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Effect of Climate Change on Energy Utilization in Residential Buildings

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ABSTRACT

Nigeria's climate has been changing, evident in: increases in temperature; variable rainfall; rise in sea level and flooding; drought and desertification; land degradation; heat wave and more frequent extreme weather events. Its effects are mainly caused by excessive emission of greenhouse gases (GHG) in the atmosphere from various sources. Owing to these unhealthy activities of man in his environment, the most widely accepted climate change scenarios predict increases of between 1 and 3.5°C for the global annual average temperatures. These effects have largely impacted the tropical monsoon climate, the climatic zone where Owerri, the capital city of Imo state lies. To ascertain the position of this work, this research studies the variables of climate change in Owerri, and quantitatively analyses primary data collected from respondents residing in Imo state using statistical models. The research findings were based on a survey carried out on the selected residents in Owerri to measure their energy utilization in responding to thermal changes in their environment which is a result of changes in temperature, humidity, and precipitation of the study area from 1979 to 2021. Previous research findings on this study area have revealed that much has not been done in promoting energy efficient designs to ensure a healthy living condition of users in building spaces owing to deficiency in a detailed study on the impact of climate change on energy utilization in residential buildings in Owerri. The results from this research are geared towards proposing adaptive strategies and system upgrade solutions to address energy utilization issues in residential buildings emanating from climate change.

Keywords: Climate Change. Energy utilization, Greenhouse gases, Residential buildings,

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1. INTRODUCTION

This study is focused on the effect of climate change on energy utilization. A study by the World Bank (2017) revealed a rise in temperature and humidity levels constitutes a potential hazard to health and human comfort and accelerates many degradation processes and material damage. Subsequently, the amount of energy needed to maintain the condition of air in spaces at comfort levels keeps increasing [1]. Furthermore, the planet is expected to face increase in temperature of an average of 0.2 degrees every ten years until the end of this century and this variation is projected to impactthe indoor climate of residential buildings prompting residents to adopt adaptive strategies, and active (cooling) systems and other measures to curtail its effects [2]. Another research on the impact of Climate change on the indoor environment of building spaces is the study of [2]. A critical review of existing body of knowledge signals that much has not been done in Imo state in promoting energy efficient buildings owing to the deficiency in studies and awareness on how changes in climate affects energy utilization in homes. Against this backdrop, this research is tailored towards articulating the effect of climatic change on the comfort of residents in Owerri encapsulated in its relationship with energy utilization among these residents. To achieve this goal, this research studies the state of the indoor environment of residential buildings in Owerri laden with thermal changes, ascertains the effect of these thermal changes on the comfort of residents, and determines the extent energy is demanded and consumed by them.Furthermore, this study ascertains the source of energy largely utilized and the period in the day / seasons with the greatest demand for energy. It proposes adaptive strategies and solutions to address issues arising from thermal changes evidenced in the indoor environment of studied residential buildings in Imo state. The research resultswere further substantiated by graphical representation of dataon how human comfort is affected in residential buildings in Owerri. Nevertheless, this study is faced with the challenge of conducting survey among residents in Owerri and to validate the findings of this study the authors adopted the use of physical observation as well. The audiences of this study are architects, users and other players in the building industry.

2. LITERATURE REVIEW

There are three distinct climate zones in Nigeria, a tropical monsoon climate in the south (which is where Imo state belongs), a tropical savannah climate predominantly in the central regions, and a Sahelian hot and semi-arid climate in the north of the country [6].

Imo State is located between latitude 4°45′N and 7°15′N and longitude 6°50′E and 7°25′E, with an area of about 5100 $km^2$is also characterized with dry and wet seasons [3]. Interestingly, these seasons is marked by varying levels of thermal changes.

2.1 Climatic classification of Owerri Metropolis

Owerri is positioned at an elevation of 123.97 meters (406.73 feet) above sea level, and is predominately of Tropical monsoon climate (Classification: Am) [3].

Its mean annual temperature is 28.88ºC (83.98ºF). It is characterized by 234.25 millimetres of precipitation and has 267 rainy days (73.67% of the time) annually [4].

2.2Changes in climate

The Paris Agreement of 2015 presents a global framework to reduce global warming below 2°C, preferably to 1.5°C (degrees Celsius), compared to pre-industrial levels. To actualize this global temperature goal, countries aim to mitigate the upsurge in greenhouse gas emissions quickly using the best instruments and methods at their disposal [4].

Climate changes are already evidenced by increasing air temperatures, melting glaciers and decreasing polar ice caps, rising sea levels, increasing desertification, heat waves, droughts, floods and storms. Evidently, climate change is not globally uniform and affects some regions more than others.

