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Climate Change and Thermal Comfort: Implications for Building Design in Southern Nigeria

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Abstract
One of the greatest challenges facing the world in this century is the twin phenomena of global warming and environmental degradation with their consequential effects. There are growing cases of ocean surge, desert encroachment, hurricanes, earthquakes, tsunamis, acid rain, heat stress, flash floods, etc. which have been claiming many lives and rendering several million homeless. Recent scientific studies have predicted that these events, rather than subsiding, would be more severe and more frequent in the future, with many of the developing countries most vulnerable. This suggests that man's response to these challenges should not be limited to combating efforts alone but should also include adequate adaptation strategies that would minimise the impending disasters. This paper examines the science of global warming and its implications on thermal comfort in buildings in Southern Nigeria. It contends that as the area becomes warmer, the cooling potential of natural ventilation in the area would be reduced with fatal consequences. The paper closes by highlighting certain design strategies that could minimise the impending catastrophes.
Keywords: Architectural Design, Climate Change, Global Warming, Hot-Humid Climate, Thermal Comfort

1.0 Introduction

One of the major problems confronting humanity in recent times is the issue of environmental degradation. The United Nations' High level Panel on Threats, Challenges and Change (2004) declared it as one of the ten threats to international peace and security. Each year, reports are presented about the increasing depletion and pollution of the natural environment by virtually all forms of developmental activities. For instance, 30% of African forests have been lost to city expansion since 1970 (Mba, 2005; Oyesiku, 2003; Zubairu, 2006). In Nigeria, over 405,000 hectares of rainforest area are lost in a year (Salami, 2006). Similarly, the ozone layer which shields the Earth's surface from direct ultraviolet rays from the sun is rapidly being eroded by certain substances released into the atmosphere through human activities such as space rocket and satellite launching, nuclear weapon testing and industrial activities (Akeredolu & Olatunji, 2008; Olamide, et al, 2008).

Perhaps more worrisome is the issue of global warming which is starring the whole world in the face. There are reported cases of severe ocean surge, hurricanes, earthquakes, tsunamis, etc. which have claimed many lives and rendered several millions homeless. The phenomenon is believed by many scientists to have been caused by human emissions of greenhouse gases which come from a variety of human activities including burning fossil fuels for heat and energy, clearing forests, fertilising crops, storing waste in landfills, raising livestock and producing some kind of industrial products (Ocampo, 2013; Dongman, et al, 2014; Zimmerman, 2008). Increase in the Earth's average temperature over the past century is put at 1.4^0F. In Nigeria alone, livestock production and rice cultivation are estimated to generate 1115 Gg and 1090 Gg of methane emission respectively, while savannah and agricultural waste burning is said to be responsible for the emission of 143Gg CH_4, 4.1Gg N_2O, 3610 Gg CO and 146 Gg of NO_X (Federal Ministry of Environment, 2003).

Based on increasing human activities and the world population, this warming has been projected to increase worldwide by 1.4^0C to 5.8^0C by 2100 (IPCC, 2012) amounting to more frequent and more intense ocean surge, hurricanes, storms, heat stress, and flooding than they are currently being experienced in the urban centres. The study warns that if mitigating steps are not taken, global warming will cause damage totalling $1 trillion annually by the year 2050. The foregoing suggests that man's response to these challenges should not be limited to combating efforts alone but should also include adequate adaptation strategies that would minimise the impending catastrophes. While the literature is replete with re growing desire by architects and planners to construct houses and develop settlements that contribute less to greenhouse emission, little is known about the efforts of these professionals at mitigating the impacts of global warming on the indoor thermal conditions in Nigeria. The purpose of this paper is to examine the science of global warming vis-à-vis human thermal comfort with a view to identifying the mitigating challenges the phenomenon poses to architects in Nigeria.

2.0 Science of climate change and disaster: an overview

Climate has been defined as an average condition of weather prevailing in an area over a long period of time usually between 30 and 35 years. It is measured in terms of average precipitation (rain, or snow), maximum and minimum temperatures, sunshine hours, humidity, wind speed and direction, and seasons (Chad & Berry, 2014). It plays an important role in determining the conditions in which all living things (including humans) exist (Fairbridge, 2008). It controls many physiological processes, from conception and growth to health and disease.

