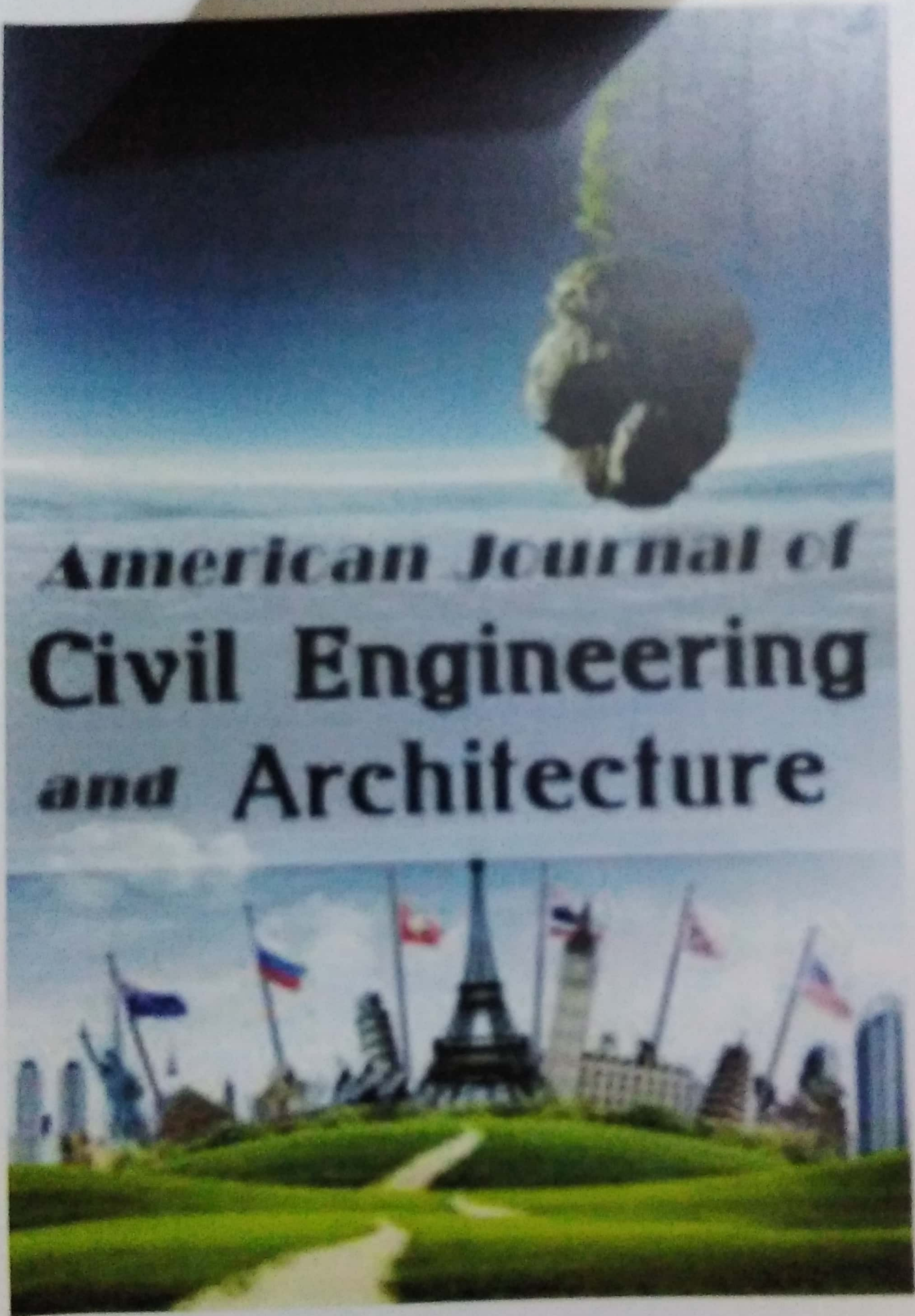
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Sustainable Approach to Developing Energy Efficient Buildings for Resilient Future of the Built Environment in Nigeria

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Abstract Globally, it is acknowledged that the building sector has a significant contribution to energy consumption and greenhouse gas (GHG) emissions. According to the united nation environmental programme (UNEP) sustainable construction and building initiative (SCBI); 30- 40% of global energy use comes from the building sector. This has been predicted to rise by 34% in the next 20 years at an average of 1.5%. In most developing countries, particularly those in tropical regions such as Nigeria, the challenge of energy consumption in buildings is exacerbated by extreme high temperature and intense solar radiation which drives the quest to use more energy within the buildings. This paper aims to explore sustainable approaches to developing and improving energy efficiency for residential buildings in Nigeria. The objective is to reduce energy consumption through the application of greener construction methods, retrofitting existing structures and introduction of self-sufficient energy supply using existing technologies. A survey method was adopted to collect internal climatic data conducted on urban residences in northern Nigeria. Findings suggests that achieving energy efficient buildings would require adapting to the changing energy constrained the world, appropriate planning and design for energy efficient buildings; and retrofitting existing buildings for a future where energy supplies are running out and prices are rising high. The paper recommended sustainable approaches such as energy efficient building envelope, use of active and passive measures and behavioural changes. It concludes that there is a need for developing, adopting and promoting resilience in policies, planning and practices for sustainable built environment. This could result in an enormous reduction of GHG emissions.