2.3 The effect of climate changes in Owerri for the past 40 years

Studies show that there has been some significant variation in the climate of Imo state from 1979 to 2021. The data source used is ERA5, the fifth generation European Centre for Medium-range Weather Forecasts (ECMWF) atmospheric analysis of the global climate with a spatial resolution of 30 km [5]. For a clearer communication, the climate data is hereby shown below;

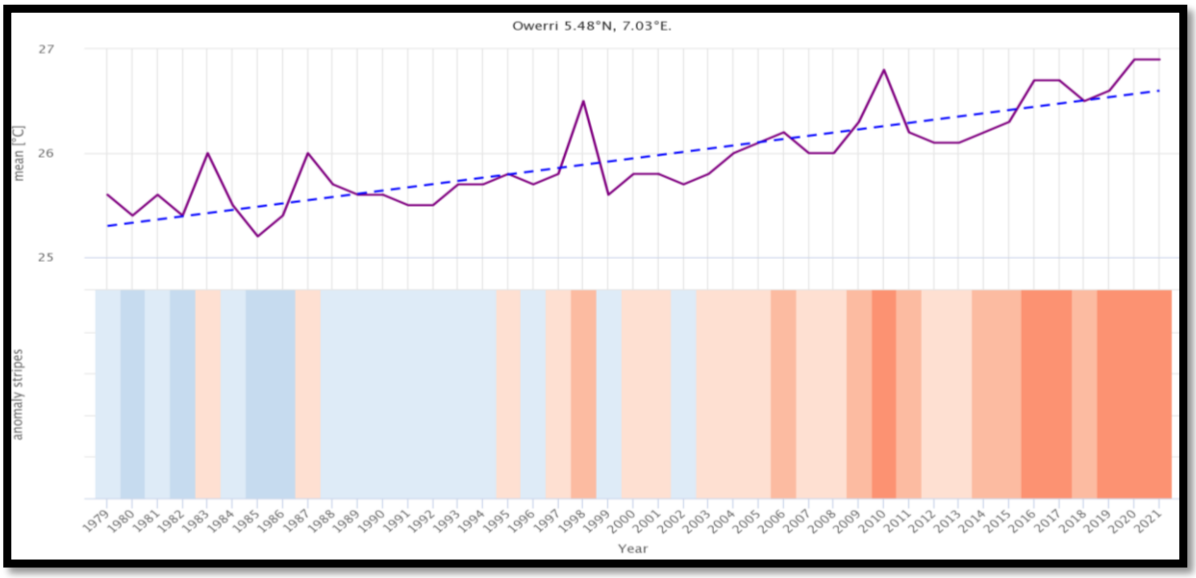

Figure 1: The mean annual temperature, and variations in Owerri from 1979 – 2022 [5].

The figure above showsan estimate of the mean annual temperature for Owerri. The dashed blue line depicts the climate change variation, which from the above graph is going up from left to right, indicating that temperature trend is positive and Owerri is getting warmer due to climate change. The lower part the graph shows the warming stripes. Each coloured stripe represents the average temperature for a year - blue for colder and red for warmer years. From the graph, the yearly average temperature rises towards year 2021 [5].

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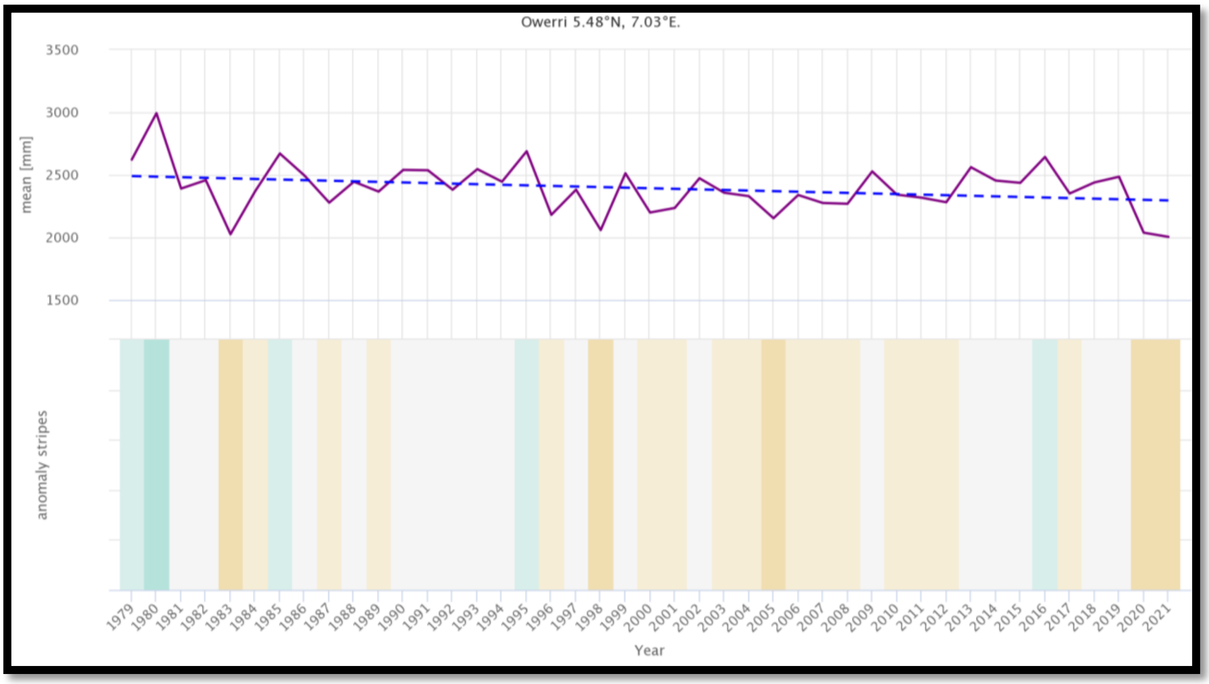

Figure 2: The mean annual rainfall, and variations in Owerri from 1979 – 2022 [5].

