ALVAN JOURNAL OF SOCIAL SCIENCES (AJSS)
FACULTY OF SOCIAL AND MANAGEMENT SCIENCES
ALVAN IKOKU FEDERAL UNIVERSITY OF EDUCATION, OWERRI
https://www-ajsspub-org.b12sites,com https://www.ajsspub2.org
E- ISSN: 3043 – 5463 ISSN: 1595 – 5842 VOLUME 2, ISSUE 2, 2025

RESEARCH ARTICLE

CLIMATE CHANGE AND THERMAL COMFORT IN BUILDINGS: A REVIEW OF CLIMATIC STUDIES FROM 1971 – 2005 IN NORTHERN NIGERIA

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ABSTRACT

Increases in the temperatures across many epochs, has exacerbated thermal discomfort in buildings. Ambience in air temperature and mean radiant temperature are becoming lost experiences in some conventional building prototypes. Hence, thermal sensations of heat and skin wetness have rubbed off on the occupants of the vulnerable buildings. Climatic changes have been contributory to it. Its harrowing impact has occupied the epicenter of many researches in architecture. This study sets out to examine climate change and thermal comfort in buildings. It adopted the review of climatic studies from 1971 to 2005 climatic years in Northern Nigeria. The temperature and rainfall data of eleven meteorological stations were obtained in the study area. They were analyzed with Linear Regression technique. The results showed an upward trend for most of the stations and for both indicators. The study concluded that the values for temperature and rainfall are increasing in majority of the stations, though with differing steepness in slopes. However, downward trends in temperature and rainfall were evinced in minority of the stations. Therefore, the study recommends: utilization of location-specific/climate-adaptive architecture, creation of architectural-meteorological synergy, strategic maintenance of ambient air quality and temperature and climate site analysis in the study area.

Keywords: Climate change, thermal comfort, meteorological stations, buildings**.**

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Received: 20/5/2025; **Revised:** 27/6/2025; **Accepted:** 20/7/2025; **Published:** 30/7/2025

1.0. INTRODUCTION

Basically, the climate of a place which is defined by the character of its weather conditions over a given period is never static but dynamic, though not as dynamic as weather which can change within a week or two, days, hours, minutes or even within seconds. Since both weather and climate are made within the earth's atmosphere, even small variations in the general circulation of the atmosphere, are nearly always reflected in changes in the weather and climatic elements. When such changes continue over a long period of time, there could be a shift in the type of climate prevailing over a given area, thereby resulting in a change in climate (Ayoade, 1983). Equally, any change in the distribution of the climatic elements which presuppose a change in climatic factors could mean climate change (Miller, 1976). Also, since an initial climate ought to be specified before identifying a change (Meyer, 1996), any marked departure from an initial climate due to a sustained trend in any climatic element over a long period of time (usually not less than 30 years) could be described as a change in climate.

The world's climate has been experiencing alternating series of warm and cool periods long before the present age. Such series include: the Ice Age that took place between 2.5 million and 10,000 years ago, Altithermal Period around 7,000 years ago, Medieval Warm Epoch around AD 1,000, and the Little Ice Age that ended at about AD 1650 (Chima, Nwagbara and Ogbonna, 2010). These changes in climate have been attributed to some extra-terrestrial factors such as: solar output, earth-sun geometry and Stellar dust, or to any of the ocean, atmosphere and land factors namely: volcanic activity, mountain building, continental drift ocean, heat exchange, atmospheric chemistry and atmospheric and surface albedos (Pidwirny, 2004).

However, most past episode of climate change have been noted to have occurred as a result of only a limited number of these factors such as variations in the earth's orbital characteristics, variations in atmospheric carbon dioxide, volcanic eruption and variations in solar output (Pidwirny, 2004). The recent change in climate is impacting in a multitude of ways upon the environment. As this change affects the environment, so also is the thermal comfort in buildings. Knowledge of the nature of comfort is essential in design with climate. The human body maintains a thermal balance by controlling heat loss and gain with the six

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E- ISSN: 3043 – 5463 ISSN: 1595 – 5842 VOLUME 2, ISSUE 2, 2025

major factors affecting comfort as: air temperature, mean radiant temperature, air velocity, relative humidity, intrinsic clothing and level of activity (Ogunsote, 1991; Alozie, 2014).

