



**The Challenges of Climate Change in National Development**  
Proceedings of the 4th International Conference (FESCON 2023) at Chukwuemeka Odumegwu Ojukwu  
University, Uli Campus, Uli, Nigeria  
18 - 21 October 2023

## **IMPACT OF CLIMATE CHANGE ON OUTDOOR THERMAL COMFORT IN A TROPICAL HUMID CITY**

**Ifeanyi Ukwe, John Amadi, Polycarp Nlem, Chinyere Charles-Akalonu, Victoria Asiegbu**  
*Department of Geography and Environmental Studies, Alvan Ikoku Federal College of Education,  
Owerri, Imo State, Nigeria*

E-mail: anyiukwe@gmail.com

### **Abstract**

*This study examined the impact of rising air temperatures resulting from global warming and urbanization on the outdoor thermal comfort of the residents of the tropical humid city of Owerri in southeastern Nigeria. The bioclimatic indices adopted to evaluate the outdoor thermal comfort based on the thermal physiological balance of the human body are Thom's Discomfort Index (DI) and the Humidity Index (Humidex) of the Canadian Center for Occupational Health and Safety. The study period spanned from 1988 to 2020. Results indicated the discomfort level deteriorated over the years of the study period. The results showed a 33-year increase in mean annual temperature of 0.45°C and in mean annual relative humidity of 0.27%. Over the 33-year study period, the DI increased from 23 to 26, while the Humidex increased from 37 to 41; suggesting that about 50% of the population felt some noticeable discomfort at the beginning of the study, but by the end of the study period, over 50% of the population felt great discomfort. Over any given time period, over 50% of the population felt intense discomfort during the dry season. At current temperature and relative humidity levels, over 50% of the population of the city feels some noticeable discomfort throughout the year. This knowledge is of immense benefit to health and tourism officials, building designers and organizers of outdoor activities. In view of the rising global temperatures, the study recommends provision of shady trees and use of cool pavements and cool roofs in city constructions to checkmate current discomfort trends from continuing. Ongoing commitments by nations to reduce greenhouse gas emissions should be fulfilled.*

**Keywords:** climatic change, heat stress, thermal comfort, urbanization

### **INTRODUCTION**

The worldwide reported record levels of rising temperatures, torrential rains and flooding, heatwave, wildfires, rising sea levels, destructive cyclonic storms, persistent drought, etc. has made climate change the most talked about developmental issue around the world. The Intergovernmental Panel on Climate Change has noted in their 2021 Summary Report that “since 2012, strong warming has been observed, with the past five years (2016 – 2020) being the hottest five-year period in the instrumental record since at least 1850” (IPCC, 2021). The report also indicates that the least impactful scenario of

zero greenhouse emission at current levels would still lead to serious effects on the environment and society.

Global warming and urbanization are two major phenomena that are causing unprecedented changes in the patterns of weather and climate around the globe. The increase in global urbanization (UNDESAPD, 2018) is also affecting regional climatic patterns through its urban heat island (UHI) effect—the “dome” of warm air that rests over every city. The increase in temperature over cities relative to their surrounding rural areas is well documented in the literature.

Several studies have revealed an intensification of the UHI phenomenon under heatwave conditions (Li & Bou-Zeid, 2013; Founda et al., 2017). Other studies have indicated that during heatwave, mortality rate increases exponentially and the synergy with UHI makes it more harmful for urban residents (Gabriel & Endlicher, 2011; Zhang, 2015). Global and regional warming will exacerbate urban warming especially during summertime and the dry season which will increase the incidence of heatwave with significant health effects (Sarofim et al., 2016; Talukdar et al., 2017; Arsad et al., 2022).

Increased environmental heat caused by global warming and urbanization has direct bearing on the activities and comfort levels of humans. Humans are sensitive to slight changes in atmospheric parameters such as temperature, humidity, wind speed, solar radiation and air pollution. There is always a certain limit beyond which these conditions are no longer tolerable by humans. Whenever the limit is exceeded, stress, discomfort and disaster are inevitable.