The figure above shows an estimate of mean total rainfall for Owerri. The dashed blue line is the climate change trend or variation. From the graph, the trend line is going up from right to left, meaning that atmospheric and environmental conditions are becoming drier in Owerri over time.In the lower part the graph denotes the rainfall stripes, and the brown coloured stripe represents the total rainfall of a year for drier years evidenced in the recent years (2020 – 2021). However, the brown coloured stripe represents the total rainfall of a year for drier years [5].

2.4 Thermal changes and human comfort

Statistics show that climate changes in Owerri is gradually making the state warmer and drier on the average as evidenced in the difference of 3.5^{0}C meanannual temperature leading to thermal changes in building spaces. These thermal changes in the indoor climate of buildings has propensity of altering the wellbeing and living conditions of residents at different periods in a day during dry and wet seasons[6].

2.5 Energy use

Studies show that the extent to which the comfort of residents are affected depends on the form, method and level of energy required to address the inherent changes based on the climatic classification of the geographical location of the study area. Energy consumption is highly needed by residents to address most of the issues emanating from indoor thermal changes. However, this research is carried out to ascertain the credibility of the existing statistics with an in-depth analysis of energy consumption of residents in Owerri. The result of this analysis will inform detailed recommendations on how to mitigate energy use in residential buildings, protect the climate, and environment.

3. RESEARCH METHODOLOGY

In this study, data was collected via responses of questionaires sent out to the residents of Owerri Municipal, Owerri North, Owerri West Local Government Areas using Google form as a medium. The e-questionaire which is the research instrument was responded to by the target respondents. The responses were coded with discrete values and properly prepared for quatitative analysis. The data gathered from the survey were analysed using Statistical Package for Social Sciences (SPSS) furnished with other necessary models to stimulate a well informed research finding.

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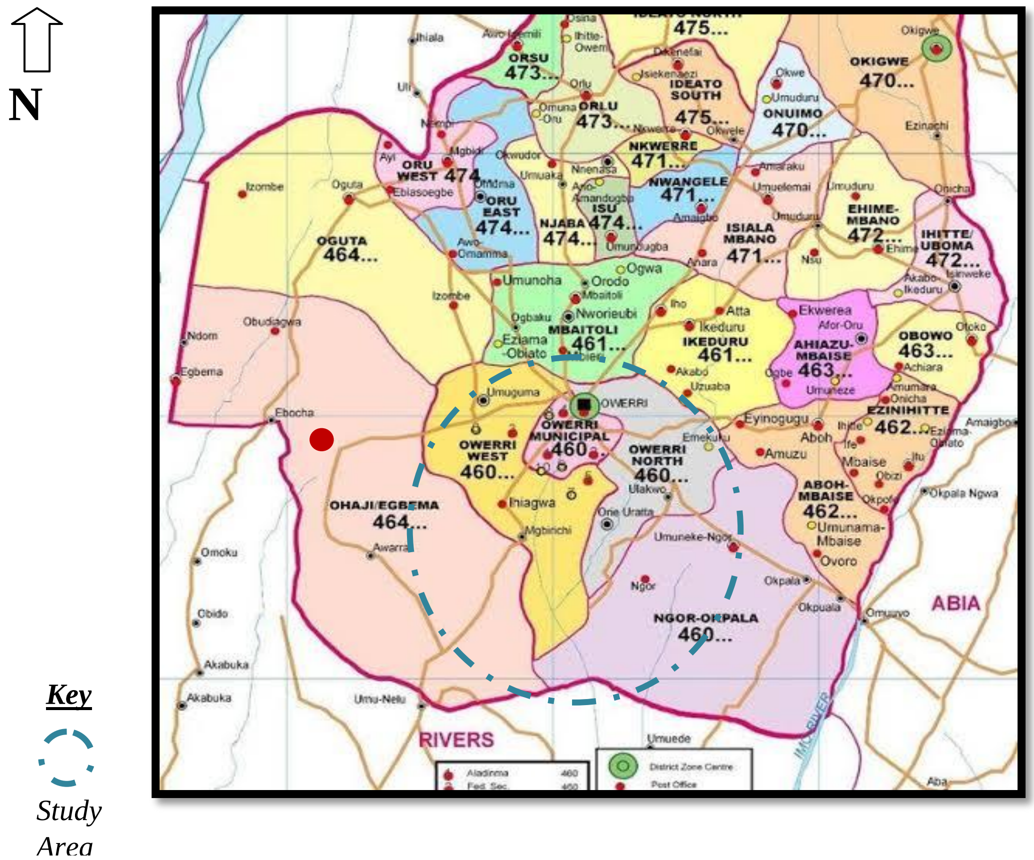

Figure 3: Map of Imo state showing the study area [6].

