	0.9
		Air Velocity (m/s	0.90	0.06	0.06	0.02	0.04	0.48	0.08	0.08	0.01	007	0.57	0.09	0.06	0.03	0.06
	Duplex (DUP)	Air Temp. (^{0}C)	35.6	30.1	30.0	31.0	1.0	32.5	32.0	31.90	31.4	0.6	34.6	29.6	29.6	29.9	0.3
		Rel. Humidity (%)	62.2	68.3	68.3	65.4	1.9	60.5	62.1	62.4	61.3	1.1	62.3	63.4	63.4	62.9	0.5
		Air Velocity (m/s	0.90	0.08	0.08	0.02	0.06	0.48	0.08	0.08	0.02	0.06	0.57	0.09	0.09	0.03	0.06
Low	Compound impluvium house	Air Temp. (^{0}C)	-	-	-	-	-	33.0	31.4	31.4	31.8	0.4	33.3	31.9	31.9	31.9	0.00
		Rel. Humidity (%)	-	-	-	-	-	60.4	62.0	62.2	61.3	0.9	62.1	64.1	64.2	64.2	0.1
		Air Velocity (m/s	-	-	-	-	-	0.40	0.06	0.06	0.02	0.04	0.62	0.04	0.04	0.02	0.02

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Residential Density	Brazilian rooming house storey	Air Temp. (^{0}C)	34.9	32.1	32.2	32.6	0.5	33.0	31.5	31.4	31.8	0.4	33.3	31.8	31.8	31.9	0.1
		Rel. Humidity (%)	62.8	62.8	62.7	60.0	2.8	60.4	62.3	62.4	61.4	1.0	62.1	64.4	64.4	64.0	0.4
		Air Velocity (m/s	0.68	0.06	0.06	0.01	0.05	0.40	0.06	0.06	0.02	0.04	0.62	0.04	0.04	0.02	0.02
	Brazilian rooming house Bungalow	Air Temp. (^{0}C)	34.9	32.8	32.7	33.0	0.3	33.0	31.5	31.4	31.9	0.5	33.3	31.7	31.7	31.9	0.2
		Rel. Humidity (%)	62.8	62.8	62.8	61.0	1.8	60.4	62.3	62.3	62.0	0.3	62.1	64.5	64.5	63.0	1.5
		Air Velocity (m/s	0.68	0.07	0.07	0.01	0.06	0.40	0.06	0.06	0.02	0.04	0.62	0.04	0.04	0.02	0.02
	Storey Flats	Air Temp. (^{0}C)	34.9	32.8	32.7	32.9	0.2	33.0	31.6	31.	31.9	0.5	33.3	31.6	31.6	31.9	0.3
		Rel. Humidity (%)	62.8	63.0	63.1	61.0	2.0	60.4	62.3	62.4	61.9	0.5	62.1	62.4	62.7	62.0	0.7
		Air Velocity (m/s	0.68	0.08	0.08	0.02	0.06	0.40	0.06	0.06	0.02	0.04	0.62	0.04	0.07	0.02	0.02
	Bungalow Flats	Air Temp. (^{0}C)	34.9	32.0	32.1	32.8	0.8	33.0	31.7	31.6	31.9	0.3	33.3	31.2	31.2	31.6	0.4
		Rel. Humidity (%)	62.8	63.4	63.5	62.9	0.6	60.4	62.7	62.8	620.	0.8	62.1	62.0	62.0	60.1	1.9
		Air Velocity (m/s	0.68	0.11	0.11	0.04	0.07	0.40	0.06	0.06	0.02	0.04	0.62	0.04	0.04	0.03	0.01
	Duplex (DUP)	Air Temp. (^{0}C)	34.9	30.1	30.1	30.4	0.3	33.0	30.1	30.1	30.6	0.5	33.3	30.1	30.0	31.2	1.2
		Rel. Humidity (%)	62.8	64.0	64.1	63.0	1.2	60.4	64.2	64.2	63.0	1.2	62.1	62.1	63.2	60.2	2.0
		Air Velocity (m/s	0.68	0.14	0.14	0.05	0.09	0.40	0.07	0.07	0.03	0.04	0.62	0.05	0.05	0.03	0.02

