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Climate Change: Resilient Design Strategies for High Rainfall Areas of Southeastern Nigeria

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***Abstract* - This paper examined rain action on buildings in South-eastern Nigeria where annual rainfall figures range from 1740mm to 2400mm. The aim of the study was to establish the importance of climatic context in building design to ensure resilience to adverse rain action. The study was conducted inside the premises of the Federal Polytechnic Nekede, Owerri. All the buildings in the institution totalling 116 were assessed based on age, design features, and types and levels of rain damage. Data collection was by physical enumeration and pictorial documentation. Analysis of results was by simple descriptive statistics. The findings identified either mild or severe rain damage on the buildings, traceable to design features, materials, and construction detailing. The study concluded that buildings in the study area should have high-pitched roofs, extensive eave overhangs, rain collection and discharge mechanism through gutters and downspouts, impervious walls, airtight openings, shaded windows, and elevated ground floor levels.**

Keywords: Climate change, building design, rainfall, Southeastern Nigeria.

I. INTRODUCTION

In Nigeria, a number of indicators point to the fact of a changing climate over the past decades. Records point to significant variations in rainfall intensity in Nigeria between 1960 to 2020 [1] The maximum rainfall peaks have also changed, with the peak in the Northern part of the country shifting from August to July, and the South shifting from July to September. These have led to more prominent intra-annual variability of rainfall across the country. The findings of the IPCC 5th Assessment Report [2], identify an increase in disruption of the climate as a precursor to severe pervasive and irreversible impacts that can limit the building of a more prosperous and sustainable future for all humans [3]. It follows that mitigation and adaptive measures must be put in place to protect people from the unwelcome effects of the changing climate. Employing sensible design strategies will require a holistic assessment of the problems to be solved.

This study focuses on rainfall as one climatic element which impacts substantially on different parts of a building, with implications that not only relate to thermal comfort, health, and well-being of residents, but also on a building's aesthetics, as it can destroy external and internal finishes, and possibly create a gateway for structural impairment of buildings in extreme cases. The aim of this research is to establish the importance of climatic context in the design of buildings in South-eastern Nigeria, such that they are resilient to adverse rain action, considering the high incidence and extreme variability of rainfall in that zone, coupled with the avoidable cost of replacement of damaged buildings in a depressed economy.

Resilient buildings fit into the concept of constructing for the future, which concept encompasses the principles and practices of sustainable and forward-thinking approaches to building design, construction, and infrastructure development. Buildings that are sensitive to climate also positively align with the long-term impacts of construction projects on the environment, society, and the economy. Such buildings are resilient, efficient, and adaptable to changing needs.

1.1 Buildings and Climatic context

Climatic context refers to the environmental conditions and factors that contribute to the overall climate of a particular region or area. It involves understanding the long-term patterns and variations in temperature, precipitation, wind patterns, humidity, and other atmospheric conditions that influence the weather experienced in that location [4].

Climate change impacts in Nigeria include increasing climate variability, which has led to more intense and untimely rainfall [6]. In the southern part of Nigeria particularly, rainfall has become both unpredictable and more intense [7]. Though rainfall data over the decades point to an incremental decrease across the country since the 1960s, in the same period, a high degree of variability has been observed in rainfall trends leading to a decrease in predictability of seasonal rains across the country [1]. Climate change trends in Nigeria point to increased frequency and intensity of rainfall, which increase not only the risk of flooding, but also of damage to physical infrastructure and buildings. In assessing the climate risk profile of Nigeria, the World Bank Group [1] identified changing precipitation patterns along with rising temperatures and extreme heat, as factors likely to induce new challenges in the environment and exacerbate new ones.

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1.2 Rainfall effects on buildings

Rainfall is liquid precipitation condensed as water vapour falling from the clouds or deposited onto the ground from the air. Rainfall characteristics which determine the levels of its impact on buildings are frequency, duration, variability, intensity, and seasonality. Rainfall affects buildings as moisture which occurs either as a result of rainwater entering directly through cracks and openings, or through surface water, ground water, or flood. Moisture from these sources impact buildings negatively through a variety of ways including air leakage; a process of infiltration and exfiltration, vapor diffusion through microscopic pores which most materials possess, capillary action, driving rain, and surface condensation [8].