SPSS was used to present the graphical models of the research findings. In analysing the responses from the target population, the research goals and objectives were placed side by side to ensure a well-informed research results.

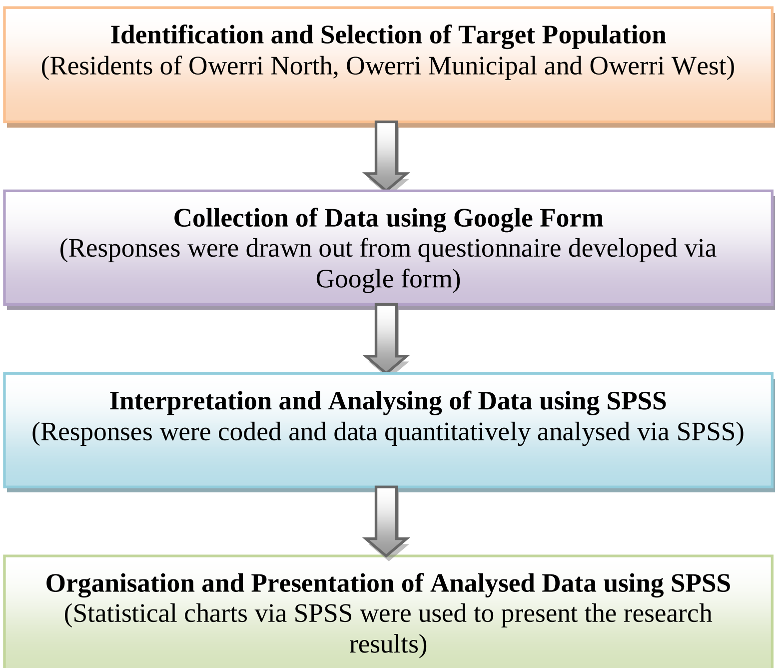

Figure 4: Steps followed in developing research results

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4.0 RESULTS AND DISCUSSION

4.1 Results

In this section the research findings were presented as captured from the analysed data collected from selected residents in Owerri masked with physical observation on their energy demand and usage. The results encapsulated the responses of the target population during the dry season (night and day). It also covers the energy source the target population depends on and utilizes in most periods during the day and night as well as deduces the particular time in the day when the residents of Owerri Metropolis need energy the most particularly for regulating the indoor climate of their building spaces.

Table 1: The percentage of the respondents from Owerri North, Municipal, and West

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Owerri North	1	5.0	5.0	5.0
	Owerri Municipal	7	35.0	35.0	40.0
	Owerri North	9	45.0	45.0	85.0
	Owerri west	2	10.0	10.0	95.0
	Owerri West	1	5.0	5.0	100.0
	Total	20	100.0	100.0	

Table 2: How the respondents felt during the day in the dry season

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	6	30.0	31.6	31.6
	Hot	10	50.0	52.6	84.2
	Cool	3	15.0	15.8	100.0
	Total	19	95.0	100.0	
Missing	System	1	5.0		
Total		20	100.0		

Table 3: How the respondents felt during the night in dry season

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Warm	5	25.0	25.0	25.0
	Hot	7	35.0	35.0	60.0
	Cold	1	5.0	5.0	65.0
	Cool	7	35.0	35.0	100.0
	Total	20	100.0	100.0	

Table 4: The energy source the respondents depended on the most

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Generator	9	45.0	45.0	45.0
	PHCN (NEPA)	10	50.0	50.0	95.0
	Solar	1	5.0	5.0	100.0
	Total	20	100.0	100.0	

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Table 5: The period the respondents demanded for energy the most

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Afternoon	1	4.8	5.0	5.0
	Night	5	23.8	25.0	30.0
	All of the above	8	38.1	40.0	70.0
	None of the above	2	9.5	10.0	80.0
	Varies	4	19.0	20.0	100.0
	Total	20	95.2	100.0	
Missing	System	1	4.8		
Total		21	100.0		