Thermal comfort therefore is defined as the range of climatic conditions considered comfortable and acceptable to humans (Givoni, 1994). This implies an absence of two basic sensations of discomfort; a thermal sensation of heat and a sensation of skin wetness (Alozie and Adiole, 2018). American Society for Heating, Refrigerating and Air Engineers Conditioning ASHRAE, (1992) however, simplified the definition of thermal comfort as the express satisfaction within the thermal environment, in which at least 80% of sedentary or slightly active persons find their environment thermally acceptable. The absence of thermal comfort in building, makes homemakers and other users of building line in calls for unhappiness (Alozie, 2014).

This Paper examined Climate Change and Thermal Comfort in Buildings with the view to expedite thermal comfort in the buildings in Northern Nigeria. In furtherance, it reviewed cognate literature on empirical climatic studies from 1971-2005 in the study area. The Paper comprised of five sections. The first section captured the Introduction and the Statement of the Research Problem, while the second section delved into the Literature Review. The third section unraveled the Research Methodology. Correspondingly, the fourth section discussed the Results. Then, the fifth section accentuated the Conclusion and Recommendations.

Buildings, whether as dwelling or structures, are impacted on by climate. Often, climate acts as a factor in their design, choice of materials and location. Generally, buildings are meant to protect their occupants against climatic elements and wild animals and create on ratified climate good enough for living accommodation, storage, working in or some other specified purpose (Ayoade, 1983). In other words, whatever, the design, material and location chosen for a building, they have to be so done to meet these requirements. People have sometimes borne great costs for designing or choosing materials and locations for their buildings which are in variance with the prevailing climatic conditions. Without bearing the great cost, the building may not withstand the stress of the prevailing climate during their anticipated lifetime (Smith, 1975). In fact, the primitive man often builds more wisely than the exposed people do, as he follows the principle of design as directed by the prevailing climate. For example, the Eskimos have learnt to solve their building problems by collaborating with nature (Rapoport, 1969). This is because any failure would mean having to face the harsh forces of nature personally.

There is therefore the need to factor the recent climate change in the design, choice of materials and site for our buildings. This is especially so because of the rapidity of the change and the magnitude of its effects (Obasi, 1992; Barry and Chorley, 1992; IPCC, 2001; and Goudie, 2002). Where this is not considered, the cost would be enormous for man. Already, recent climatic events have shown that great number of people lose their lives due to the collapse of buildings and sometimes their roofs upon them as they are and/or broken down by violent winds and massive floods.

The ease with which roofs of buildings are blown off and the buildings themselves blown or broken down usually depends on their design, materials with which they were built and their location. The strength of the buildings often do not matter when the design, materials and site are selected without bearing in mind the common wind type of an area. Hurricanes and tornadoes are increasing in their frequency and magnitude with the present climate change. And they are climatic phenomena with very violent winds and storms, thus making them very destructive especially to buildings, both dwellings and other structures. It is therefore, not surprising the great number of buildings that are usually destroyed by these events whenever they occur. The damage is increasing by the decade (NOAA, 1993).

Flooding which is being presently aggravated by the change in climate, has remained a source by which buildings are damaged. Since flooding operates on the surface of the earth, it often weakens the base of buildings as it infiltrates through the building materials and disintegrates and/or decomposes. Sometimes too, buildings are washed away by floods. Also, floods do undermine buildings through erosive power, thereby causing collapse of the buildings sometimes immediate and some other times after a period of time.

The life span of buildings is likely to be reduced by the prevailing climate change. This assumption is yet to interest many researches. The assumption is proposed here because the materials used for existing buildings globally, were likely not made with the recent climate change in mind. For example, temperatures are rising for most regions, so also are rainfall totals, thus requiring that building materials be made to suit these changes. The same is required where temperatures and rainfall totals are dropping. Increasing air temperature equally implies that in-door temperatures are increasing. This further means an increase in the discomfort indices of buildings located in regions experiencing warming. Invariably, the scenario of thermal discomfort in buildings, leaves much to be desired. This imbalance forms the basis for this Paper.

2.0. LITERATURE REVIEW

This section reviewed literature on empirical studies on climate change from 1971-2005 in Northern Nigeria. In furtherance, it unraveled the results of the Intercepts, Slopes and Regression Line Equation for Annual Temperature (^{O}C) and Annual Rainfall Totals (mm) over the study period.