Damage to buildings as a result of moisture action can be very expensive. Moisture related issues in buildings include corrosion of metals, peeling of paint, damaged finishes, growth of mould on surfaces, wood decay, among others [9]. All these can lead to health problems, as well as the constant need for repairs and replacement of building components. Repair and replacement costs drastically increase life cycle costs of buildings, and do not promote economic sustainability which is a key component of constructing for the future. The most practical ways of controlling moisture damage in buildings involve controlling entry of moisture into the building, controlling its accumulation if it has entered already, and removing the moisture as fast as possible if the first and second options fail [10]. Control of entry of moisture into buildings can be achieved to a significant extent through design.

1.3 Climate change and resilient building design

Resilience in a building is the ability of the building to maintain or regain functionality and vitality in the face of attendant stresses and disturbances. Resilience is explained in the IPCC policy paper as the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure while also maintaining capacity for adaptation, learning and transformation [2]. The essential role of resilience in building design is adaptation to the changing climate, as well as the ability to learn from the experience and transform. It follows that resilient buildings should be able to reduce risk to the buildings, by successfully overcoming the problem of multiscalar uncertainties associated with climate change.

Important aspects of building resilience as posited by Pham, Palaneeswaran and Stewart [11] include building performance over time in relation to strength, robustness, durability, and adaptability. This is achieved by ensuring that building design remains context-specific, in this case, climatic context. Since climatic zones differ from place to place, it supposes that there is no single recognized approach to adaptation, as different climatic zones must apply appropriate strategies to address their specific peculiarities.

Nigeria like other world economies, has developed a policy document to tackle the effects of climate change. This national climate change policy is four-pronged and includes a national environmental policy. The aim of the climate change policy is to mitigate the economic and environmental effects of climate change on a large scale. The policy acknowledges that all aspects of Nigeria's development are vulnerable to climate change-related stressors, including its physical capital made up of cities, infrastructure, and buildings. Specifically, the policy in addressing the issue of human settlement, provides for ensuring that settlements are made resilient to long term climate risks and that they are managed in ways that protect people [12].

1.4 Design Requirements for High Rainfall areas

Changing climate brings with it changing requirements for building design. Sudden heavy downpours make it necessary to direct rainwater away from the building fabric, building interiors, paved areas and roads, to avoid deterioration and to channel flooding away from the building. Higher groundwater levels increase chances of rising damp and water seepage into the building. In flood prone areas, buildings must be designed to rise above flood level and exclude water deluge during the rains. The level of negative impact of rainstorm on a building will depend on the physical susceptibility of the building, including how much of the roof, facades, materials, and structures are exposed to rain action [13]. Materials and construction methods should expectedly withstand negative fall outs of weather elements, to ensure resilience.

In Nigeria, the National Building Code [14] provides guidelines for rain control in buildings. The code in section 5.13.1 requires all weather exposed surfaces to have resistive barriers to protect the interior wall covering. It further regulates in 5.13.2 that where exterior openings are exposed to weather, they should be made waterproof. Metals used on all external surfaces must be not less than 26-gauge corrosion resistant metal. Damp-proofing of foundation walls is required for all areas with high ground water levels as provided for in 5.13.4 of the code. Section 10.16.5 regulates that roof pitch for high rainfall areas should be a minimum of 30^o. Where there are parapets, they shall be coped with approved materials including residential buildings, hotels, childcare facilities and schools, the maximum percentage of unprotected exterior wall openings shall be 5%.

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Notwithstanding the provisions of the National Building Code, building typology in the South-eastern part of Nigeria has continued to evolve away from the climatic requirements in line with supposed trends in civilization. This new trend includes flat roofs, unshaded curtain walls, and other features that show scant regard for climate, leading to high maintenance architecture [15]. As human civilization continues to grapple with climate change, building designs must also evolve to adapt to its effects. Cramer (2018) [16] sees climate change as the fundamental design problem of this time. Climate context therefore becomes critical in building design, seeing that the primordial function of buildings has remained relevant, as buildings are expected to maintain structural, functional, and aesthetic integrity in the face of extreme climatic events.