Climate is usually affected by natural processes such as changes in the sun's energy, shifts in ocean current, etc., which in turn affect the weather, oceans, snow, ice, ecosystems and the entire society. Small changes in the average temperature of the planet Earth, for example, can translate to large and potentially dangerous shifts in local climate and weather. In recent times, Earth's climate has been observed to be facing a rapid warming. Scientists reported that the Earth's average temperature has risen by 0.6 – 0.8^{0}C over the past century (Wilby, 2009; NRC, 2010; IPCC, 2007). According to them, most of the warming has been caused by human emissions of greenhouse gases which come from a variety of human activities including burning fossil fuels for heat and energy, clearing forests, fertilising crops, storing waste in landfills, raising livestock and producing some kind of industrial products. As explained by the scientists, the greenhouse gases such as water vapour, carbon dioxide ($CO_{2)}$, methane, nitrous oxide, etc. trap a portion of the heat that are released into the space by the Earth's surface in form of long-wave infrared radiation, thus causing the Earth to retain more heat than it reflects into space (Ocampo, 2013; Dongman, et al, 2014). This ultimately resulted in increase in global temperature.

Several studies have raised alarm over rapid increase in the amount of these gases being released into the atmosphere through human activities (Wilby, 2009; IPCC, 2007; NRC, 2010; IPCC, 2012). For example, carbon dioxide concentration which was reported to be 281 parts per million (ppm) in 1750, has increased to 368 ppm in 2006, representing 31%. This translates to 1.5 ppm increase per year. The concentration of nitrous oxide, which traps 300 times more than does the same amount as CO_2 has equally been reported to be 17% more than it was during the preindustrial period (IPCC, 2007).

Activities such as agriculture and road construction have also been identified as causes of global warming. Both of them can change the reflectivity of earth surface, leading to local warming or cooling (Olamide, et al, 2008). This is more pronounced in urban centres which are often warmer than surrounding less populated areas (NRC, 2010). Emission of aerosols (which reflects or absorb sun's energy) and ozone layer depletion have also been linked to global warming. The layer which shields the Earth's surface from direct ultraviolet rays from the sun is rapidly eroded by certain substances released into the atmosphere through human activities such as space rocket and satellite launching, nuclear weapon testing and industrial activities (Akeredolu & Olatunji, 2008; Olamide, et al, 2008).

The resultant effect of this warming is increase in humidity as a result of more water evaporating from the oceans, which in turn will increase rainfall (about 1% for each Fahrenheit degree of warming). Not only does the warming accelerate water evaporation, it causes the surface layer of the ocean to warm as well, expanding in volume and thus raising sea level. Wind speed is also expected to decrease in frequency and intensity in areas that are close to the equator, which will subsequently raise heat stress (Eichelberger, et al, 2008; Roaf, et al, 2009). The higher temperatures and solar radiation also stimulate the production of photochemical smog as well as ozone precursor biogenic volatile organic compounds (VOCs) by some plants (Wilby, 2009).

This warming has, however, been projected to increase worldwide by 1.4^{0}C to 5.8^{0}C by 2100 (IPCC, 2012) amounting to more frequent and more intense heat wave, rainfall, storms, flooding and acid rain than they are currently being experienced in the urban centres. According to Holm (2003) and Dongman, et al (2014), the developing countries of the world are predicted to be the most vulnerable. They are the most vulnerable because they are least endowed with resources and technology to combat the problem. Besides, their economies are based largely on natural resources-dependent sectors that are climate sensitive. Further complicating the situation is the revelation about the life span of CO_2 which indicates that it will take one hundred years for nature to dispose of the current amount of the gas in the atmosphere. Thus, if the concentrations of the gas should cease growing today, the whole world still stands the risk of being starred by the global warming effects in the next one hundred years. It therefore follows that man's response to these challenges should not be limited to combating efforts alone but should also include adequate adaptation strategies that would mitigate its consequential effects.

3.0 Climate and human thermal comfort

Human being keeps its internal body temperature constant at 37^{0}C under different inner and outer conditions in order to stay healthy. He does this by maintaining a balance between the heat produced and acquired by the body, and the amount of heat lost by the body (Royle & Walsh, 2006; Stathopolous, 2009). This is maintained by physiological processes. Increased production of heat is compensated by increasing heat loss through sweating while a fall in body temperature leads to increased heat production through shivering. The excess heat produced within the body is normally eliminated through the physical processes of radiation, conduction and evaporation. These processes are usually influenced by the ambient and radiant temperatures, humidity of the air, wind speed and the degree of exposure to sunshine (Ayoade, 2011; Akinyeye, 2000; Umoh, 2000; Evans, 1976).