Keywords: *sustainable, energy efficiency, practices, retrofitting, passive design*

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1. Introduction

The availability and the use of energy in a building are pivotal to the building's functionality within the confines of its purpose. However, if energy use in buildings is not regulated, can steadily lead to costly waste to the building users and more importantly to through continuous release of CO_2 into the atmosphere leading to global rising temperatures and climate change. The United Nations Environmental programme (UNEP) sustainable construction and Building Initiative (SCBI) noted that 30-40% of the global energy use comes from the housing sector. This implies that achieving energy efficiency in buildings could offset the greenhouse gases (CO2, CO, CH4) by 30-40% which could have emanated from the housing sector thereby saving the climate from the negative effect of these gases [1]. According to [2] buildings constitutes 40 % of total European Union's energy consumption and generate 36 % of greenhouse gases in Europe. This makes energy efficiency in buildings to be taken seriously by the governments in the developed world. Therefore, concerted efforts are constantly made by the governments to ensure that their countries continually tend towards buildings that use less energy while still sustaining appreciable levels of functionality for its operations and comfort for its occupants.

In developing countries such as Nigeria, with a growing population of over 160 million people currently generating total energy below 5,000 MW. However, in 2012, the distribution of the energy use was 116,457 ktoe with the residential sector accounting for the greater percentage. According to [3] this is attributed to the low development level of other sectors. According to Figure 1, it can be seen that the domestic sector is constantly responsible for more than half of Nigeria's energy use from 1996 to 2005 varying from 55% - 61% [4]. The major and the single most significant end use of energy in Nigerian residential sector has been attributed to space cooling, lighting including the combination of other substantial uses such as cooking and appliances [5].

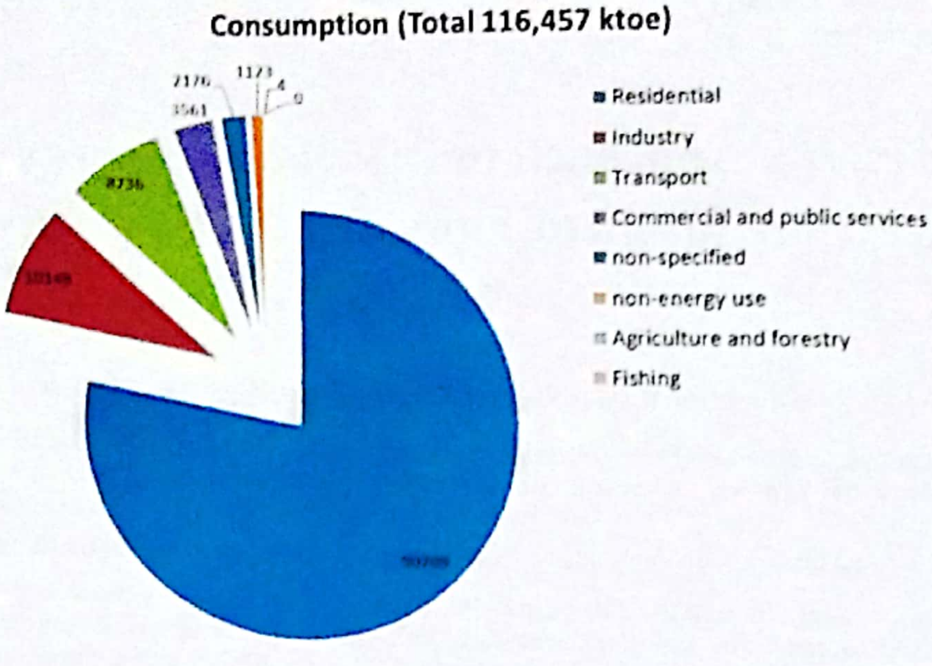

Figure 1. Energy consumption by economic sector in ktoe (Source: IEA [6])

The climate in Nigeria is characterized with high temperature and humidity all year round. Observation shows that internal house temperatures during the dry period in some part of the country varies beyond satisfactory temperature level that support occupant's well-being. This result to the occupants experiencing thermal stress because of internal extreme temperature. Therefore cooling is required in order to achieve the required thermal comfort. Due to this, buildings normally opt for mechanical cooling strategies that inevitably use a considerably large amount of electricity. Presently, the rate of electricity consumption in Nigeria is increasing as the population continue to increase leading to an uncontrollable increase in the demand for energy and improved comfort levels. As shown in Figure 1, the 'residential and commercial' sector in Nigeria consumes the highest amount of electricity compared to other sectors. Exacerbating this problem is the poor thermal performance of most residential buildings that also result in dependence on 'active' and expensive-to-run cooling systems.