II. THE STUDY AREA

The study was conducted within the premises of the Federal Polytechnic Nekede, Owerri, a tertiary institution in the capital of Imo state.The study area is the South-eastern part of Nigeria. This area comprises five (5) states namely, Abia, Anambra, Ebonyi, Enugu, and Imo, with a total land area of over 29,000km2. This area falls broadly within the tropical rainforest climatic zone, with a small area skirting the coastal climate of the South-south zone. The tropical rainforest is warm and humid, with abundance of palm trees and leafy deciduous trees. The zone is characterized by heavy and abundant annual rainfall. It experiences two high rainfall peaks from March to end of July, a short dry break in August, and another rainy season around September to late October. The zone experiences strong rainfall events during the rainy season, and annual rainfall amounts are usually in excess of 2000mm for most locations. Rainfall figures for the period covering 1901 to 2020 reveal that volume of precipitation has declined over the decades (see Table 1), but rainfall events have become more intense, affecting both peak periods and duration. This is largely attributed to temperature increases because of climate change. These variations have made rain control strategies critical for building design within the zone.

Table 1: Volume of Precipitation Observed From 1901- 2020

Location	1901-1930	1931-1960	1961-1990	1990-2020
Imo	2308.18	2299.43	2218.98	2209.58
Anambra	1992.12	1972.41	1918.65	1930.39
Enugu	1828.53	1803.16	1743.13	1747
Ebonyi	2107.58	2099.43	2009.35	1987.95
Abia	2389.07	2384.49	2285.1	2252.45

Source: World Bank group (2021)

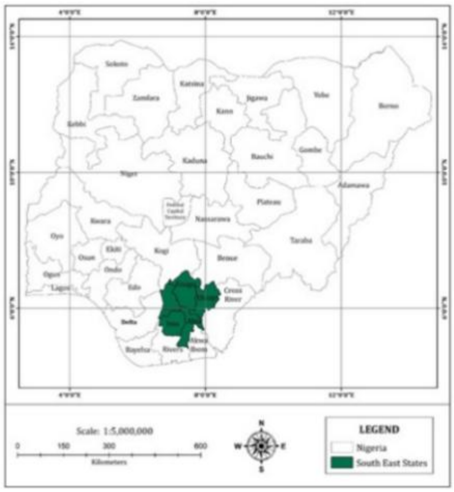

Figure 1: Map of Nigeria showing South-eastern zoneSource – Department of Surveying and Geoinformatics, Nnamdi Azikiwe University Awka

2.1 Research Methodology

This research is aimed at establishing the importance of climatic context in the design and development of buildings in high rainfall areas of South-eastern Nigeria. The research involved assessment of buildings based on *age*, *design features*, and *type and severity of rain action*. Since rainfall data are uniform across the different towns and villages in South-eastern Nigeria, any buildings within the study area were considered appropriate for the study.

The study area Federal Polytechnic Nekede Owerri was selected for convenience. Firstly, it falls within the climatic zone of study. Secondly, it has a large collection of buildings that fall into different typologies including educational, administrative, commercial, religious, civic among others. In addition, the ages of the buildings range from less than five (5) years to a little over forty (40) years, which is considered a good spread of building lifespans for the study. The entire buildings in the institution, numbering one hundred and sixteen (116) were studied, and they include lecture halls, workshops, offices, hostels, churches, banks, and multi-activity social buildings.

The study involved physical enumeration of buildings and observation of the effects of rain action on the internal and external components of the buildings. Since the objective of the research was to identify types and severity of rain action, once any of the parameters used in measuring rain action was identified in a building, the researchers recorded it and moved to another building. The study was conducted in a controlled community, and the researchers had free access to the buildings and were granted necessary assistance as required. Data analysis was by simple descriptive statistics. Frequency of occurrences were presented as percentages.

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III. RESULTS AND DISCUSSIONS

3.1 General information

A total of one hundred and sixteen buildings were studied. The ages of the buildings were documented. 25.86% of the buildings were over twenty (20) years old, 22.41% were under five (5) years old, while the majority of the buildings ranged from five (5) to twenty (20) years old. All the buildings were less than fifty (50) years old and were therefore considerably new. This information is important to underscore the fact that the buildings should still be in good condition having not reached the end of their useful lives.