High temperature causes human thermal discomfort or heat stress. Heat stress is “an increase in human body temperature and metabolism caused by physical exertion and/or heated environment, which can lead to exhaustion, mental confusion, disorientation, dehydration, loss of consciousness, heart attack, stroke and other fatal illnesses” (Shaibu & Utang, 2016). The American National Standards Institute (ANSI) and American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) defined thermal comfort as “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (ANSI/ASHRAE, 2010).

Being satisfied with the thermal environment calls for the need to devise means of monitoring and measuring human thermal discomfort, especially within urban areas. Therefore, the knowledge of human discomfort conditions especially within cities is necessary as it has been shown that people living in large cities have greater risk of morbidity and mortality than the surrounding countryside due to higher air temperature (Nastos & Matzarakis, 2006; Pyrgou & Santamouris, 2018). This situation has necessitated the aim of this research which is to investigate the variations in outdoor human discomfort in the tropical humid city of Owerri in southeastern Nigeria resulting from rising temperatures. The study would be of interest to building designers, health officials, tourist officials and organizers of outdoor activities.

### **Area of the Study**

Owerri is the administrative capital of Imo State in southeastern Nigeria. It is located between latitudes 5° 11' N and 5° 33' N, and longitudes 6° 53' E and 7° 10' E, covering three administrative regions, namely, Owerri Municipal, Owerri West and Owerri North Local Government Areas. It covers an area of approximately 3,600 km<sup>2</sup>. It has a population of 1,401,873 (NPC, 2006). The population is mainly engaged in civil service, artisan works, commercial activities and subsistence farming.

The climate of the city lies within the tropical wet and dry climate (Aw) of the Koppen-Geiger climate classification system. It experiences two distinct seasons: a wet season that lasts from April to October, with a brief dry spell in July/August, which is dominated by rain-bearing southwesterly winds from the warm Atlantic Ocean; and a dry season that lasts from November to March, with a period of cool and dry conditions between December and early February known as the harmattan, which is dominated by the dry hazy northeasterly winds from the Sahara Desert. The mean annual temperature, rainfall, relative humidity and wind speed are 27.5oC, 2,200 mm, 77% and 3.36 m/s, respectively. Its mean elevation is 73 m above mean sea level. The relief is composed of flat to undulating lands and there is a general absence of highlands.

## METHODOLOGY

Two sets of data were used in this investigation of global warming and human physiological comfort interactions in a tropical humid urban environment. The first set of data included the mean monthly maximum and minimum temperatures (oC) and the second set included the monthly relative humidity (%). Both data sets were recorded at the Alvan Ikoku Federal College of Education, Owerri weather station. The data spanned from 1988 to 2020, covering a period of 33 years.

Many indices have been developed to assess the level of discomfort of humans to changes in atmospheric elements such as air temperature, relative humidity, solar radiation and wind speed (see, for example, Epstein and Moran, 2006). The study adopted the Discomfort Index (DI) (Thom, 1959). Originally, the DI was used to determine the discomfort level of the city environment. It is the bioclimatic index most commonly used in urban climate studies to describe the level of thermal sensation that a person experiences due to the modified climatic conditions of an urban area. The DI is a physiological thermal stress indicator for people based on the dry-bulb and wet-bulb temperatures. It reflects the proportionate contribution of air temperature and relative humidity on the human thermal comfort. Arguably, the DI is the most commonly used in both temperate and tropical regions. The DI is derived from:

$$DI = T - (0.55 - 0.0055HR)(T - 14.5)$$

where DI is the discomfort index, T is the ambient air temperature (oC) and HR is the relative humidity (%) of the air. The accompanying discomfort index assessment values are given in Table 1.