Source: Author’s analysis from field data, 2020

Indoor Environmental Quality Performance of Houses.
The indoor Environmental Quality Performance during the afternoon period in the study area as shown in Table 6 indicated that majority of the house (96.7%), of which, 46.3% were from Ibadan, 41.2% were from Ogbomoso and 12.5% were from Kisi were worst (1 star) in IEQ performance scale. Another 3.1% houses, out of which, 1.4% were from Ibadan, 0.9% were from Ogbomoso and 1.2% were from Kisi were below average (2 star) in IEQ performance scale.

The IEQ performance of houses across the cities of Ibadan, Ogbomoso and Kisi as shown in Table 6.15 indicated that in Ibadan, greater percentage of houses (97.3%) were rated worst (1 star) in IEQ performance scale, out of which, 24.3% were from Brazilian rooming house story, 31.9% were from Brazilian rooming house bungalow, 19.8% were from flats, 15.5% and 5.7% respectively were from bungalow flats and duplex. Another 2.3% houses were below average (2 star) in IEQ performance scale, of which, 1.5% and 0.8% respectively were from Brazilian rooming house bungalow and storey flats. There was only one house (0.4%) among the bungalow flats with best (5 star) in IEQ performance scale. In Ogbomoso, 79.9% houses were rated worst (1 star) in IEQ performance scale, out of which, 4.7% were from compound impluvium house, 15.5% were from Brazilian rooming house storey, 47.6% were from Brazilian rooming house bungalow, 9.9%, 18.9% and 1.3% respectively were from storey flats, bungalow flats and duplex. Another 2.1% were below average (2 star) in IEQ performance, of them, 1.3% were from Brazilian rooming house bungalow and 0.4% each were from Brazilian rooming house storey and storey flats.

The situation in Kisi was similar to what obtained in Ibadan and Ogbomoso, greater percentage of houses (90.8%) were worst (1 star) in IEQ performance scale, of which, 19.7% each were from compound impluvium house and storey flats, 31.6% were from Brazilian rooming house storey, 7.9% each were from Brazilian rooming house bungalow and bungalow flats and 3.9% were from duplex. Another 9.2% houses were below average (2 star) in IEQ performance, out of which, 5.3% were from Brazilian rooming house storey, 1.3% each were from compound impluvium house, Brazilian rooming house storey, 1.3% each were from compound impluvium house, Brazilian rooming house bungalow and storey flats.

Table 6: Indoor environmental quality calculator (Afternoon)