Table 2: Age of the buildings (N = 116)

Age of building(s)	Frequency	%
0-5 yrs	26	22.41
5-20 yrs	60	51.73
Above 20 yrs	30	25.86
Total	116	100%

Source: Authors' Field survey 2022

3.2 External features of the buildings

The buildings were further assessed for character of design features used on external facades. The elements included in the survey are roof, external walls, external openings, ground floor level of buildings, and paved surfaces in the immediate vicinity of the building. The requirements in the National Building Code (2006) are applied in the assessment to ascertain the extent of compliance of the buildings. Pitched roofs should have minimum inclination of 30^o.

Table 3: External design features of the buildings (N = 116)

S/N	Description	Frequency	%
1.	Pitched roof (complete coverage)	80	68.97
2.	Pitched roof (with wall abutments)	26	22.41
3.	Flat roof with parapet walls	10	8.62
4.	Roof overhang (600mm and above)	70	60.34
5.	Roof overhang (less than 600mm)	36	31.03
6.	Concrete eaves	30	25.86
7.	Impervious wall tiles/cladding	2	1.72
8.	Painted wall over cement/sand screed rendering	114	98.28
9.	Wooden doors and/or windows (frames and all)	20	17.24
10.	Metal and glass doors and windows (frames and all)	96	82.76
11.	Window hoods/shading devices	50	43.10
12.	Raised floor level (300mm min)	80	68.97
13.	Floor level below 300mm from ground level	36	31.03
14.	Plinth	96	82.76
15.	Paved entry to the building	63	54.31

Source: Authors' Field survey 2022

The survey showed that a total of 91.38% of the houses had pitched roofs, 68.97% of which had full coverage while the remaining 22.41% had abutments. All the pitched roofs were covered with long span aluminium sheets. However, only 60.34% of the buildings have overhanging eaves up to or more than 600mm wide. The predominant finish for external walls was painted cement sand screed rendering. This was seen in 98.28% of the buildings. This finish is ideal for its heat resistant properties. However, quality of materials including composition of the cement sand screed and the properties of the paint used affect its moisture resisting properties. Only 43.10% of the buildings provided any form of shading or protection over the windows. In addition, buildings raised 300mm and beyond off the ground level totaled 68.97%. Paving of entrance ways and immediate vicinity of buildings was found in 54.31% of the buildings.

Rain damage to the buildings

The buildings were observed for rain action, and this was documented through physical enumeration and pictorial recording.

Table 4: Severity of rain action on the buildings (N = 116)

Type of rain action	None	%	Mild	%	Severe	%	Cumulative (M +S) Mild+severe	Ranking in order of severity
Leaking roof	41	35.34	50	43.11	25	21.55	64.66	6
Leaks from parapets/gutters/abutments	60	51.72	40	34.48	16	13.80	48.28	9
Excess moisture on external walls	20	17.24	60	51.72	36	31.04	82.76	4
Penetrating damp on internal walls	20	17.24	56	48.28	40	34.48	82.76	4

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Flaking of paint on walls	16	13.8	80	68.98	20	17.24	86.22	3
Growth of microorganisms on walls (mould, moss, algae)	10	8.62	70	60.34	36	31.04	91.34	2
Water penetration through openings (doors/windows) and cracks on the wall	50	43.10	50	43.10	16	13.80	56.90	7
Water-damaged wall, window, door, and floor finishes	5	4.31	91	78.45	20	17.24	95.69	1
Exposed/damaged foundation walls	92	79.31	15	12.93	9	7.76	20.69	10
Rising damp	56	48.28	50	43.10	10	8.62	51.72	8
Seepage of flood water into internal spaces	103	88.79	13	11.21	0	0	11.21	11
Grand Total	**473**	**37.07**	**575**	**45.06**	**228**	**100**		

Physical enumeration involved observing the type of rain damage in a building and recording same for further analysis. Rain damage was categorized as mild, severe, or none. Mild damage is moderate in type and effect. It would usually require minor rehabilitation and is mostly aesthetic damage. Severe damage is more intense, and often extremely bad and unsightly, affecting the proper functioning of the building component or element, and oftentimes requiring major remedial action to bring the building back to proper functioning and aesthetics.

IV. DISCUSSION

The survey showed that the prevalent type of rain damage in the buildings was damage to walls, windows, doors, and floor finishes which was seen either in mild or severe degrees in 95.69% of the buildings. Growth of microorganisms on the walls came a close second with 91.38%, while flaking of paints as a result of repeated cycles of wetness and dryness was seen in 86.22% of the buildings. Direct entry of flood into the buildings was rare and was seen in 11.21% of the buildings. 82.76% of the buildings had plinths protecting the foundation walls as documented in Table 2. This may have accounted for the low percentage of damaged or exposed foundation walls recorded in Table 4.