Compounding this problem is the inability of most occupants to afford high energy which can lead to disconnection of services to the house. In addition to the above-mentioned problems comes the problem of poor internal temperature control and with the inability to afford cooling systems often lead to overcrowding of the room the house owners can afford to cool. Thus leading to overcrowding which promotes the spread of infection. To moderate these problems, demand for energy consumption needs to be minimized and sustainable approach needs to be sought with consideration for better internal air quality, thermal comfort of occupants and more importantly, reduction in greenhouse gas emissions. Several attempts have been made to address energy crises that confront Nigeria. For instance, the United Nations Development Programme (UNDP) combined with Nigeria government and support of the Global Environment Facility (GEF- 4) developed a strategic program. The programme was called 'Climate Change Strategic Programme 1, Promoting Energy Efficiency in Residential and Commercial Building'.

The aim of the programme was to encourage energy efficiency for the end-use appliance in the residential and public sectors by introducing policies and measures (e.g. Standards and Labels) to achieve energy efficiency and demand-side management programme. The residential building sector is identified as a useful area for studying energy conservation due to its contributions to GHG (greenhouse gas) emissions especially with the greater part of up to 80% of the emissions coming from the city areas [7]. However, these figures can be decreased by constructing energy efficient buildings for future resilience of the built environment and simultaneously this can improve the internal and external air quality, social welfare and enhance energy security [8]. According to [9] resilience from the built environment perspective implies the integration of building design, aspects and features which permit the building to carry out its intended functions, now and in the foreseeable future.

In the context of this study, resilience implies the building's ability to continue performing as planned in spite of environmental challenges from climate change. Thus it could be argued that to achieve resilience for the future of the built environment, there is a need for building resilience through design. This could be achieved and addressed through energy efficiency in building from the perspective of sustainability. Thus, according to [10] this has made energy efficiency become the main driver of sustainable development in several economies in the world. Thus, the building design is one of the key factors determining the building's energy efficiency besides occupant behavior. Numerous researchers [11,12,13,14] have conducted well documented studies on thermal comfort in residential buildings. However, little is known about the indoor living environment and the consequences of its impact on energy use in naturally ventilated residential buildings in hot dry climatic zone of the country using objective and subjective assessment of the building occupants.

Whilst the study conducted by [14] in warm humid climatic zone of the country adopted both methods, it was however conducted within student's hostel buildings. This identified gap thus formed the basis of conducting this study to identify the impact of indoor environmental conditions on occupants' energy use and thermal comfort in a naturally ventilated residential building in hot-dry climate of Nigeria. The findings from this study would be useful in developing and recommending sustainable approach for better design, refurbishment and future resilience of Nigeria's built environment. This paper aims to explore sustainable approaches to developing and improving energy efficiency for residential buildings in Nigeria. The rationale for this study is that much of the existing residential buildings in Nigeria does not provide an acceptable internal living environment as their internal temperature ranges are beyond the range that promote their occupants' well-being.

The argument of this study is based on the premise that sustainable approach to new design and retrofitting of the existing buildings could result to improvement of the internal living environment, reduce energy demand and the running costs for the occupants and consequently safeguard the built environment. Thus, the key question that this study seeks to answer is 'how can energy efficiency of residential buildings in Nigeria be improved to reduce energy demand while simultaneously the occupants' well-being and that of the built environment is not jeopardized and/or compromised'?

2. Methodology

The study is non-experimental therefore, a descriptive research "methodology" design was adopted. Borg et al. [15] described descriptive research as a form of quantitative research to explore the possible causal relationships between different variables. This research design was considered appropriate to answer the key questions posed for this study.

2.1. Study Area

The study was conducted in Bauchi metropolis. Bauchi metropolis is a state capital lies within the Northern Guinea Savannah vegetation zone in Nigeria.

In 2006, the national population census estimated the total population to be 4,676,465. Its location in the climatic zone of the country is characterized by intense heat (Figure 2) making it suitable as a case study area. It has a tropical climate with a long dry period of seven (7) months from May to September. The dry period is marked by a cool dry period (Harmattan) from November to January and a hot period from February to May. At the peak of the period, the relative humidity is usually very low. In Bauchi metropolis, the external relative humidity ranges from 35% at 07:00 to 10% at 16:00 hours on the average in February [16].

