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Assessment of heat stress in high-density residential areas in hot–dry climate: A case study of Bauchi Town, Bauchi State, Nigeria

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Abstract
This study assesses heat stress in high-density residential areas of Bauchi Town. It uses field measurements and surveys to evaluate environmental conditions and human comfort. Objectives: To assess heat stress levels in high-density residential areas of Bauchi Town., to measure environmental parameters influencing heat stress (temperature, humidity, airflow), to evaluate spatial variation of heat stress within selected high-density neighborhoods, to assess residents' perception of heat stress and thermal comfort, to identify urban design factors contributing to heat stress and to propose mitigation strategies for reducing heat stress in Bauchi. Methodology: Quantitative approach was adopted**.** The study was conducted in Bauchi Town, located in northeastern Nigeria. The area experiences a hot–dry climate with high temperatures and seasonal variations. The findings suggests that urban planning strategies would reduce heat stress and improve living conditions in hot–dry climates. The study unveiled that high density residential areas exhibit higher heat stress levels, nightmare stress heat is more pronounced high density residential areas, urban form significantly influences heat stress and that residents of high-density residential areas report high thermal discomfort.

Keywords: Heat stress, high density residential areas, hot dry climate

Introduction
Heat stress has emerged as a critical environmental and public health concern globally, particularly in rapidly urbanizing regions of the Global South. Urban areas in hot–dry climates are increasingly experiencing elevated temperatures due to a combination of climate change and urbanization processes, resulting in significant thermal discomfort for residents (Nasara et al., 2025). In Nigeria, rising temperatures and increasing frequency of heat extremes have intensified human exposure to thermal stress, especially in densely populated urban settlements (Nasara et al., 2026).

Concept of High-Density Residential Areas
High-density residential areas are particularly vulnerable to heat stress due to compact urban form, limited vegetation, high building coverage, and the extensive use of heat-retaining materials such as concrete and asphalt. These conditions contribute to the Urban Heat Island (UHI) effect, where urban areas experience higher temperatures than surrounding rural environments (Oke, 1987; Givoni, 1998). In hot–dry climates, the impact of UHI is further exacerbated by intense solar radiation and low humidity levels.

In cities like Bauchi Town, rapid urban growth has led to increased population density and unregulated development, often without adequate consideration for climatic responsiveness. As a result, residents in high-density neighborhoods experience prolonged exposure to heat stress, which can affect health, productivity, and overall quality of life. This study aims to assess heat stress conditions in high-density residential areas of Bauchi Town, with a view to understanding the relationship between urban form, environmental conditions, and human thermal comfort.

Impact of Problem Statement/Justification:
Impact of Urbanization
Urbanization in Nigeria has led to the proliferation of high-density residential areas characterized by poor planning, inadequate ventilation, and limited green spaces. In Bauchi Town, these conditions have contributed to increased exposure to heat stress among residents. Studies have shown that densely built urban environments tend to retain heat, particularly at night, due to the UHI effect, resulting in persistent thermal discomfort (Oke, 1987). However, there is a lack of localized empirical data on heat stress levels in Bauchi, particularly in high-density residential areas.

Furthermore, most existing studies in Nigeria focus on large cities such as Lagos, leaving medium-sized cities like Bauchi under-researched. This gap limits the development of effective urban planning strategies and policies for mitigating heat stress in such environments.

Objectives of the study
1. To assess heat stress levels in high-density residential areas of Bauchi Town.
2. To measure environmental parameters influencing heat stress (temperature, humidity, airflow).
3. To evaluate spatial variation of heat stress within selected high-density neighborhoods.

Literature Review
Heat Stress Conceptualize
Heat stress refers to the physiological strain experienced by the human body when exposed to excessive heat, particularly when the body's thermoregulatory system is unable to maintain equilibrium (Parsons, 2014). It is influenced by a combination of environmental factors, including air temperature, humidity, solar radiation, and wind speed (ASHRAE, 2017).