Climate change is most easily accepted when evidences of it, start manifesting in the environment. As an example, the present radical change in climate was realized only during the 1840s when indisputable evidence of former ice ages was obtained (Chima, et al., 2010). Generally, the evidence of climate change varied globally, since different regions are differently affected due to differences in geography. The on-going climate change via warming has not been globally uniform, so also are its evidences. For example, for some regions, the rising temperature has increased their rainfall levels while it has reduced the levels for some other regions, thus making some areas wetter and others drier. Though the tropics, within which Nigeria is located, is being least warmed in the present warming of the world (Meyer, 1996), any warming at all, makes it an area of very high temperature which could cause an increase in rainfall levels or a reduction in them with enormous implications for the environment.

An analysis of the temperature and rainfall data over northern Nigeria covering 34 years (1971 - 2005) and 11 meteorological stations, shows an upward trend for most of the stations and for both indicators (Chima, et al., 2010). That is, temperature and rainfall values are increasing for most stations as seen in Tables 1 and 2.

An examination of Table 1 reveals that among the 11 stations, nine of them have positive slopes and consequently upward trends, though with differing steepness in slopes. The other two, Jos and Maiduguri have negative slopes implying downward trends. Kaduna possesses the steepest slope of 0.04 among the stations with upward trends while Maiduguri has -0.04 as the steepest slope among those with negative trends. On the other hand, the gentlest is 0.01 for stations warming and -0.01 for those cooling.

Table 1: Intercepts, Slopes and Regression Line Equation for Annual Temperature (^{O}C)

S/N	Station	a (Intercept)	b (Slope)	Regression Line Equation
1	Gusau	26.47	0.03	Y=26.47 + 0.03x
2	Jos	22.80	-0.01	Y=22.80 - 0.01x
3	Kaduna	22.07	0.04	Y=22.07 + 0.04x
4	Kano	26.58	0.02	Y=26.58 + 0.02x
5	Maiduguiri	28.17	-0.04	Y=28.17 - 0.04x
6	Makurdi	26.47	0.02	Y=26.47 + 0.02x
7	Minna	26.02	0.02	Y=26.02 + 0.02x
8	Nguru	26.83	0.01	Y=26.83 + 0.01x
9	Sokoto	26.87	0.02	Y=26.07 + 0.02x
10	Yola	25.94	0.03	Y=25.94 + 0.03x
11	Zaria	23.36	0.02	Y=23.36 + 0.02x

Source: Chima, *et al.* (2010).

All but one station out of the eleven in Table 2 possess positive slopes. It is only the slope of Jos that is negative, thus implying that all but Jos have upward trends in their annual rainfall totals. Put differently, the other stations are experiencing a steady increase in annual rainfall totals. The slopes are generally gentle except for Kano with a slope of 24.83 while Nguru has the lowest positive gradient of 0.01.

Table 2: Intercepts, Slopes and Regression Line Equation for Annual Rainfall Totals (mm)

S/N	Station	a (Intercept)	b (Slope)	Regression Line Equation
1	Gusau	386.10	5.88	Y= 386.10 + 5.88x
2	Jos	1611.70	-4.08	Y= 1611.70 – 4.08x
3	Kaduna	1198.67	0.38	Y= 1198.67 + 0.38x
4	Kano	-1293.33	24.83	Y= 1293.33 + 24.83x
5	Maiduguiri	414.90	1.79	Y= 414.90 + 1.79x
6	Makurdi	1167.47	0.14	Y= 1167.47 + 0.14x
7	Minna	1018.38	1.90	Y= 1018.38 + 1.90x
8	Nguru	407.71	0.01	Y= 407.71 + 0.01x
9	Sokoto	90.14	6.07	Y= 90.14 + 6.07x
10	Yola	816.46	0.95	Y= 816.46 + 0.95x
11	Zaria	497.99	5.76	Y= 497.99 + 5.76x

Source: Chima, *et al*. (2010).

From both tables, it could be seen that there is a corresponding relationship between temperature and rainfall trends. Basically, connective activities that usually generate precipitation (rainfall being a form of it) are temperature powered. Thus, an increase in temperature will increase such activities while the reverse will be true if temperature drops. When connective activities (process implying the transfer of heat from the earth's surface to the atmosphere are reduced, condensation and cloud formation are likely to be reduced too, thereby reducing the tendency for rainfall (Precipitation). Jos with a negative trend in its mean annual temperature (Table 1) equally possess a positive annual rainfall trend but relatively very gentle, possibly due to the moderating effect of Lake Chad.