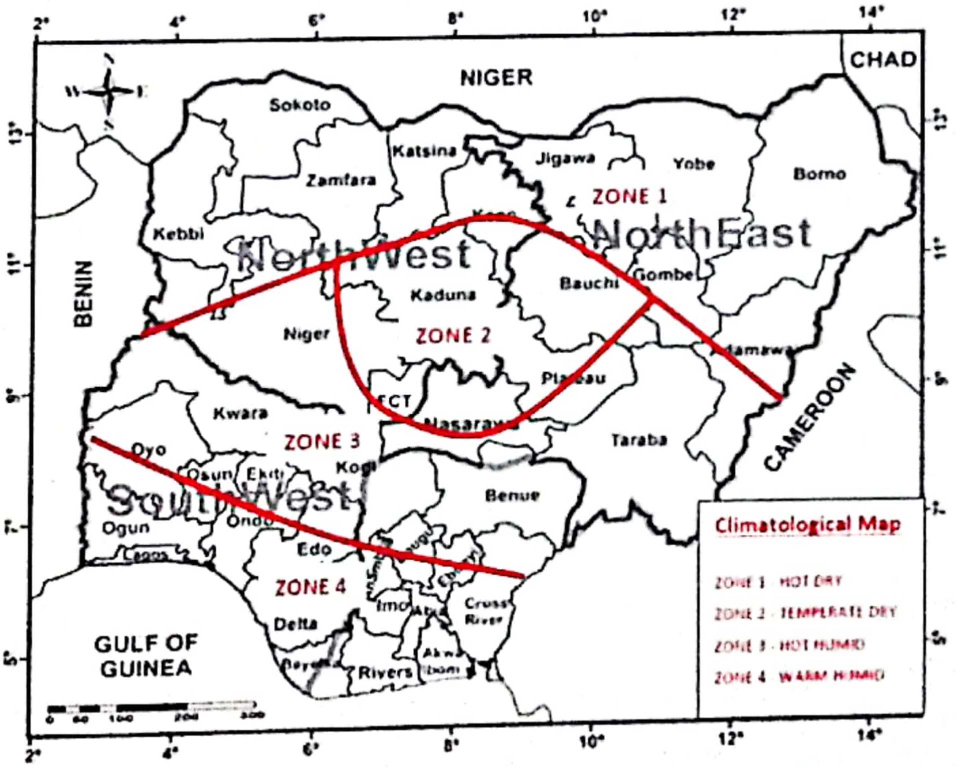

Figure 2. Climatological zones in Nigeria. Adapted from Izomoh [17]

The diurnal temperature varies from an average daily maximum of 31.6oC to a daily minimum of 13.1oC in January. In August, there is a daily mean maximum of 28.5oC and a daily mean minimum of 19.90C while the relative humidity is 94% at 07;00 and 16;00 hours. Rainfall in Bauchi state ranges between 1300mm per annum in the south and only 700mm per annum in the extreme north.

2.1.1. Population and Sample Selection

The research population comprises of naturally ventilated low-rise residential buildings found in Bauchi metropolis. Bauchi metropolis consists of three (3) senatorial districts with a total number of 20 wards namely: Bauchi (8 wards), Zugur (8 wards) and Galambi (4 wards). A convenience purposive sampling technique was adopted to select ten (10) wards across the three (3) senatorial districts. A random sampling technique was used to select three (3) neighborhood/areas each out of the ten (10) wards selected. However, to accommodate a representation of the existing house types, house units were randomly selected from the total units of 649. In accordance to [18] a sample size greater than 200 for a population of 600 for categorical data would be appropriate. However, due to the variation in the number of selected house type, a number of sixty-eight (68) residential buildings were randomly selected giving a sample size of 206 subjects.

2.1.2. Instrumentation

Field work was conducted using questionnaire survey. The use of questionnaire was adopted as it is a means of collecting data due to its highly structured format [19]. In addition, the questionnaire has the advantages of low cost and reduces bias. Besides, similar studies evaluating the internal thermal environment and energy use had been conducted through questionnaire surveys. Although this study is part of a larger study on internal thermal environment of residential buildings in Nigeria, However, the relevant aspects suitable to achieve the aim and objectives of this paper deals with the occupants' perception of internal temperature, humidity, and air speed.

2.1.3. Data Collection

The data collected from the survey included internal environmental data on internal temperature, relative humidity and air speed, shaded external air temperature (ambient air temperature), relative humidity from the existing buildings. The data was recorded using thermometers, hydrometer and electronic devices that can record information on internal air flow. Energy and water use could not be ascertained as most occupants have no energy and water bills available to them. Data were collected using local community health workers to install and record temperature in the investigated buildings. It was considered appropriate to recruit these people as they are in the best position to collect the data due to their knowledge of the local language and the area. In addition, they visit the area as community health workers, therefore, could gain access to the buildings to collect the require data with minimal restrictions from the occupants. The thermometers were located inside and outside the investigated buildings at the minimum height of 1.2 meters above the floor level. The temperature data were recorded at hourly intervals.

2.1.4. Spaces Evaluated and Subjects Investigated

The living room was used as the evaluated space. This was chosen as it is a good representative space of the building and lots of activities take place there in the house. It also provided a more convenient space due to the limitation of bedroom privacy. The subjects included adult men and women living in the building from the age of 16 years old and above. The rationale was meant to get the proper response for the thermal perception of space.

3. Results and Discussion

The analysis of the data collected confirms that both the internal and external of the buildings are quite hot beyond human comfort. It can be seen from Table 1 that the internal air temperature in the buildings ranges from 22°C to 40°C minimum in the dry period. Meanwhile, the internal relative humidity (RH) was found to be between 29% and 82%. In the wet period, the internal temperature in the buildings was recorded to be between 19°C and 29°C. These findings indicate that the internal temperature and relative humidity exceeded the established standard [20] for sedentary activity during the dry period. According to [20], the specified temperature for the internal environment should be between 23°C and 26°C while RH should be between 30% and 70%. Surprisingly, the average air speed was 0.13 m/s was within the threshold of < 0.2 m/s [20] for sedentary activity.