City	Residential Building Types	IEQ Performance (Morning) (%)					Total (%)
		Worst (1 star)	**Below Average (2 star)**	**Average (3 star)**	**Above average (4 star)**	**Best (5 star)**	
Ibadan	Compound impluvium house	-	-	-	-	-	-
	Brazilian rooming house storey	64 (24.3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	64 (24.3%)
	Brazilian rooming house	84 (31.9%)	4 (1.5%)	0 (0%)	0 (0%)	0 (0%)	88 (33.5%)
	bungalow	52 (19.8%)	2 (0.8%)	0 (0%)	0 (0%)	0 (0%)	54 (20.5%)
	Storey flats	41 (15.6%)	0 (0%)	0 (0%)	0 (0%)	1 (0.4%)	42(16.0%)
	Bungalow flats	15 (5.7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	15 (5.7%)
	Duplex						
	Sub-Total	**256 (97.3%)**	**6 (2.3%)**	**0 (0%)**	**0 (0%)**	**1 (0.4%)**	**263 (100%)**
Ogbomoso	Compound impluvium house	11 (4.7%)	0 (0%)	0(0%)	0(0%)	0(0%)	11 (4.7%)
	Brazilian rooming house storey	36 (15.5%)	1 (0.4%)	0(0%)	0(0%)	0(0%)	37 (15.9%)
	Brazilian rooming house	111(47.6%)	3 (1.3%)	0(0%)	0(0%)	0(0%)	114 (48.9%)
	bungalow	23 (9.9%)	1 (0.4%)	0(0%)	0(0%)	0(0%)	24 (10.3%)
	Storey flats	44 (18.9%)	0 (0%)	0(0%)	0(0%)	0(0%)	44 (18.9%)
	Bungalow flats	3 (1.3%)	0 (0%)	0(0%)	0(0%)	0(0%)	3 (1.3%)
	Duplex						
	Sub-Total	**228 (79.9%)**	**5 (2.1%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**233 (100%)**
Kisi	Compound impluvium house	15 (19.7%)	1 (1.3%)	0(0%)	0(0%)	0(0%)	16 (21.1%)
	Brazilian rooming house storey	24 (31.6%)	4 (5.3%)	0(0%)	0(0%)	0(0%)	28 (36.8%)
	Brazilian rooming house	6 (7.9%)	1 (1.3%)	0(0%)	0(0%)	0(0%)	7 (9.2%)
	bungalow	15 (19.7%)	1 (1.3%)	0(0%)	0(0%)	0(0%)	16 (21.1%)
	Storey flats	6 (7.9%)	0 (0%)	0(0%)	0(0%)	0(0%)	6 (7.9%)
	Bungalow flats	3 (3.9%)	0 (0%)	0(0%)	0(0%)	0(0%)	3 (3.9%)
	Duplex						
	Sub-Total	**69 (90.8%)**	**7 (9.22%)**	**0 (0%)**	**0 (0%)**	**0 (0%)**	**76 (100%)**
	Overall Total	**553 (96.7%)**	**18 (3.1%)**	**0 (0%)**	**0 (0%)**	**1 (0.2%)**	**572 (100%)**

Source: Author's analysis from field data, 2020

CONCLUSION

The indoor temperature and relative humidity in the three cities were higher during the afternoon period making it the most discomfort period of the day. Thermal Comfort condition during the afternoon period in the three cities offered great thermal discomfort with average thermal stress index of 39.4^{0}C, 36.9^{0}C and 38.4^{0}C respectively for Ibadan, Ogbomoso and Kisi, with Ogbomoso offered the best thermal comfort than Kisi and Ibadan in that order. The best house type in terms of thermal comfort during the afternoon period was the duplex house type with average thermal stress index of 35.4^{0}C.

It was also found out that none of these spaces satisfied the effective indoor ventilation comfort criteria of between 0.5 -1.5 m/s The best result of 0.19m/s was recorded in the living room of duplex house type and the least value of 0.0m/s was recorded in the bedrooms of the compound impluvium house type. The best residential house types in terms of indoor ventilation in the study area was duplex house type with average indoor ventilation value of 0.19m/s and the worst was the traditional house type with the value of 0.06m/s

Generally all the spaces except the bedroom space in the compound impluvium house type satisfied the illumination range of between 50 – 60 lux. The highest indoor illumination in the study area was recorded in the living room spaces of duplex house type (Ibadan = 526 lux; Ogbomoso = 531 lux) Kisi = 504 lux) and the lowest indoor illumination was 20 lux and 16 lux respectively for the bedroom space of compound impluvium house type in Ogbomoso and Kisi. The maximum indoor environmental noise level during the morning, afternoon and evening periods in the study area were 58db, 59db and 58db respectively. In terms of noise level, the best house type was the bungalow flat the worst was the compound impluvium house type. Result from the IEQ calculator indicated that majority of the houses (83.6%) were star 2 in the IEQ performance. The implication was that these houses were below average in terms of indoor environmental quality.

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