**Table 1: Thom’s discomfort index assessment**

DI	CONDITION
< 21	No discomfort
21 – 24	Under 50% of population feels discomfort
25 – 27	Over 50% of population feels discomfort
28 – 29	Most of the population feels discomfort
30 – 32	Everyone feels discomfort
> 32	State of imminent emergency

Source: Thom (1959)

The study also employed the Humidity Index (HX; shortened to Humidex) of the Canadian Centre for Occupational Health and Safety (Masterton & Richardson, 1979; CCOHS, 2011). The HX is a

parameter intended for the general public to express how the combined effects of warm temperature and humidity are perceived. It is therefore used to analyze risks associated with exposure to heat and excessive moisture. It achieves this by combining together temperature and humidity parameters. Compared to temperature readings, HX is regarded as a better measure of how stifling, stuffy or sultry the air feels (Epstein and Moran, 2006). The index is derived from the relations:

$$HX = T + 0.5555(e - 10)$$

where HX is the humidex index, T is ambient air temperature (oC) and e is the vapour pressure (mb). The vapour pressure is related to the saturation vapour pressure (es) and relative humidity (HR) by:

$$e = HR \cdot es / 100$$

The value of es is evaluated from Varmaghani (2012) as:

$$es = 6.1078 \exp((17.2693882(T^* - 273.15))/(T^* - 35.86))$$

where T\* is the air temperature (oK) and calculated as:

$$T^* = T + 273.15$$

The accompanying discomfort assessment level is given in Table 2. The method of analysis involves graphs and simple percentages to display temporal and seasonal variations in discomfort values.

**Table 2: Assessment scale of humidex degree of discomfort**

H <sub>x</sub>	DEGREE OF DISCOMFORT
< 29	No discomfort
29 – 39	Noticeable discomfort
40 – 45	Intense discomfort
46 – 53	Dangerous discomfort
> 54	Heat stroke imminent

Source: The Canadian Centre for Occupational Health and Safety (2011)

The choice of DI and HX is due to their wide applicability in the tropics where temperatures and relative humidity are oftentimes high (Yousif & Tahir, 2013; Akinbobola et al., 2017; Talukdar et al., 2017; Olatunde & Kabir, 2019; Ajeel & Abbood, 2021). The relative availability of temperature and humidity data from which they were derived also informed our choice of the two indices.

## RESULTS AND DISCUSSION

### Temperature and humidity patterns

Table 3 shows the standardized coefficients of skewness (z1) and kurtosis (z2), means ( $\bar{x}$ ), standard deviations (s), slopes of regression (b) and coefficients of correlation (r) of the annual maximum, minimum and mean temperatures and the relative humidity for Owerri between 1988 – 2020.

**Table 3: Descriptive statistics for mean annual temperatures and relative humidity for Owerri (1988 – 2020)**

ELEMENT	$z_1^*$	$z_2^*$	$\bar{x}$	s	b	$r^{**}$
$T_{max}$	0.0631	-1.3498	32.3°C	0.2667°C	0.0054°C/yr	0.1841
$T_{min}$	-0.0882	-1.5960	22.8°C	0.3365°C	0.0215°C/yr	0.2583
$T_{mean}$	-0.4743	-0.4458	27.5°C	0.2007°C	0.0136°C/yr	0.2301
RH	0.2199	-0.9839	77%	1.0181%	0.0079%/yr	0.0283

\* Absolute values of  $z_1$  or  $z_2$  above 2.02 are significant at the 95% confidence level.

