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Urban heat island and bioclimatological conditions in a hot-humid tropical city: the example of Akure, Nigeria

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Abstract
The impact of weather on human health has become an issue of increased significance in recent times, considering the increasing rate of urbanisation and the much associated heat island phenomenon. This study examines the urbanisation influence on human bioclimatic conditions in Akure, a medium sized hot-humid tropical city in Nigeria, utilising data from measurements at urban and rural sites in the city. Differences in the diurnal, monthly and seasonal variation of human bioclimatic characteristics between both environments were evaluated and tested for statistical significance. Higher frequencies of high temperatures observed in the city centre suggest a significant heat stress and health risk in this hot-humid city.

Zusammenfassung
Die Auswirkungen des Wetters auf die menschliche Gesundheit sind in letzter Zeit zu einem Thema von wachsender Bedeutung geworden, insbesondere angesichts der zunehmenden Urbanisierung und des mit ihr einhergehenden Wärmeinsel-Phänomens. Diese Studie untersucht den Einfluss der Urbanisierung auf die bioklimatischen Bedingungen in Akure, einer Stadt mittlerer Größe in den feuchtheißen Tropen Nigerias. Sie verwendet Daten aus Messungen an einem städtischen und einem ländlichen Standort im Stadtgebiet. Unterschiede im täglichen, monatlichen und saisonalen Ablauf der bioklimatischen Parameter zwischen beiden Raumtypen wurden ausgewertet und auf ihre statistische Signifikanz geprüft. Größere Häufigkeiten hoher Temperaturen in der Stadtmitte deuten auf beträchtlichen Hitzestress und auf ein besonderes Gesundheitsrisiko in der tropischen Stadt hin.

Keywords Urbanisation, bioclimatological conditions, heat island, Akure, Nigeria

1. Introduction

Rapid pace of urbanisation has been reported to be a global problem present in most of the developing countries. Evidence has revealed that the world is becoming increasingly urbanised, with 45 % of the population already living in urban areas in the year 2000 (*Arnfield* 2003). It has been estimated that by the year 2025, 60 % of the world's population will live in cities (UNEP 2002; *Ichimura* 2003). World population is forecast to reach 9 billion by 2050, with almost all the growth in developing countries (UN Development Programme 2010). The UN predicts that 60 % of the world's population will be living in cities by 2030 and that nearly all the population growth will be in the cities of developing countries. Cities are places where people exist

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more densely than in other places and natural source destruction is at its maximum (*Toy* et al. 2007). Akure is not in any way going contrary to this as the population has more than tripled from 157,947 in 1990 to ~ 500,000 in 2006 (*Balogun* et al. 2011). This urbanisation-induced rapid population growth will largely drive the extent and rate of environmental changes. Many of these changes are related to the climate and atmospheric composition of cities, including the canopy layer urban heat island (UHI), thermal sensation and various forms of air pollution. Human settlements modify the materials, the structure and the energy balance of the surface and the composition of the atmosphere compared to the surrounding 'natural' terrains. There has been evidence of such urbanisation-induced significant changes and their resultant inadvertent local weather and climate changes (*Chu* and *Ren* 2005; *Ren* et al. 2008; *Zhang* et al. 2005; *Kaufmann* et al. 2007; *Xu* et al. 2013; *Balogun* et al. 2012).

Thermal comfort may be expressed by a large number of biometeorological indices and it is used to quantify the integral effects of the heat exchange between the human body and the thermal environment (*Nastos* and *Matzarakis* 2006; *Jendritzky* and *de Dear* 2009). It is affected by several parameters which include air temperature, wind speed, radiation, humidity, clothing and activities performed. A good number of studies have applied different theoretical and empirical models in deriving human thermal comfort and bioclimatological conditions. Some of the methods emphasise non-meteorological parameters while some appear complex and require multi-variants in determining the conditions. *Unger* (1999) discusses several methods such as the *Fanger's* "comfort equation" for calculating the predictive mean vote (PMV), the physiologically equivalent temperature (PET) calculated from the Munich energy-balance model for individuals (MEMI) which is most suitable for urban planners. *Pecelj* (2013) presents several bioclimatic indices based on the human heat balance according to the bioclimatic model menex (man-environment exchange), considering heat load in man, physiological strain, subjective temperature, subjective physiological temperature.