Table 1. Internal and external environmental data

	Dry Period			Wet Period		
	Mean.	Maximum.	Minimum.	Mean.	Maximum.	Minimum.
Internal Air Temperature (°C)	34.5	40.0	22	23.5	28	19
External Air Temperature (°C)	36.7	42.0	24	21.0	26	17
Internal Relative Humidity (%)	55.4	81.0	29	69.5	76	37
External Relative Humidity (%)	47.5	77.5	19	66.7	83	53
Internal Air Velocity (m/s)	0.15	0.60	00			

Further findings indicate that buildings had poor thermal performance when there were extremes in ambient temperature (Figure 3) as it can be seen that average internal temperature in the morning and afternoon time is 30°C and 37°C respectively (Figure 4). The houses were not providing thermal benefit and were not designed to suit the climate. Occupants either relied on active cooling systems to reduce extremes in temperature. This implies using more energy to provide the needed internal comfort. In a situation they are unable to afford the high costs of using these systems to regulate the internal temperature, these often lead to disconnection of utility services to the house due to non-payment of bills. The houses were not providing thermal benefit and were not designed to suit the climate. Occupants either relied on active cooling systems to reduce extremes in temperature. This implies using more energy to provide the needed internal comfort. In a situation they are unable to afford the high costs of using these systems to regulate the internal temperature, these often lead to disconnection of utility services to the house due to non-payment of bills. The situation becomes aggravated where the buildings are badly designed. However, the application of passive design and retrofitting of existing houses could result to less dependent on the use of energy to improve the occupants. This would also result to substantial savings in running costs of active cooling systems. In addition to the findings above, regression analysis was performed to determine the occupant thermal sensation and internal air temperature for both dry and wet period.

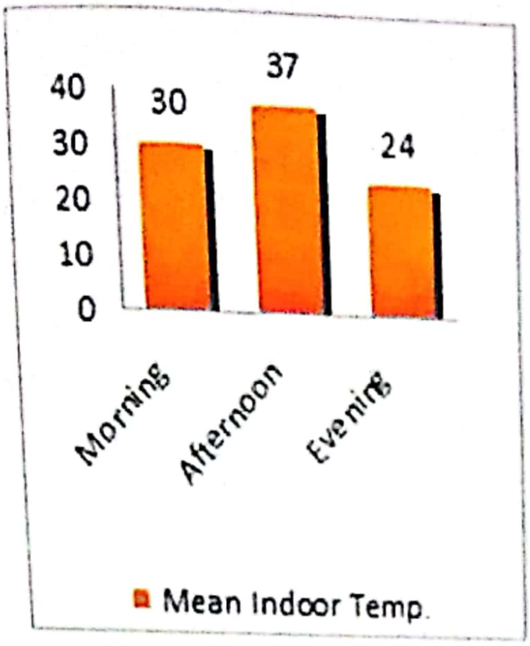

Figure 3. Mean indoor temperature

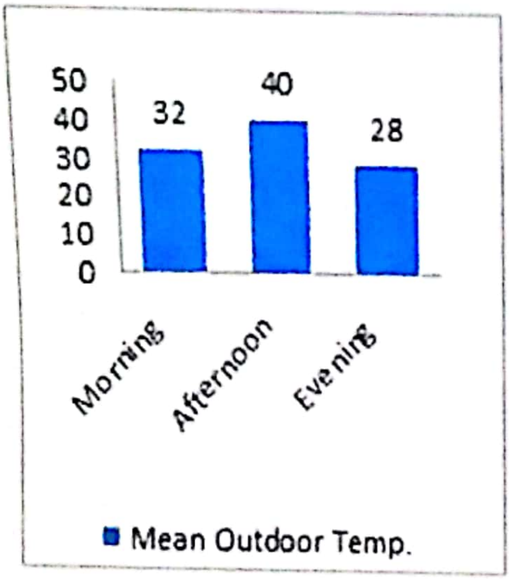

Figure 4. Mean outdoor temperature

It can be seen in Figure 1 and Figure 2. That the regression curves shows a high correlation between thermal sensation and internal temperature. The regression equation for dry period (R2 = 0.8846) was determined and given in equation 1 as:

$$y = -10.2 + 0.357x\,(R2 = 0.8846) \qquad (1)$$

While the regression equation for rainy season (R2 = 0.9119) was determined and given in equation 2 as:

$$y = -15.4 + 0.618x\,(R2 = 0.9119) \qquad (2)$$

Figure 5 shows that the thermal neutral temperature is 28.44°C in the dry period. According to Figure 6 the thermal neutral temperature is 25.04°C in wet season. However, based on PMV (Predicted Mean Vote) evaluation index established by [21] the neutral temperature in summer (dry period) should be 25.1°C while in winter (wet period) should be 22.4°C. These findings is in agreement with the above explanation as the result indicates that the testing neutral temperature is quite higher compared to the theoretic value by 3.34°C and 2.64°C for dry period and wet period respectively. The implication of this is that the actual thermal comfort range for the occupants is much wider than the theoretically calculated value. While this difference in neutral temperature for both periods between the established values obtained by [21] could be associated to the climatic conditions which perhaps could have affected the subject's perception; it could also be perceived that the design of the buildings could add to the difference between the thermal performances of the buildings surveyed. While it is not possible to categorically say that the perceived difference is as a result of a single factor. However, another possible explanation is that buildings that have tree plantings around them could be shaded and could record cooler ambient and internal temperatures than other buildings within the survey. Other possible factors perceived to contribute to the differences affecting the temperature could probably be attributed to difference in the orientation of the buildings, shading of the buildings from trees on neighboring properties and occupant behavior such as opening or closing windows. As it could be observed the seasonal difference of 3.4°C between the dry and wet period exist in the comfort temperature. The possible explanation for this is the result of a drastic drop in both internal and external temperature in the peak of rainfall. It might be argued that there is need to provide some internal temperature control mechanisms either within or outside the buildings through the design and construction of new residential buildings in this climatic zone if internal acceptable range temperature is to be achieved without depending on any form of mechanical cooling systems. This could also reduce the demand for more energy use to provide occupants' comfort. For instance, Figure 7 and Figure 8 show that a greater percentage of the occupants in their thermal preference prefer their houses to be cooler (Figure 8) as they currently find their thermal environment too warm (57%) and much too warm (20%). Meanwhile, very few found it to be comfortably warm (13%) and comfortably neutral (2%) (Figure 7). Thus, it could be seen that the thermal preference of the occupants of the residences shows the need for internal cooling of the building for occupants comfort.