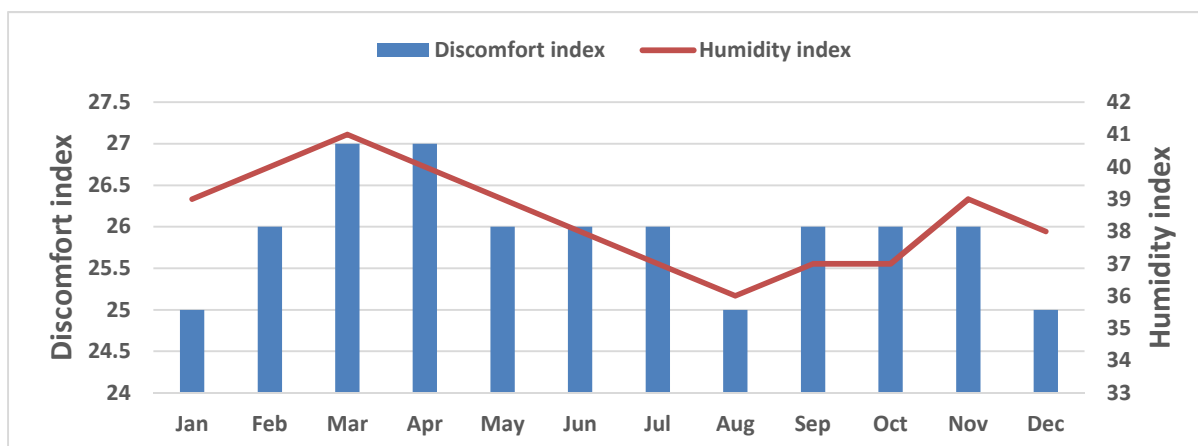
\*\* Correlation coefficients above 0.30 are significant at the 0.95% confidence level.

The results suggested that:

- (1) The  $z_1$  and  $z_2$  revealed no significant departures from normality in the data arrays during the study period.
- (2) The maximum, minimum and mean temperatures recorded a yearly increase of 0.0054°C, 0.0215°C and 0.0136°C, respectively, amounting to a net increase of 0.18°C, 0.71°C and 0.45°C, respectively, over the 33 years.
- (3) The minimum temperature increased at a rate of about four times than the maximum temperature. Increasing minimum temperature at a time of the day when it is supposed to have reached its lowest ebb can be attributed to forcing radiative factors such as global warming and the UHI.
- (4) The relative humidity recorded an annual increase of 0.0079% resulting in overall net increase of 0.26%.
- (5) The general strength of the increases as determined by the slope of regression (b) and correlation coefficient (r) showed that the increases did not reach any significant level.

### Comfort level of the human population

The seasonal variations in the 33-year values of DI and HX are shown in Fig. 1. All the months recorded DI and Humidex values above 24 and 36, respectively, indicating that presently, “over 50% of the population” experienced “noticeable discomfort” throughout the year. However, about same percentage of the population felt “intense discomfort” during the dry season when the values of DI and HX hit 27 and 41, respectively, between March and April just before the onset of the rains. Generally, the residents of the city felt less discomfort during the wet season and the brief harmattan period.



**Fig. 1: Seasonal variations in discomfort and humidity indices for Owerri (1988 – 2020).**

**Impact of climate change on human comfort**

To evaluate probable effect of increasing temperatures on human discomfort, the study period was divided into three equal periods of eleven years (1988 – 1998, 1999 – 2009 and 2010 – 2020). The mean annual temperature and relative humidity were calculated for each period. Subsequently, DI and HX values were also calculated for each period. The DI and HX values of past years were compared with values of equal number of current years, respectively. The results are displayed in Table 4.

**Table 4: Temporal patterns in discomfort and humidex indices**

PERIOD	MEAN DI	PERCENTAGE	MEAN H <sub>x</sub>	DEGREE
1988 – 1998	23	Under 50%	37	Noticeable discomfort
1999 – 2009	24	About 50%	38	Noticeable discomfort
2010 – 2020	26	Above 50%	41	Intense discomfort

**(a) Temporal patterns of discomfort index**

From Table 4 above, during the earliest years (1988 – 1998), the 11-year mean DI was 23. This shows that “under 50% of the population felt some discomfort” during this early period. In the mid period (1999 – 2009), the 11-year mean had increased to 24, indicating that “about 50% of the population felt some discomfort”. In the most recent period (2010 – 2020), the mean DI had increased to 26. This reveals that “over 50% of the population felt some discomfort”. However, the situation did not reach the point where “most of the population felt some discomfort” as a result of increasing temperatures.