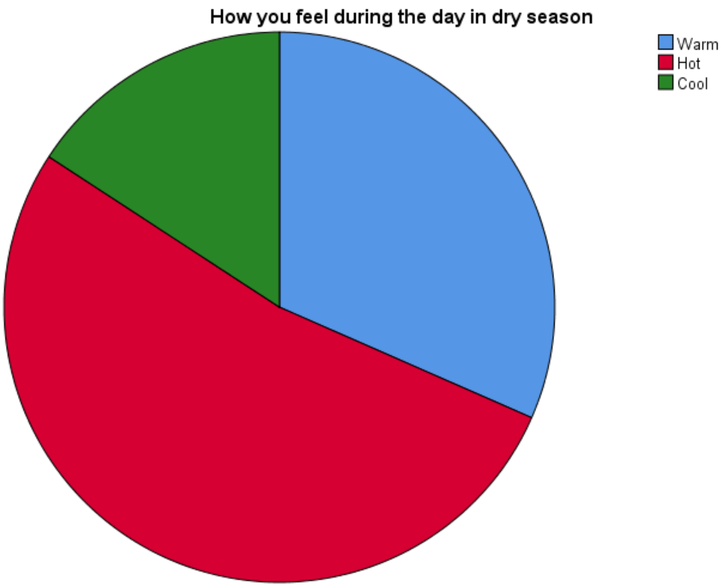

Figure 5: A pie chart showing how the respondents felt during the day in dry season

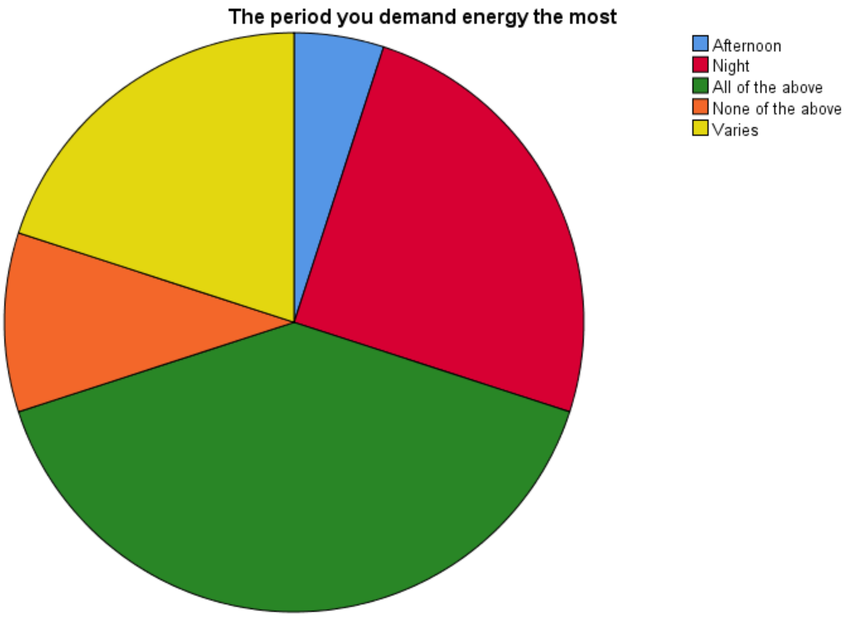

Figure 6: A pie chart showing the period the respondents demanded for energy the most

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Table 6: The relationship between the extent of energy demanded by the respondents in response to how they felt during the day in dry seasons

			How you feel during the day in dry season	The period you demand energy the most
Spearman's rho	How you feel during the day in dry season	Correlation Coefficient	1.000	.292
		Sig. (2-tailed)	.	.212
		N	20	20
	The period you demand energy the most	Correlation Coefficient	.292	1.000
		Sig. (2-tailed)	.212	.
		N	20	20

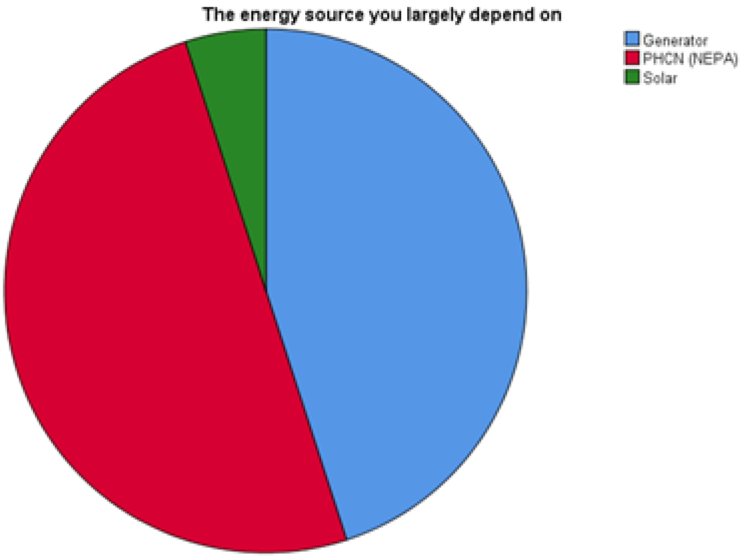

Figure 7: A pie chart showing the energy source the respondents depended on the most