In spite of the general positive trend in rainfall in the sample stations in northern Nigeria, there has been increase in the frequency and duration of droughts in the Sahel region of Nigeria due to the present climate change (Tegen and Fung, 1995; Meyer, 1996; and Obioha, 2005). Such climatic conditions will usually rub-off conspicuously on the land cover vegetation in particular. As a result, while areas affected by this condition are experiencing withering of vegetation, famine, drying-up and/or shrinking of water-bodies (including dams) and increased dust loading (Alpert et al., 1998; Miller and Tegen, 1998; Dube, 2002; and Obioha, 2005), the ones without it but with increasing rainfall have noticeable improvement in agricultural productivity and vegetation condition. Negatively, the increase in rainfall seems to have increased the frequency and magnitude of flooding occurring in riverine and dam areas, as rivers and dams fail to contain increased water occasioned by the increased rainfall.

By this means, dams have collapsed, farmlands and residential areas overrun and bridges washed away by floods. The common existence of dams and large ones at that, in northern part of Nigeria increased the impact of flooding in the area. Flooding has often threatened food supply as vegetation in general is destroyed; drinking water as streams and springs in rural communities are polluted; human existence as people are rendered homeless and incommunicado as bridges are broken or washed away. For some few years now, these happenings have become common news items in the print and electronic media in Nigeria.

Also, recent coastal flooding in Nigeria which seem to be increasing in frequency and magnitude are attributable to climate change. This is because the melting of glacier and frozen sea water, as a result of increasing global temperature (Ayres and Walter, 1991; Meyer, 1996) is adding to the volume of water in the world's oceans (which are really one large body of water). And coastal flooding usually comes with coastal erosion.

3.0. RESEARCH METHODOLOGY

This study adopted the review of cognate literature to examine Climate Change and Thermal Comfort in Buildings. Empirical studies on both the variability of temperature and rainfall from 1971 – 2005 in Northern Nigeria by Chima, et al. (2010), were reviewed.

Eleven meteorological stations were sampled in the study area over the epochs. Then, their respective temperature and rainfall data over study period were ascertained (Tables 1 and 2). The Regression analysis technique was leveraged for the data analysis. The results showed the Intercepts, Slopes and Regression Line Equation for Annual Temperature (^{O}C) and Annual Rainfall Totals (mm) in the study area.

4.0. PRESENTATION OF RESULTS AND DISCUSSIONS

This section discussed the empirical findings in Chima, *et al*., (2010) on the variability of temperature and rainfall from 1971 – 2005 in Northern Nigeria. It also expatiated on the results and speculatively correlated the probable domino effects of the results with thermal comfort in the buildings in the study locations over the study period. In their study, the authors analyzed the variability of temperature and rainfall data from 11 meteorological stations in northern Nigeria. It subsumed a period of 34 years (1971 - 2005). The results showed an upward trend for most of the stations and for both indicators. In other words, temperature and rainfall values are increasing for most stations as evinced in Tables 1 and 2.

Putting things in perspective, Table 1, reveals that among the 11 stations, nine of them have positive slopes and consequently upward trends, though with differing steepness in slopes. The other two, Jos and Maiduguri have negative slopes implying downward trends. Kaduna possesses the steepest slope of 0.04 among the stations with upward trends while Maiduguri has -0.04 as the steepest slope among those with negative trends. On the other hand, the gentlest is 0.01 for stations warming and -0.01 for those cooling.

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E- ISSN: 3043 – 5463 ISSN: 1595 – 5842 VOLUME 2, ISSUE 2, 2025

Upward trends in annual temperature is usually predicated on the latitude (i.e., the location of an area in relation to the equator), altitude (i.e., the height of an area from the sea level), distance from the sea, ocean currents (i.e., large masses of water moving in regular patterns to a definite direction), wind (i.e., air in motion), land surface characteristics, cloud cover (i.e., the amount of suspended tiny water droplets in the lower atmosphere) and artificial heat sources.

Increase in annual temperatures in most of the stations will orchestrate increased evapo-transpiration, unprecedented rainfall, flooding, and other adverse weather phenomena in the nine susceptible areas while the reverse will be the case in Jos and Maiduguri over the study period.

Subsequently, the buildings in the nine susceptible areas will probably bear the brunt of thermal discomfort due to the upward trends in the annual temperature. Perhaps, thermal discomfort will adversely affect the in-door temperatures in the areas. Hence, the discomfort indices of the air temperatures, mean radiant temperature and relative humidity of the buildings located in the susceptible regions will presumably be exacerbated. But a dissimilar scenario will likely be the case for the buildings in Jos and Maiduguri.