Urbanization has been identified as a major driver of increased heat stress, particularly in developing countries. Rapid population growth and urban expansion have led to the transformation of natural landscapes into built environments dominated by impervious surfaces such as concrete and asphalt. These surfaces absorb and store heat during the day and release it slowly at night, contributing to the UHI effect (Oke, 1987; Santamouris, 2020).

In high-density urban areas, the UHI effect is more pronounced due to compact building arrangements, reduced ventilation, and limited vegetation cover. Studies have shown that such environments experience higher nighttime temperatures, which prolong heat exposure and increase discomfort (Emmanuel, 2021; Alrashed & Asif, 2021). This is particularly critical in hot–dry climates, where daytime temperatures are already high.

Research in Nigeria indicates that heat stress is increasing due to climate change and urbanization. A long-term study using the Universal Thermal Climate Index (UTCI) revealed a significant rise in heat stress levels across the country, with urban areas being particularly affected (Nasara et al., 2025). Another study comparing heat stress indices found that Nigeria is experiencing frequent moderate to extreme heat stress conditions (Nasara et al., 2026).

Urban morphology plays a significant role in influencing heat stress. Factors such as building density, street orientation, and material properties determine how heat is absorbed, stored, and released within urban environments (Givoni, 1998; Szokolay, 2014). High-density developments in hot climates have been shown to exacerbate heat retention, thereby increasing cooling demand and reducing thermal comfort.

Vegetation also plays a crucial role in mitigating heat stress by providing shading and promoting evapotranspiration. However, the loss of vegetation due to urbanization—referred to as “urban browning”—has been identified as a key factor contributing to increased heat stress in cities of the Global South. Field-based studies in Nigerian cities have highlighted the lack of adequate data on urban heat stress, particularly in medium-sized cities. For example, a study in Akure emphasized the need for more localized measurements of thermal comfort variables to support urban planning decisions (Balogun et al., 2010).

Despite growing awareness of heat stress issues, there remains a significant gap in empirical research focusing on high-density residential areas in hot–dry regions such as Bauchi. This study aims to address this gap by providing field-based evidence on heat stress conditions and their determinants.

Research Methodology

This study adopted quantitative research approach**.** The study was conducted in Bauchi Town, located in northeastern Nigeria. The area experiences a hot–dry climate with high temperatures and seasonal variations.

1. Study Sites

High-density residential neighborhoods within Bauchi Town were selected based on population density and building compactness.

1.1 Study Subjects

- Residential buildings in high-density areas Adult residents of selected

1.2 Conceptual Data Collection

The primary method collect response directly from the respondents or participants using structured questionnaires in order to assess the loyalty of the respondents. In the secondary methods, existing data sources such as published journals articles, conference proceedings and literature materials were adequately used. Primary data were collected on air temperature, relative humidity, speed of heat stress indices and universal thermal climate index (UTCI). Environmental Measurements parameters encompasses:

- Air temperature
- Relative humidity and speed Heat Stress Indices
- Universal Thermal Climate Index (UTCI)

2. Survey

Data were gathered on thermal comfort perception, heat stress experiences as well as coping mechanisms.

- Thermal comfort perception
- Heat stress experiences
- Coping mechanisms

3. Data Analysis

Data analysis techniques were used to interpret data and draw conclusions. Analysis of data is a process of inspecting, cleaning, transforming, and modelling data with the goal of highlighting useful information, suggesting conclusions, and supporting decision making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, science, and social science domains. The quality of the data should be checked as early as possible. Data quality can be assessed in several ways, using different types of analyses: frequency counts, descriptive statistics (mean, standard deviation, and median), normality (skewness, kurtosis, frequency histograms, normal probability plots), associations (correlations, scatter plots). Data analysis is a body of methods that help to describe facts, detect patterns, develop explanations, and test hypotheses.