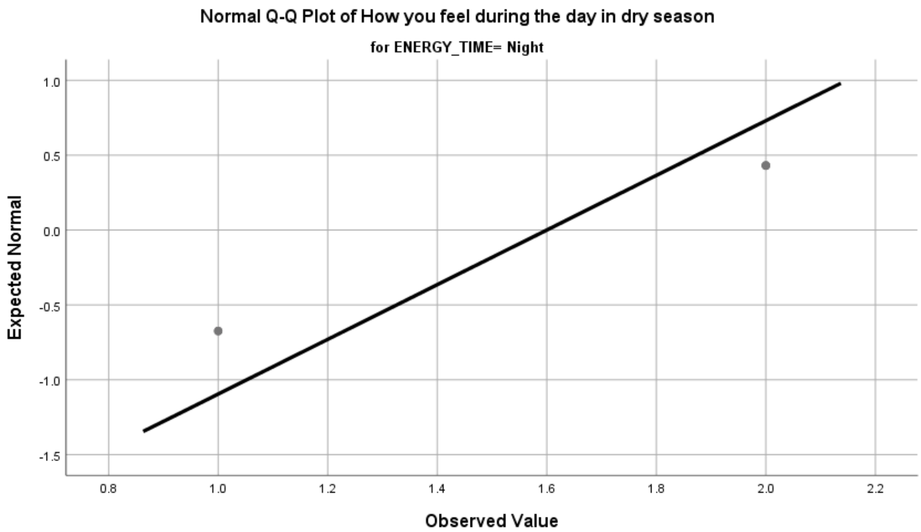

Figure 8: A Normal Q-Q Plot showing how the respondents felt during the day in dry season

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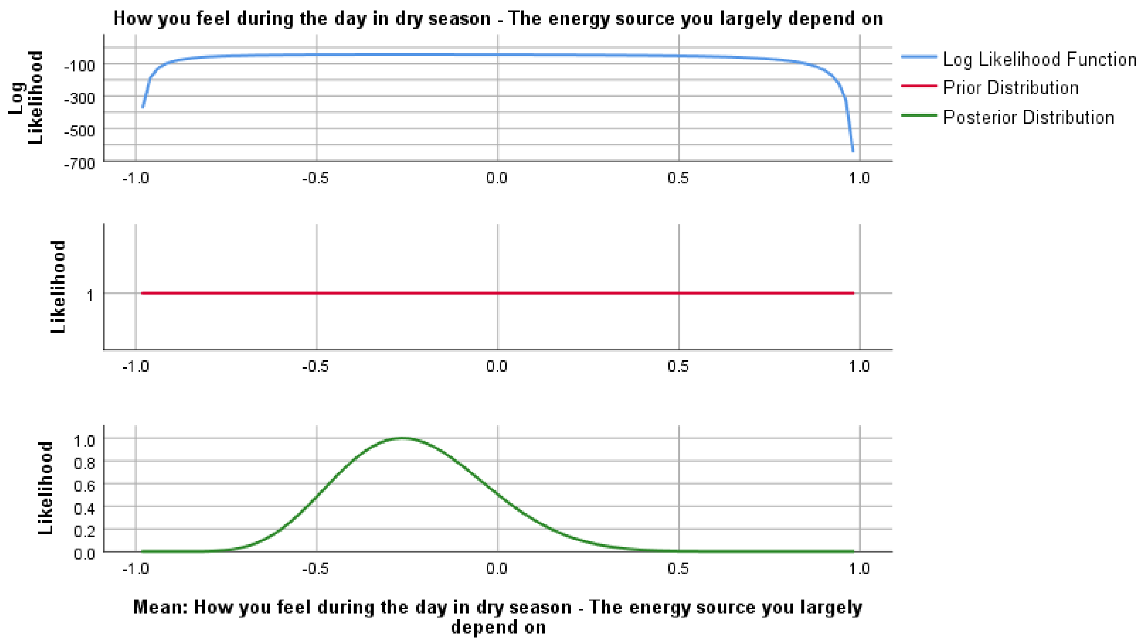

Figure 9: A correlation between the thermal conditions of the respondents during the day in dry season with the corresponding energy source relied on by them to address it.

4.2 Discussions

For the purpose of this study, a survey was carried out in Owerri city which is made up of three (3) Local Government Areas namely; Owerri Municipal, Owerri North, and Owerri West with Owerri North having the highest number of respondents of 45%. The result from the analysed data shows that 52.6% and 31.6% of the residents in the study area experience hotness and warmness respectively during the day. This proves that fact that increase in daily temperature and dryness laden by climate change has invariably led to the increase in room temperature. By Night, 60% of residents still felt some degree of discomfort usually in the evenings (before 12:00am) though 35% of them experienced comfort in the night. That level of comfort experienced by these residents was observed to be precipitated by the loss in the latent energy in the heated indoor air due the absence solar isolation. This comfort was further substantiated by the cool land breeze and harmattan wind.

Furthermore, the analysed data reveals that 45% and 50% Owerri residents depend on generator and NEPA light respectively. Also, 40% of them demanded for energy (day and night) mostly to power their cooling units at their disposal so as to deal with the increase in air temperature felt during the day and sometimes in the night. 25% of the residents interviewed specifically needed energy (electric power) in the evening and night most likely to enhance sleep and illuminate their spaces while 20% of the population agreed that their demand for energy varies at different periods in a day/night.