**(b) Temporal patterns of humidex index**

From Table 4, the 11-year mean HX was 37 during the earliest years (1988 – 1998). This indicates that the general population felt some “noticeable discomfort” during this early period. In the mid period (1999 – 2009), the 11-year mean increased slightly to 38, indicating that the population still felt some “noticeable discomfort”. In the most recent period (2010 – 2020), the mean of HX increased to 41. This shows that the general population experienced “intense discomfort” resulting from increasing temperature and varying humidity levels.

Combining the two discomfort indices, a more meaningful conclusion can be made as follows: during the earliest period, “about 50% of the population felt some noticeable discomfort”. In the mid-period, “over 50% of the population still experienced noticeable discomfort”. By the end of the study period, “over 50% of the population now felt intense discomfort” as a result of rising temperatures and varying humidity. At no time however did the discomfort situation reach the “state of medical emergency” ( $DI \geq 32$ ) or a level of “imminent heat stroke” ( $HX \geq 54$ ).

## CONCLUSION AND RECOMMENDATIONS

The results presented in this investigation revealed that the discomfort level of the population of Owerri increased between 1988 and 2020. At the start of the study period in 1988, under 50% of the population experienced some noticeable discomfort. By the end of 2020, over 50% of the population experienced some intense discomfort. The greatest discomfort was felt during the dry season (February, March, April and the brief dry period around July/August). The least discomfort period occurred during the wet season (May – September) and the brief harmattan period in December and January. This knowledge is of immense benefit to building designers, health officials and organizers of outdoor activities.

The study has highlighted the impacts of global and urban warming and attendant climate change on outdoor human comfort. It also highlights the need to adopt effective measures to reduce the heat input into the environment and exposure of humans to environmental heat in view of the anticipated continued increase in global temperatures and urbanization. It is expected that as the global temperatures continue to rise in the future, human discomfort levels will also deteriorate and getting into the stage where “most of the population” ( $DI > 27$ ) begin to experience “dangerous discomfort” ( $HX > 45$ ). Measures recommended to reduce thermal loads include inclusion of vegetation canopies in city planning and use of cool pavements and cool roofs in city constructions. Ongoing commitments by nations to reduce greenhouse gas emissions should be fulfilled.

## ACKNOWLEDGEMENTS

The authors express their sincere gratitude to the Head of the Department of Geography and Environmental Studies of the Alvan Ikoku Federal College of Education, Owerri for providing all the necessary support needed to conduct this study.

## REFERENCES

- Ajeel, A. A., & Abbood, M. N. (2021). The effect of climate change on human comfort in Nineveh and Basra Governorates using the Heat Discomfort and Discomfort Index (DI). *Multicultural Education*, 7(6), 489 – 501.
- Akinbobola, A., Njoku, C. A., & Balogun, I. A. (2017). Basic evaluation of bioclimatic conditions over Southwest Nigeria. *Journal of Environment and Earth Science*, 7(12), 53 – 62.