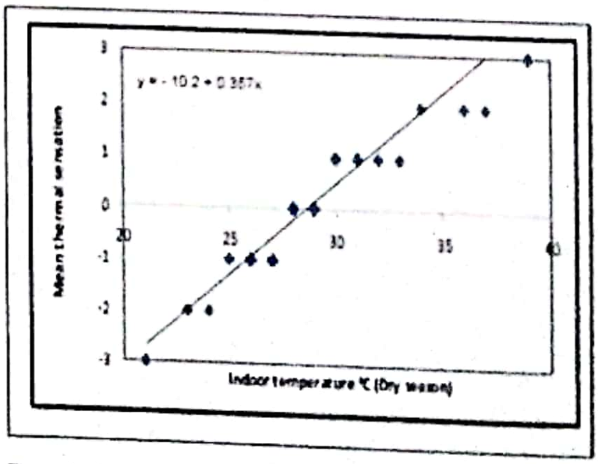

Figure 5. Thermal sensation scale against Indoor air temperature in dry season

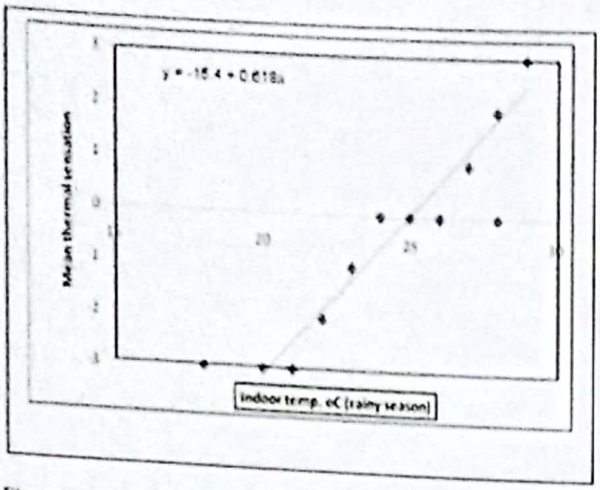

Figure 6. Thermal sensation scale against indoor air temperature in wet season

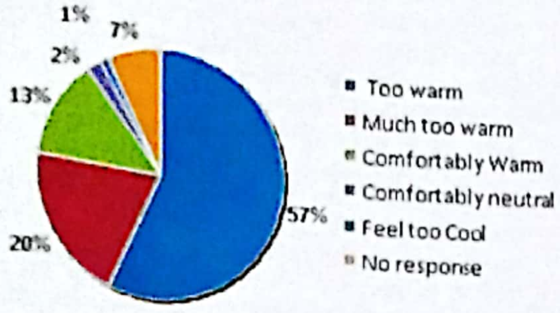

Figure 7. Thermal comfort vote

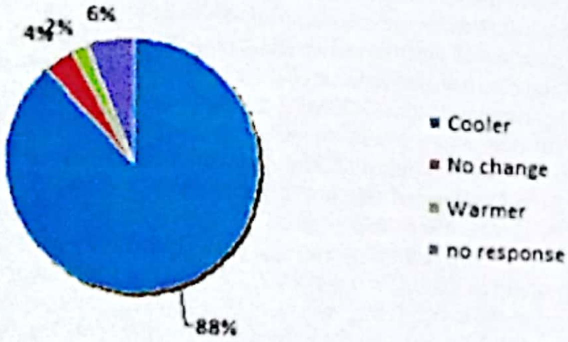

Figure 8. Preference thermal comfort vote

4. Recommendations for Sustainable Approach

It is important to note that in the light of the current global climate change, the characteristics features of any residential building should be prioritized to take account of environmental, economic and social factors at the design and construction stage if the building is to be sustainable as well have low impact on the built environment. This should include low energy use, good and acceptable internal thermal environment and occupant comfort. An energy efficient building would have to be design and constructed first to provide a high level of comfort for the occupants to be able to perform the designated function for which it has been designed and intended. The following are suggested as sustainable approaches to reducing energy demand and carbon footprint from residential buildings in Nigeria.

4.1. Building Techniques and Energy Efficient Materials for Building Envelope

One of the sustainable approaches to energy efficient in residential buildings in Nigeria is through the reduction of energy-intensive building materials and technologies. A huge prospect for sustainable construction technologies and practices encompassing environmentally friendly techniques, healthy and safe building materials still exists. While a good advancement has been seen with regard to this approach, from a typical example in the Agenda 21: Sustainable Construction in Developing Countries [22] this is yet to be fully taken up in Nigeria building industry. For instance, local traditional materials having lower embodied energy and much smaller environmental impact when compared to other building materials (i.e. bricks, concrete and iron) are yet to be fully explored for residential building envelope in Nigeria. Typical examples of these materials are adobe or compressed earthen blocks, earthen and lime-based plasters, the use of ash in replacement for Portland cement, straw-bale, and several locally affordable biomass products (e.g. hemp, bamboo). These could be used as raw material to produce resilient building materials [23]. Meanwhile, great caution is still needed to be exercised as suitability of any particular materials would need to be determined based on the adequate understanding of the climatic conditions and geographical risks they may pose as a result of being used.

4.2. Use of Passive-active and Systems

In order to minimize energy use and as well as provided the required internal comfort level for the building occupants, architectural design of residential buildings would need to adopt passive measures. The passive measure is a method that does not involve energy input either by the building or through a mechanical device. This include designing for solar protection such a veranda roof designed to shade a wall or a window type incorporated as a means of making adequate provision for natural ventilation to reduce the internal temperature of the building or a concrete slab over the window to provide shade from a sunny day; providing controlled daylighting, specification of low-emitting materials, controlled natural ventilation (Figure 9) and natural vegetation. Although these measures depend on meteorological conditions and/or the specific characteristics of the location (i.e. climate, vegetation, topography and geology, as well as the existing built environment), it is required that they should be designed to adapt to the location. This requires much studies and creativity from the architects and as the error in designing them could have dramatic consequences. Active measures include making provision for active cooling. However, some of these could be very expensive run in a house with a very poor passive design, therefore, active measures should only be considered after passive design measures have been adequately implemented.

4.3. Developing and Adopting an Energy Use Index (EUI)

The EUI is an expression of energy use by a building and directly as a function of its size or other characteristics. It is expressed as energy per square foot per year. The EUI is useful in identifying acceptable energy use levels for buildings of all types. In the United States of America, the EUI is well defined and adopted the Energy star programme of the US Environmental Protection Agency (EPA). In the same regard, a EUI for residential buildings in Nigeria could also be developed for specific climatic zones in the country. This could help to curtail energy waste in the residential sector where energy use is currently at a higher percentage than other sectors. If appropriately developed, the application of EUI could serve as a means to establish energy benchmarks for the built environment professionals (e.g. architects, property developers, engineers) and owners to consider the energy use requirements of their building design. This would provide a sustainable approach to reducing the impact of energy use on the built environment.