However, one of the best and accessible indices for estimating the effective temperature is *Thom's* discomfort index (DI); often referred to as thermohygrometric index (THI). The THI, which requires only temperature and humidity data, is a widely and easily used biometeorological index that can be used to evaluate thermal comfort (*Toy* et al. 2007). The aforementioned climatic elements are strongly affected by the physical environment (*Chronopoulos* et al. 2012). Other related literatures discuss the system dynamics of heat waves and the urban heat islands (*Li* and *Bou-Zeid* 2013; *Keeler* and *Kristovich* 2012) with regards to sustainable development (*Golden* 2004; *Golden* et al. 2006).

However, the bioclimatological indices used in this study may not be as factual as more recent indices that require more variables such as wind speed, radiative processes and other subjective parameters that could have additional scientific merit in the field of human bioclimatology. But the THI still helps in providing an insight on the basis of what is obtainable in this hot-humid tropical location. Studies in this context are still relatively scarce in the low tropics, particularly in Sub-Saharan Africa due to the non availability of needed equipment and funding challenges.

This paper investigates the urbanisation influence on bioclimatological conditions of Akure, using the simple thermohygrometric index (THI), discomfort index (DI) and the relative strain index (RSI) to assess the differences between the urban and rural environments in the city.

2. Study area and measurement sites

Akure, the capital city of Ondo State, Nigeria, is located on latitude 7°25' N and longitude 5°20' E (*Fig. 1*). The rapid growth of the city, particularly in the last few decades, has made it one of the fastest growing metropolitan areas in south-western Nigeria. Its population has more than tripled from 157 947 in 1990 to ~ 500 000 in 2006. The city became the administrative and economic seat for Akure South Local Government Authority and for Ondo State, with the latter's creation in 1976 from the old Western Region. Since then, the city has been witnessing immense growth in the size of the built-up area, number of immigrants, transportation, and commercial activities. The climatic condition of Akure follows the pattern of southwestern Nigeria where the climate is influenced mainly by the rain-bearing southwest monsoon winds from the ocean and the dry northwest winds from the Sahara Desert. Akure experiences a warm-humid tropical climate, with two distinct seasons, the wet (rainy) and dry (harmattan) seasons. The rainy season lasts for about seven months (from April to