From the normality test carried out, the Q-Q plot diagram and graph confirms the fact that how residents feel during day and night affects the extent to which energy is demanded and utilized by them. Conclusively, the analysed data proves that a majority of Owerri residents feel hot in most of the periods during the dry season leading them to adopt different strategies to deal with the intense weather changes.

4.3 Adaptive strategies adopted by the sampled Owerri residents

The research results also critically captured the fact these residents expressed adaptation strategies to cope with the harsh weather conditions particularly in hot periods which characterize most of the days in Owerri. These adaptive strategies include; putting off of heavy or thick apparels, opening of windows, regular and cold bathing, regular in-take of water (cold) and the likes. The reason for this was not investigated by this study but preliminary survey x-rays that this could have been instigated by high cost of fuels, low purchasing power on the part of consumers, and erratic power supply by public utility systems.

Apart from the dependency on energy to regulate the indoor environment by the residents of Owerri, most of the sampled residents suggested some ways to address the issue of thermal discomfort felt by them as shown below.

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Table 7: Suggestions on how thermal changes experienced in Owerri can be addressed	
1.	By providing of trees (vegetation) around the residence, soft landscape, use of thermal resistant and insulated building materials.
2.	By planting greens in and outside spaces as well as adopting renewable / clean energy sources such as solar energy.
3.	By use of building components / materials that are responsive to climate change.
4.	By creating a naturally well-ventilated environment
5.	By taking enough water and creating an airy environment
6.	By using blocks with cavity and roof vent

Deductions from the adaptive strategies utilized and suggested by Owerri residents brings to fore that these sampled population are knowledgeable of the effects of climate change in buildings and how these effects can be addressed. Furthermore, this will trigger the consciousness of all the players in the built environment to consider the effect of climate change in all their building deliverables for an adaptable, sustainable and healthy living environment.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The effects of weather changes have generally experienced in different parts of the world. In Owerri, the capital city of Imo state has averagely been marked with increase in daily temperatures and dryness. Evidently, this rise in temperature has led to thermal discomfort of residents. In this work, we accessed the effect of these changes in weather on energy use of the 20 Owerri residents using statistical models. Findings from the study proves that the upsurge of hotness / warmness felt among these residents prompted them to adopt varying adaptive strategies which was chiefly characterised by high demand on energy to power cooling systems tailored towards regulating the indoor climate of their residences for human comfort. Unknowing to most of the sampled residents, the generators which they rely on to augment energy shortage by the electricity providers in Owerri runs on fossil fuel and constantly emits carbon monoxide which contributes to global warming (same problem which they are struggling to contain). On this note, this paper strongly recommends the adoption and utilization of clean and renewable energy sources in meeting their energy needs. In addition, Owerri residents are urged to maximize the use of natural adaptive strategies (e.g., taking cold bath during hot periods of the day / night) to reduce over-dependency on fossil fuel, mitigate carbon footprints, cut down on money expended on energy use, protect the environment and their health.

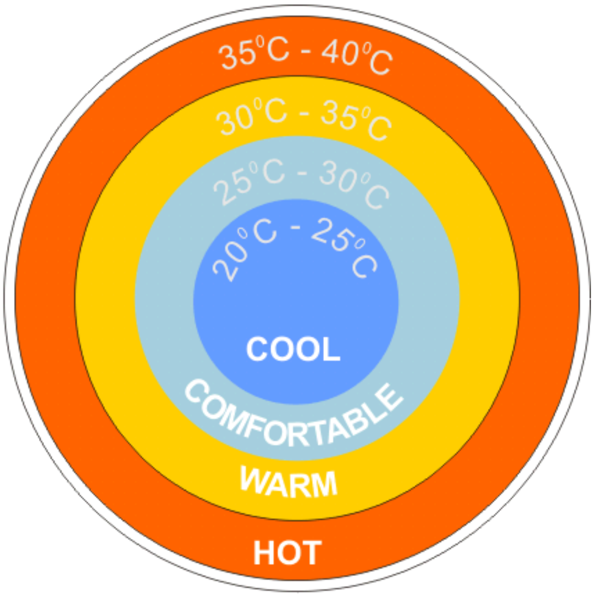

Figure 10: *Proposed Room Temperature Wheel of Owerri Metropolis*

The proposed Room Temperature Wheel (RTW) above summarizes the temperature range at which residents of Owerri metropolis experienced hotness, warmness, comfort, and coolness at certain periods of the day and night. Hotness with temperature range of

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35^0C – 40^0C was experienced from 12:00pm to 3:00pm; Warmness with temperature of 30^0C – 35^0C was experienced from 9:00am to 11:00am as well as from 4:00pm to 12:00am; and Comfort with temperature range of 25^0C – 30^0C was experienced between the hours of 1:00am to 3:00am as well as 6:00am to 8:00am while Cold (Coolness) with temperature range of 20^0C – 25^0C was experienced between the hours of 4:00am to 6:00am.