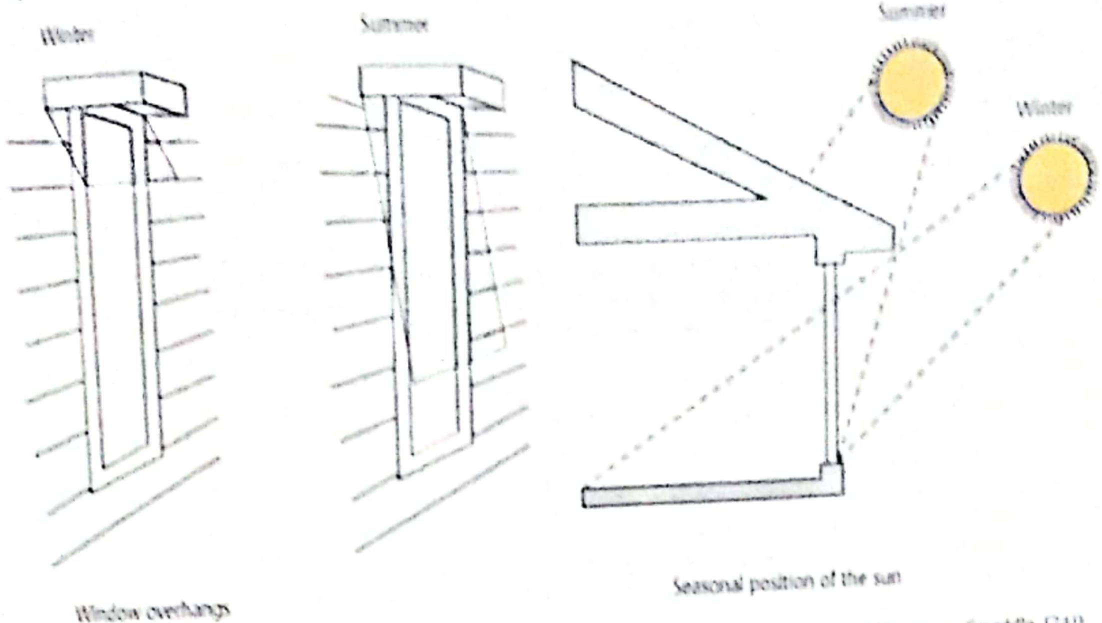

Figure 9. Shaded window overhangs using passive lighting and active shading. (Adapted from Hendler and Thompson-Smeddle, [24])

4.4. Planning and Implementing Regular Energy Audit Of Buildings

According to [25] an energy audit is a process of determining the types and costs of energy use in the building, evaluating where it is used and identifying opportunities to reduce its consumption. Energy auditing of a building put into consideration all the elements of a building (i.e. the building envelope, lighting; heating, ventilation, air-conditioning and cooling (HVAC); appliances & equipment and plug loads) to ascertain the cause of energy consumption in the building. Energy auditing could be applied to new design as well as existing buildings to develop and implement energy efficiency measures (EEMs) and interventions needed to make the building sustainable. Constant energy auditing of buildings would help to drastically reduce building's energy consumption, energy expenses and reduction of carbon emissions with little or no disruption to occupants' comfort and functionality of the building. In Nigeria, where the power supply is mainly rationed, the energy auditing of buildings would need to be introduced as part of building regulations and policies to regulate building energy consumption in design and operation of energy-efficient buildings.

4.5. Developing, Adopting and Implementing Energy Building Codes

One of the bedrock for the design and construction of energy-efficient and environmentally friendly buildings is the use energy building codes. The energy building codes covers every aspect of a building from building materials to best practices to be employed in constructing energy-efficient building. They are used to regulate all energy-related elements of either a new build or refurbished building. This may include building design, interior climatic conditions, ventilation, air quality, cooling, lighting, building orientation etc. Usually, different parameters are stipulated for different climatic zones. In most developed countries, building codes are compulsory and according to [26] and [8] they are among the most effective measures to ensure improved energy efficiency and performance of buildings.

In Nigeria, mandatory energy codes for residential buildings are rare and where they exist, it only exist on paper and rarely implemented. In order to develop sustainable approach for energy efficiency in residential buildings, like other developed countries, Nigeria could also develop and set targets for the purpose of controlling energy-related elements in either existing or newly built residential buildings. This would need to be integrated to guarantee implementation of passive, zero-energy, and zero-carbon buildings.

The limitation of this in the case of Nigeria is that adequate caution is required in adopting this type of regulations as such it may not be feasible for growing developers and self-build individual builders. However, this may be introduced gradually to avoid it resulting to forcing growing developers and builders into informal practices. Meanwhile, [27] has advised that the adoption of building codes should be supported by other instruments such as subsidies, capacity building and leadership development. Further recommendations by the UNHABITAT advocated that self-building designs that can be easily understood and adopted should be developed for low-income groups. According to [23] they may include a range of designs for different incomes and specific locations, all ensuring energy and water efficiency.

5 Conclusion

This study presented the findings on the link between indoor living environments and energy use of the existing residential buildings in the hot-dry climatic area of Nigeria. Existing residential buildings in this climatic area was discovered to deliver less than acceptable indoor living environment with inadequate indoor environment temperature that promote occupants' wellbeing. The main conclusion arising from this study is that sustainable approach can lead to improved architectural design and retrofitting of the existing residential buildings can greatly improve not only the indoor environment; but also offer the potentials of reducing energy consumption along with long-term running costs of the buildings. Findings suggests that achieving energy efficient buildings would require adapting to the changing energy constrained world, appropriate planning and design for energy efficient buildings; and retrofitting existing buildings for a future where energy supplies are running out and prices are rising high. The significant of this study is that it identified sustainable approaches to achieve low energy in the design and production of residential buildings using a specific climatic zone of Nigeria as a case example. The sustainable approaches recommended can help to improve occupants' well-being while at the same enhance resilience in policies, planning and practices for sustainable built environment. This could result in an enormous reduction of GHG emissions. It should be noted that the suggested sustainable approach discussed above may not see the light of day if the relevant legal framework within which they would find the appropriate platform to have a smooth takeoff is not in place. Thus, the government through the Standard Organization of Nigeria (SON) would need to create the right atmosphere to institute these approach if buildings in Nigeria are to become energy efficient for a resilient future of built environment

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