Moisture damage on external walls was significant in buildings with incomplete pitch roof covering, unshaded openings, and insufficient eave overhang (less than 600mm).

Plate 1 - Flaking of paint on interior wall

Plate 2 – Moisture through expansion joint

Plate 3 – Moisture action on unprotected wall

Plate 4 – Effect of rising damp on walls

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Unprotected external walls also suffered the most rain action and impacts on aesthetics and maintenance of the building as shown in Plate 3. The combined effects of repeated wetting and drying cycles of moisture and rising damp can be seen in the flaking of internal walls as shown in Plate 1. The effect of improper channeling of water from a roof abutment leading to leakage on the internal wall of the building through the expansion joint can be seen in Plate 2. Plate 4 shows the action of rising damp on external walls of a building.

The problems of rain damage identified in this study exist because the building designs were deficient in measures for rain and moisture control in high rainfall areas. Moisture control can be achieved in buildings through the combined factors of design, materials specification, construction detailing, and workmanship. Design is a fundamental factor because it dictates type of construction detailing to be used and determines effectiveness of materials specified as well as regularity of maintenance. All these impact a building's ability to adapt to the climate, which is a critical aspect of resilience.

The buildings that make up the study population range from five (5) to forty (40) years old. These fall within the range of new buildings and should expectedly be in good functional and aesthetic condition. The result of the study however shows that the buildings have undergone extensive deterioration expected of older buildings, and this can be traced to design. In constructing for the future, the pillars of sustainability, resilience, adaptability, and life cycle assessment are paramount. These are achievable when building design is in accordance with climatic context.

The study area with its high rainfall incidence and variability demands application of effective moisture control strategies in building design and construction. The ability of buildings tocontrol penetration of rain is a function which the building enclosure must perform. The high prevalence of rainwater damage on the buildings studied establish the fact that the relevant climate science was not followed. The climate science for high rainfall areas favours protection of the building envelope from direct rain and moisture penetration through adequate roof pitches, avoidance of flat roofs, use of extensive overhangs (600mm wide or more), discharge of rain directly from the roofs to the ground through a system of rain collector gutters, downspouts and pipes, impervious walls, airtight openings, shaded window openings, damp proofing of floors and walls, and elevated ground floor levels.

V. CONCLUSION

Water penetration into buildings significantly alters both their aesthetic and indoor thermal properties. For the buildings to remain safe, periodic large scale remedial actions would be required on a regular basis. This is even as infrastructure funding in Nigeria continues to be plagued by challenges. Designing buildings that are resilient to adverse weather action, in this case heavy rainfall, will not only be an environmentally sustainable decision, but an economically viable one as well. Ignoring climate considerations in building design and development will only compound the already subsisting infrastructure challenges in Nigeria.

With sustained high rainfall figures in the study area as a result of current climate events, climate sensitivity must become of prime consideration in building design. Expectedly, approach to building development in the study area must change to embrace the climate science and create buildings that can adapt to the extreme rainfall action occasioned by climate change. It has become imperative that in constructing for the future, buildings are designed for maximum protection against rain action.

Shelter, health and comfort requirements for humans have remained consistent, regardless of the complexities in achieving them as a result of climate change. It is easier to adapt buildings to the changes in climate, than for humans to adjust their comfort requirements which are not only psychological but physiological as well. The buildings on their own can be better equipped to withstand the vagaries of climate if adaptation measures are considered from the beginning.

To properly tackle the challenges posed by rainfall on buildings in the study area, built environment professionals must design with climate. It is critical that they understand the local climatic context that will form the basis of their designs. This is to ensure that the solutions they proffer are also local and organically evolved. A building is a complex interplay of function, form, climate control, durability, and structural integrity, making it a viable investment both in the present and future. Poor climate control has the capacity to compromise all other aspects of a building, and designing with climate should be the prime consideration in building development. Climatic context should direct building form, aesthetics and structure. This is a sure way of achieving climate-sensitive, resilient buildings, and through this, the pillars of constructing for the future which include social, environmental, and economic benefits can be fully harnessed.

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