According to Ferguson-Hill (2002), low humidity encourages evaporation of perspiration from the human body which allows a rapid cooling of the skin. The converse is also true: increase in humidity decreases the evaporation of perspiration, thereby inhibiting the cooling efficiency of sweating (Indraganti, et al, 2012). Scientists aver that the evaporation process is further influenced by wind speed and exposure to sunshine. As explained by Ayoade (2011), high wind speed facilitates the constant replacement of air around the body which accelerates the evaporation process. However, if the air is calm the air layer close to the body becomes saturated and little or no further evaporation takes place. This is further reduced by direct exposure to sunshine (Salmon, 1999). The interaction of all these climatic variables and such other physiological factors as metabolic rate, clothing, age and degree of acclimatisation can thus be said to be responsible for the human thermal comfort (Indraganti, et al, 2012; Ayoade, 2011; Stathopoulos, 2009; Ogunsote, 1991; Evans, 1980).

Many attempts have been made by climatologists to devise indices which combine some or all of these variables into one value to assess the level of human thermal comfort. Such indices include the Effective temperature (ET), Corrected Effective Temperature (CET), Standard Effective Temperature (SET), the Resultant Temperature (RT), the Heat Stress Index (HSI), the Equivalent Warmth (EW), the Equatorial Comfort Index (ECI), the Predicted Four Hour Index (P4SR), the Operative Temperature (OT), the Index of Thermal Stress, (ITS), the Bioclimatic Chart, the Mahoney Scale and the Evans Scale, the Predicted Mean Vote (PMV), the Predicted Percentage Dissatisfied (PPD). The commonly used scales in the tropics are, however, Bioclimatic chart, the Standard Effective Temperature, the Effective Temperature, the Mahoney Scale and the Evans Scale. Some of these indices, like the Mahoney Scale shown in Table 1, compare predetermined comfort limits with the meteorological data obtained in an area to determine the comfort level in the area. These limits, however, vary from country to country, culture to culture and from one climatic belt to another.

Table 1: The Mahoney scale of comfort limits

Relative Humidity	Average monthly temperature					
	Over 20^0C		15^0C – 20^0C		Under 15^0C	
	Day	Night	Day	Night	Day	Night
0 -30%	26 – 34	17 – 25	23 – 32	15 – 23	21 – 30	14 – 21
30 – 50%	25 – 31	17 – 24	22 – 30	15 – 22	21 – 27	14 – 20
50 – 70%	23 – 29	17 – 23	21 – 28	15 – 21	19 – 26	14 – 19
70 – 100%	22 – 27	17 – 21	20 – 25	15 – 20	18 – 24	14 – 18

Source: Ogunsote (1991)

Southern Nigeria lies within hot-humid climate which is characterised by high temperature and humidity. Wind speeds are generally low (Salmon, 1999). Design for this area should therefore aim at reducing incident solar radiation and the transmission of such into living areas and also allow or enhance adequate airflow for ventilation and body cooling in order to improve thermal comfort (Oluigbo, 2004).

4.0 Impacts of global warming on built environment in Nigeria

Global warming has also been predicted to lead to changes in the local climate in several parts of the world (Holm, 2003). In Nigeria, there is increasing evidence of global warming with climatic variations and severe weather conditions. Available meteorological data even indicates a temperature rise of 0.2 – 0.5^0C in some cities since 1920. A comparison of the day and night comfort limits in Table 1 with the monthly mean maximum and minimum temperatures in Table 2 corroborates this fact. Virtually all the cities are experiencing hot weather both in the day and in the night. Other climatic variables other than temperatures have shown significant variations. Table 3, for example, reveals increasing trend in humidity in coastal and rainforest areas of the country. Umoh (2000) also observed a general increase in the sunshine hours from the Atlantic coast to the interior. According to his findings, the amount of sunshine on annual basis ranges from a minimum of 1300 hours in the Niger Delta to over 3200 hours in the extreme north-east.