5.2 Recommendations

Table 8: Architectural solution to energy utilization in residential buildings

Building Components	**Passive Design Recommendations**
FOUNDATION	- The provision of weep holes at the sub-structural component to regulate the environmental conditions of the foundation - The Damp Proof Membrane (D.P.C) should be characterized with sustainable materials and the Damp Proof Course (D.P.C) should be high and structurally constructed to totally separate sub soil conditions from factors such as atmospheric conditions.
FLOOR	- Use of carpets and other floor covering materials that promotes thermal insulation should be encouraged. - Use of composite floor systems with layers of materials with high thermal resistance such foam, fiber-board to accelerate in the regulating the indoor space.
WALL	- Walls are to externally composed with weather resistant / sustainable materials such as hollow blocks, mud etc. and finished / covered with materials such as tiles, marbles etc.to keep the indoor climate conducive. - Composite wall materials with layers that will damp the permeation of the external environmental condition into the indoor space. - Air spaces such as cavities should be incorporated in the wall component to protect the indoor climate. - Internal walls should be finished with elements with high thermal resistivity. - Double or triple glazed windows / paneled doors that have the capacity of preventing heat transfer into building spaces should be used.
ROOF / CEILING	- The roof space should be high and considerate to serve as a buffer zone for the heated air temperature from the roof covering. - Suspended ceilings should be encouraged. Mechanical and electrical fixtures should be accommodated in the ceiling to prevent the infiltration of hot air into the indoor spaces. - Sustainable roof materials and structures such as green roof, thatch should be used as roof covering to absorb solar isolation and prevent it from permeating into the indoor spaces. Solar roofs /panels (solar thermal cool) with super insulation should be encouraged.
BUILDING ENVELOPE	- Passive solar designs, low energy and zero energy building systems that supports the provision and utilization of energy by itself is ideal for Tropical monsoon climate. Photovoltaic cells should be incorporated into surfaces that are sufficiently exposed to sun rays such as shading devices to create avenue for self-electricity generation by the structure. Shading devices such as fins, pergolas, plants should be provided in parts of the building exposed to solar heat.
BUILDING SERVICES	- Sustainable approach towards the collection, purification, recycling of water waste should be utilized such water collection from roof using collectors. Harnessing indigenous approach in mitigating the dependency on active systems for energy generation should be encouraged such tanks that can be exposed the solar heat to provide bathing water for building users.

Orientation of buildings: Residential buildings should be well positioned on site with good consideration to the rising and setting of the sun, wind direction / speed, solar isolation, and other meteorological phenomena within the geographical location of the proposed building geared towards mitigating the level of thermal transmission into building spaces.

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*Landscape:*Ample use of soft landscaping features characterized by green and sustainableelements that have the capacity of improving human comfort in building spaces should be encouraged. Such features should be able to improve the indoor air quality, and mitigate thermal transmission into spaces.

*Optimal use, re-use, and recycling of building water, waste and other resources:*There should be provision for collecting rain water for different purposes such as washing, bathing, irrigation, cleaning and other purposes. This collected water can also be treated for drinking purposes. Sustainable waste management systems should be incorporated in the buildings systems. Waste water from buildings should be treated and recycled for other purposes. Facilitiesthat utilize zero or minimal water for operation should be used in buildings. Innovative and adaptable strategies of optimally using systems should be adopted as well as re-using by-products from these systems.

Energy management and efficiency: Players in the building industry should aim for low and zero energy buildings that meets standard energy and environmental regulations due to the that the fossil fuels the residents of Imo state depends on contributes to the GHG and comes at a high cost. However, this study suggests the use of systems that rely on renewable and rechargeable sources. This recommendation should be supported by incorporating design features in buildings that has the propensity of nullifying the rate of thermal transmission in spaces. These features include; green roofs, good attic spaces, thermal insulated roof/ceilings, sizeable headroom, thermal insulated building components, long roof overhangs, shading devices, atriums, green/water elements, green walls, sufficient and sizeable windows, outdoor spaces, indoor pools, free flowing spaces, indoor gardens etc. Building should be designed to stimulate dependency on passive cooling systems and be economical with fossil fuels as energy source geared towards reducing the effects of climate change. This conscious effort should be led by legislation and enforcement by the federal, state, and local government.

Careful selection of sustainable building materials, components, and systems:
Architects and developers should study and evaluate the effect of any building deliverables they intend using in buildings. They should go for materials with low thermal conductivity for building spaces as well as apply thermal insulated spaces and layers between building elements. Design considerations such as the colour/texture of materials, nature/thickness of elements, method of application, distance between layers, susceptibility to heat, fire and moisture etc. should be taken note of in buildings. All parameters that constitute the building should be climate responsive to stimulate human comfort in spaces. Architects should ensure energy analysis and models are obtained and implemented in all buildings as spelt out in the energy codes.

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