- ANSI (American National Standards Institute) / ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers). (2010). Standard 55 (Thermal environmental conditions for human occupancy). Retrieved from [http://arco-hvac.ir/wp-content/uploads/2015/11/ASHRAE\\_Thermal\\_Comfort\\_Standard.pdf](http://arco-hvac.ir/wp-content/uploads/2015/11/ASHRAE_Thermal_Comfort_Standard.pdf)
- Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., Osman, Y., Radi, M. F. M., & Tangang, F. (2022). The impact of heatwaves on mortality and morbidity and the associated vulnerability factors: A systematic review. *International Journal of Environmental Research and Public Health*, 19(23), 16356.
- CCOHS (Canadian Centre for Occupational Health and Safety). (2011). Humidex rating and work. Retrieved from [https://www.ccohs.ca/oshanswers/phys\\_agents/humidex.html](https://www.ccohs.ca/oshanswers/phys_agents/humidex.html)
- Epstein, Y., & Moran, D. S. (2006). Thermal comfort and the heat stress indices. *Journal of Industrial Health*, 44(3), 388 – 398.
- Gabriel, K. M. A., & Endlicher, W. R. (2011). Urban and rural mortality rates during heatwaves in Berlin and Brandenburg, Germany. *Environmental Pollution*, 159, 2044 – 2050.
- IPCC (Intergovernmental Panel on Climate Change). (2021). *Climate change 2021: The physical science basis*. The Working Group I contribution to the Sixth Assessment Report addresses the most up-to-date physical understanding of the climate system and climate change, bringing together the latest advances in climate science. Technical Summary, p. 41.
- Li D., & Bou-Zeid E. (2013). Synergistic interactions between urban heat islands and heatwaves: The impact in cities is larger than the sum of its parts. *Journal of Applied Meteorology and Climatology*, 52, 9 – 17.
- Masterton, J. M. M., & Richardson, F. A. (1979). Humidex: A method of quantifying human discomfort due to excessive heat and humidity. Report No. CLI, 1 – 79, Atmospheric Environment Service, Canada.
- Nastos, P. T., & Matzarakis, A. (2006). Weather impacts on respiratory infections in Athens, Greece. *International Journal of Biometeorology*, 50, 358–369.
- NPC (National Population Commission). (2006). Report of Population Census and Housing of the Federal Republic of Nigeria.
- Olatunde, A., & Kabir, A. (2019). Decadal and sub periods assessment of temperature influenced outdoor thermal discomfort from 1950 – 2015 in cities of Northwestern Nigeria. *Journal of the Environmental and Social Sciences*, 25(1), 55 – 66.
- Sarofim, M. C., Saha, S., Hawkins, M. D., Mills, D. M., Hess, J., Horton, R., Kinney, P., Schwartz, J., & St. Juliana, A. (2016). Temperature-related death and illness. In *The impacts of climate change on human health in the United States: A scientific assessment*. U. S. Global Change Research Program, Washington, DC. pp. 43 – 68.
- Shaibu, V. O., & Utang, P. B. (2013). Human comfort and microclimate drivers across different landuse types in Port Harcourt Metropolis, Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 6, 737 – 745.

- Talukdor, M. S. J., Hossen, M. S., & Baten, M. A. (2017). Trends of outdoor thermal discomfort in Mymensingh: An application of Thom's Discomfort Index. *Journal of Environmental Science and Natural Resources*, 10(2), 151 – 156.
- Thom, E. C. (1959). The discomfort index. *Weatherwise*, 12, 57 – 60.
- Pyrgou, A., & Santamouris, M. (2018). Increasing probability of heat-related mortality in a Mediterranean city due to urban warming. *International Journal of Environmental Research in Public Health*, 15(8), 1571 – 1574.
- UNDESAPD (United Nations, Department of Economic and Social Affairs, Population Division). (2018). *World urbanization prospects: The 2014 revision, highlights*. New York: United States. Retrieved from <https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html>
- Varmaghani, A. (2012). Analytical formula for potential water vapour in an atmosphere of constant lapse rate. *Journal of Terrestrial and Oceanic Sciences*, 23(1), 17 – 24.
- Yousif, T. A., & Tahir, H. M. M. (2013). Application of Thom's thermal discomfort index in Khartoum State, Sudan. *Journal of Forest Products and Industries*, 2(5), 36 – 38.
- Zhang, F. (2015). The impacts of temperature and the urban heat island on mortality in the West Midlands and greater London. Unpublished Ph.D. Thesis, University of Birmingham.