- **Descriptive statistics**

Descriptive statistic was used in this research where mean; mode and median were employed to interpret the data. Descriptive statistics is the act of quantitatively describing the main features of a collected data. This generally means that descriptive statistics, unlike inferential statistics, are not developed on the basis of probability theory. Even when a data analysis draws its main conclusions using inferential statistics, descriptive statistics are generally also presented. It is a set of brief descriptive coefficients that summarizes a given data set, which can either be a representation of the entire population or a sample. The measures used to describe the data set are measures of central tendency and measures of variability or dispersion (Zylke, 2024).

- **Correlation analysis**

Correlation is a statistical technique used to determine the relationship among the air temperature, relative humidity, speed of heat stress indices and universal thermal climate index (UTCI) as well as environmental measurements parameters of this study. It shows whether and how strongly pairs of variables are related. The main result of a correlation is called the correlation coefficient (or "r") that ranges from -1.0 to +1.0. This study used correlation to determine the relationship between air temperature, relative humidity, speed of heat stress indices and universal thermal climate index (UTCI).

The closer r is to +1 or -1, the more closely the two variables are related (strong relationship). If r is close to 0, it means there is weak or no relationship between the variables. If r is positive, it means that as one variable gets larger the other gets larger. If r is negative, it means that as one gets larger, the other gets smaller (otherwise known as an "inverse" correlation). While correlation coefficients are normally reported as r = (a value between -1 and +1), squaring them makes then easier to understand. The square of the coefficient (or r square) is equal to the percentage of the variation in one variable that is related to the variation in the other. For instance, an r of .5 means 25% of the variation is related (.5 squared =.25).

Similarly, an r value of .7 means 49% of the variance is related (.7 squared = .49). A correlation report can also show a second result of each test - statistical significance. In this case, the significance level will tell you how likely it is that the correlations reported may be due to chance in the form of random sampling error. If you are working with small sample sizes, choose a report format that includes the significance level. This format also reports the sample size. A key thing to remember when working with correlations is never to assume a correlation means that a change in one variable causes a change in another. The second caveat is that the Pearson correlation technique works best with linear relationships: as one variable gets larger, the other gets larger (or smaller) in direct proportion. It does not work well with curvilinear relationships (Nor, 2009 and Archambault, 2000).

Table 1: Relationship between Air Temperature and Relative Humidity

	95% CID		t.	Df.	Sig. (2) Tailed
Elements	**Lower**	**Upper**			
Air Temperature	.586	1.030	7.165	296	.000
Thermal comfort perception	.486	.881	6.800	296	.000
Heat stress experiences	1.289	1.640	16.415	296	.000
Coping mechanisms	.062	.456	2.587	296	.010
Relative Humidity	-.329	.087	-1.146	296	.253
Environmental parameters	.441	.892	5.819	296	.000

Source: SPSS T – Test Statistics, (2026).

The significant 2 tailed value of air temperature is .000 which yielded t – value 5.819 showing statistically highly significant difference between thermal comfort perception, heat stress and relative humidity.

Table 2: Relationship between Heat Stress and Hot Dry Climate

Elements	95% CID		t.	Df.	Sig. (2) Tailed
	Lower	**Upper**			
Heat Stress	1.547	1.908	18.815	296	.000
Thermal comfort	-.107	.330	1.001	296	.318
Coping mechanisms	1.147	1.465	16.180	296	.000
Coping mechanisms	1.097	1.469	13.565	296	.000
Hot Dry Climate	1.063	1.368	15.681	296	.000
Environmental parameters	-.504	-.237	-5.455	296	.000

Source: SPSS T – Test Statistics, (2026).

The significant 2 tailed value of heat stress is .000 which yielded t – value -5.455 showing statistically highly significant relationship between thermal comfort perception, heat stress and relative humidity.

Findings of the study

The study unveiled that high density residential areas exhibit higher heat stress levels, nightmare stress heat is more pronounced high density residential areas, urban form significantly influences heat stress and that residents of high-density residential areas report high thermal discomfort.

Conclusion

This study assesses heat stress in high-density residential areas of Bauchi Town. It uses field measurements and surveys to evaluate environmental conditions and human comfort. The findings will inform urban planning strategies aimed at reducing heat stress and improving living conditions in hot–dry climates.

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