Table 2: Average monthly maximum and minimum temperatures of the selected cities

Month	Lagos		Port Harcourt		Benin		Ibadan	
	Max (^{0}F)	Min (^{0}F)	Max (^{0}F)	Min (^{0}F)	Max (^{0}F)	Min (^{0}F)	Max (^{0}F)	Min (^{0}F)
Jan	87.8	68.0	59.2	55.6	52.5	54.0	89.6	68.0
Feb	87.8	69.8	41.5	46.9	40.8	45.3	91.4	69.8
Mar	89.6	71.6	43.2	45.3	42.3	47.3	91.4	68.0
Apr	89.6	73.4	48.0	50.9	42.4	50.0	93.2	73.4
May	87.8	73.4	46.8	50.7	44.4	51.1	89.6	71.6
Jun	86.0	73.4	50.7	49.6	50.0	48.6	86.0	68.0
Jul	84.2	71.6	53.1	53.6	45.5	48.9	84.2	69.8
Aug	80.6	71.6	47.5	52.3	45.3	50.9	82.4	69.8
Sep	82.4	69.8	47.8	52.7	46.8	48.7	86.0	68.0
Oct	86.0	69.8	46.8	54.9	42.6	50.5	87.8	68.0
Nov	87.6	69.8	48.2	38.3	57.6	52.2	89.6	66.2
Dec	89.6	69.8	55.0	50.4	48.9	46.6	91.4	69.8
Average	86.6	65.2	61.0	50.1	46.6	49.5	88.6	69.2

Source: www.meoweather.com/history/nigeria

Table 3: Average weather conditions of selected cities in Southern Nigeria (2012 – 2015)

City	2012			2013			2014			2015		
	T (^{0}F)	RH (%)	WS (m/s)	T (^{0}F)	RH (%)	WS (m/s)	T (^{0}F)	RH (%)	WS (m/s)	T (^{0}F)	RH (%)	WS (m/s)
Lagos	86	82	4.5	86	89	3.6	91	82	4.0	90	70	4.9
Port Harcourt	81	93	2.7	75	96	2.7	82	93	2.7	77	94	2.7
Benin	86	89	1.8	84	97	1.8	88	90	1.8	90	73	2.7
Ibadan	81	96	2.2	84	97	1.8	90	92	1.8	91	61	2.7

Note: T= Temperature (degree Fahrenheit); **RH=** Relative Humidity (%); WS = Wind Speed (mile per hour)

Source: www.meoweather.com/history/nigeria

All these trends could have significant consequences. Increase in humidity and temperature is expected to exacerbate perspiration and general discomfort (Ferguson-Hill, 2002; Ayoade, 2011). The cooling potential of natural ventilation that has been a technique of choice for mitigating this effect in hot humid region would fall with rising outdoor temperatures which can trigger public health crises and health-related deaths in the country (Wilby, 2009; Salmon, 1999). A new meningococcal strain has just been discovered which was reported to be responsible for significant increase in cases and outbreaks of meningitis in African countries especially in Burkina Faso, Mali, Niger and Nigeria (Perea, 2007). Severe perspiration has also been found to cause a reduction in plasma volume, dehydration and hyponatraemia (Ferguson-Hill, 2002). The effect is not limited to heat stress alone; the indoor air quality would be very low as air purification function of ventilation would be impaired (Umoh, 2000). This poor air quality may lead to high prevalence of respiratory infection, chronic obstructive pulmonary disease, respiratory tract cancers, tuberculosis, cataracts and asthma (Lawanson, 2008). Incidence of tuberculosis, for example, that was 130.5 per 100, 000 people in 1990 rose to 172 per 100,000 people in 2000 and jumped to 338 per 100,000 people in 2013 (Trading Economics, 2015). Similar trend was observed with cataracts. The low structural cooling brought about by this poor cross ventilation, and the intense sunshine would also put the structural integrity of buildings in danger. This may further aggravate the incidence of building collapse being witnessed in the country. Colour deterioration and dilapidation of buildings are also known to increase with extreme high humidity and intense solar radiation (Salmon, 1999; Umoh, 2000; Givoni, 1981).