More so, all but one station out of the eleven in Table 2 possesses positive slopes. It is only the slope of Jos that is negative, thus implying that all but Jos have upward trends in their annual rainfall totals. In other words, the other stations are experiencing a steady increase in annual rainfall totals. The slopes are generally gentle except for Kano with a slope of 24.83 while Nguru has the lowest positive gradient of 0.01.

Upward trends in annual rainfall is a corollary of temperature, moisture, cloud cover (i.e., the amount of suspended water droplets in the atmosphere), latitude (i.e., the location of a place in relation to the equator), distance from the sea, vegetation (i.e., the type of plant cover in an area), shape of the land, presence of mountain ranges, to mention but a few.

The upward trends in rainfall will probably orchestrate an increase in the relative humidity of the buildings in the ten susceptible areas, there by plummeting the thermal discomfort indices in the areas while the reverse will presumably be the case for the buildings in Jos. Perhaps, the upward trends in the annual temperatures and rainfall totals in the most of the

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E- ISSN: 3043 – 5463 ISSN: 1595 – 5842 VOLUME 2, ISSUE 2, 2025

meteorological stations in the area, will rub off on the thermal discomfort indices of the buildings in the susceptible areas. While the buildings in the non-vulnerable areas may have unperturbed thermal comfort indices in them.

5.0. CONCLUSION AND RECOMMENDATIONS

The average weather conditions over multiple epochs, has been altered by natural and anthropogenic forces in the study area. It has resulted in upward trends in the annual temperature and rainfall trends across most of the regions under study.

However, downward trends were conspicuously present in the indicators of minority of the regions in the study area. Inferentially, there is a strong correlation between the temperature and rainfall trends in the areas as evinced in Tables 1 and 2. These phenomenal results buttress that the issue of climate change is neither a cunningly devised fable nor a figment of men's imaginations. Rather, it's real. And its impacts leave much to be desired.

Hence, a concerted effort by both the architects, builders and other relevant stakeholders should be brought to bear, in order to sustain thermal comfort in buildings in the study area. Pragmatic steps towards the attainment of this milestone achievement are thematically presented and extensively discussed in what follow.

1. Utilization of Location-Specific/ Climate-Adaptive Architecture

Tables 1 and 2 established that the annual temperature and rainfall trends exuded diverse levels of distinctiveness for the stations with upward trends in the study area. Correspondingly, the variability also holds sway in the values of the indicators for the stations with downward trends. Consequently, appropriate considerations should be given to location and climate while designing, by the architects and builders, to expedite and maintain thermal comfort in the buildings in the area. In other words, the climatic characteristics of the different sites should be taken into cognizance by the architects and builders while designing, not only to facilitate thermal comfort but also to sustain it in the buildings in the area.

2. Creation of Architectural-Meteorological Synergy:

Architects and builders are advised to obtain basic data from meteorological stations nearer to the proposed site and analyze such data for climatic design. To put the proposition above, into perspective, the results of the annual temperature and rainfall trends in the study area (Tables 1 and 2) should be ascertained by the architects and builders from the meteorological stations in the study area. The posterior knowledge from the results will serve as a classic guide and facilitator to a climate-adaptive architecture in the study area.

3. Strategic Maintenance of Ambient Air Quality and Temperature

The results of the annual temperature and rainfall lend credence to an upward trend in the indicators in most of the stations in the study area (Tables 1 and 2). Consequently, these accentuate the expediency for a strategic maintenance of the ambient air quality and temperature in the buildings in the area. As an example, in window designs, Screen should be installed to regulate the ventilation and day lighting thereby expediting thermal comfort in the buildings.

4. Climate Site Analysis

This involves identifying key climate factors such as: temperature, wind, precipitation and solar radiation, and how these factors influence the site and surrounding areas. Climate site analysis should be executed in the sites of the eleven study locations (Tables 1 and 2) in the study area. This will provide design guidelines for layout, orientation and spacing, cross ventilation, treatment of spaces between buildings, shade trees, courtyards, shape and height of the buildings as well as house form. And also enable the architects and designers to create structures that are cozy, energy-efficient and sustainable in cognizance with the micro-climate in the areas.

Competing Interest

The author declares that no conflicting interest exist in this paper.

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E- ISSN: 3043 – 5463 ISSN: 1595 – 5842 VOLUME 2, ISSUE 2, 2025

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