Unfortunately, Nigeria has been predicted to witness a further temperature rise of 3.2^{0}C and other weather extremes by 2050 (DFID, 2009). Consequently, building fabrics would retain more solar energy during the day, and their rate of radiative cooling during the night would be low. Wind speeds in urban areas would also be lower, with less convective heat losses and evapotranspiration, thus yielding more energy for surface warming (Wilby, 2009; Eichelberger, et al, 2008; Roaf, et al, 2009). Heat stress and other heat-related illnesses are, thus, expected to increase in frequency and severity especially in the arid and littoral areas. Adequate adaptation strategies that would minimise the impending catastrophes are therefore imperative. If architecture is understood as a responsive and problem-solving effort, then architects have a great role to play in this effort.

5.0 Conclusion and recommendations

The foregoing discussion has established that the urban centres in southern part of Nigeria are getting warmer by the year. This has been predicted to be on the increase by 2050 irrespective of the intensity of carbon reduction effort. Humidity is expected to increase and the wind speed would be reduced. The implication of this on building is that the outdoor temperatures would rise thus reducing the cooling potential of natural ventilation. This could be made worse by tall solid fence-wall that are usually built very close to the buildings, and those aspiring western forms which are both economically and environmentally burdensome, utilizing similar designs, materials and technologies in different climatic regions. This, according to the paper, portends danger to the health and survival of the urban dwellers.

If the environmental goal of reducing greenhouse gas emission is to be achieved, and at the same time build resilient cities and structures that can stand up to the imminent overheating, then the key to comfortable survival is an urban and architectural design that reduces solar penetration into the building and enhances air circulation within and between buildings. This can be achieved by following the design guidelines recommended below:

1. *Layout and Form*

Buildings should be arranged in such a way that one does not cast shadow over the other. Streets should be aligned in parallel, or up to 30^{0}C to the prevailing wind direction to minimise the penetration of prevailing wind through the array of buildings in the towns and cities. According to Ogunsote (1991), optimum ventilation can be achieved if the distance between these buildings does not exceed six times the height of the building. The enactment of setback and height regulations that ensure adequate air space and low rise building corridors is therefore important.

2. *Roof Design and Materials*

Roof is a building element that receives direct sunlight. Its design and construction therefore plays an important role in the mitigation of heat stress. A highly reflective roofing material with a wide overhang for protection against direct sunlight should therefore be used. A pitched roof of considerable slope can be of immense benefit. This lowers incidence of global solar radiation (Melo, et al (2014). Higher ceiling height can further improve the thermal climate of buildings. This causes the hot air layers to be pushed away from the occupants of the space (Guaramaes, et al, 2013; Mofrad, 2013).

3. *Landscape Materials*

Mitigation of thermal discomfort can be accomplished through careful design of external areas. Hard paving materials such as concrete, bitumen, stones, etc have high heat capacity and thus dissipate much heat at night. Extensive and continuous stretch of parking lots should therefore be avoided. Interwining the parking lots with green areas would go a long way in improving thermal comfort. Vegetation, by absorbing unwanted carbon dioxide, cleans the air; reduces the sun glare; absorbs solar radiation; and by transpiration, cools the air. Greenery reduces overheating of air and thus paralyses the formation of rising air currents that create clouds and smoke over the environment. This can be complemented by the use of green roofs. The roof plants cool the structure through evaporation while the earth upon which the vines are planted insulates the roof from deleterious effects of sunlight.

4. *Shading Devices*

Projecting structures such as overhanging cornices and vertical screens can be used as sun control measures. Balconies, verandas, courtyards and other outdoor living areas should be generously used also. These structures shade the building walls, openings and outdoor floor surfaces, and thus keep the temperature of the outdoor air low, making natural ventilation more suitable and minimising conductive heat gain through walls (Salmon, 1999). Light-coloured curtains with high reflectance properties can further be used to improve upon the internal climate of the rooms.

5. *Material Specifications*

There is an established relationship between building materials and the thermal comfort desirable in a space. All enclosure materials must therefore be carefully selected. Extensive use of fixed glass, in particular, should be avoided. This simulates greenhouse effect which creates heat in buildings and thus renders the internal climate uncomfortable.

6. *Fence-Wall Design*

Fence-walls contribute much to heat gain in the buildings. They should, therefore, not be too close to the building. A tall, impermeable fence alters the speed and direction of wind, creating a region of positive pressure on its windward side and a suction pressure on its leeward side (Oluigbo, 2004). Buildings located on the latter side experience poor ventilation. Fence-walls should therefore be as low as possible. A see- through fence-wall should be used also. This would permit a large quantity of air into the building it encloses.

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