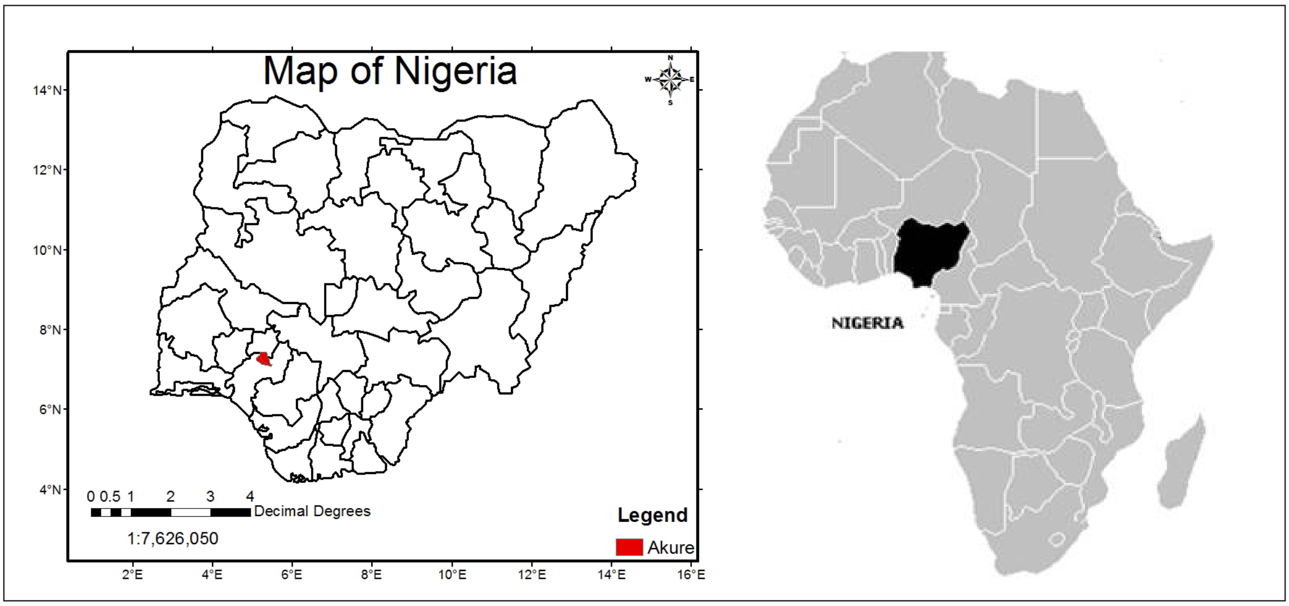

Fig. 1 Maps showing the position of Akure (red) in Nigeria (left) and of Nigeria in Africa (right)

October), while the harmattan is between November and March. The harmattan season, which is associated with haze, poor visibility and a prevalence of cold, cough, catarrh and conjunctivitis (an eye disease) in Nigeria, is extremely hot during the daytime and harshly cold at nighttime. Akure records an average rainfall of about 1500 mm per annum. Monthly average temperatures range between 21.4 and 31.1°C, and its mean annual relative humidity is about 77.1 % (based on 1980-2007 data from the Nigerian Meteorological Agency). Its vegetation is a type of tropical rainforest. Akure lies on a relatively flat plain, about 360 m above sea level, in the Western Nigerian plains.

The urban site is located in the city centre and characterised by dense population, intense transportation and commercial activity. The rural reference site is situated at the meteorological service observatory of the seldom used local airport, located about 15 km east on the outskirts of the city, and is characterised by massive grass-covered open plots, few bungalow office buildings and the control tower. *Figure 2* shows the google map of the study sites with eye-level photos and sky-view features of both the urban and rural stations taken during our measurements. Issues pertaining to discrepancies in the classification of urban-rural measurement sites for defining the urban heat island reported by *Stewart* and *Oke* (2009) and their consequences for the universally applicable scheme have been taken into consideration in our earlier work (*Balogun* et al. 2010). Hence, the city centre, having a sky-view factor of 0.83, is classified as 'compact low rise' local climate zone, and the airport, which has a sky-view factor of 0.98, is classified as 'sparsely built' local climate zone. The position of the sensor at the urban site was carefully selected to prevent the impact of elevated heat sources such as rooftops.

3. Materials and methodology

Investigations were conducted on the data obtained from a year-long experiment of fixed point observations at the urban city centre and the rural reference site. Simultaneous measurements of temperature and humidity were taken from shielded portable Lascar EL-USB-2 temperature/humidity data loggers, sampled at 5-minute intervals and mounted on a lamp post above head height (3 m) in the city and on a mast at the same height at the airport for a year (January to December 2010). The difference in temperatures between the city and the out-of-town stations, denoted by ΔT u-r, is the most commonly used index of the intensity of the UHI (*Klysik* and *Fortuniak* 1999). In this paper the quantity of this difference is accepted as a measure of the city's influence on thermal conditions. The hemispherical images were taken using a digital camera (Nikon Coolpix 950 with a 183-degree field of view fisheye lens) and the sky-view factors were calculated from the hemispherical images using a method outlined by *Chapman* et al. (2001).

The bioclimatological conditions were analysed in terms of the mean hourly values of the thermohygrometric index (THI), discomfort index (DI) and the rel-

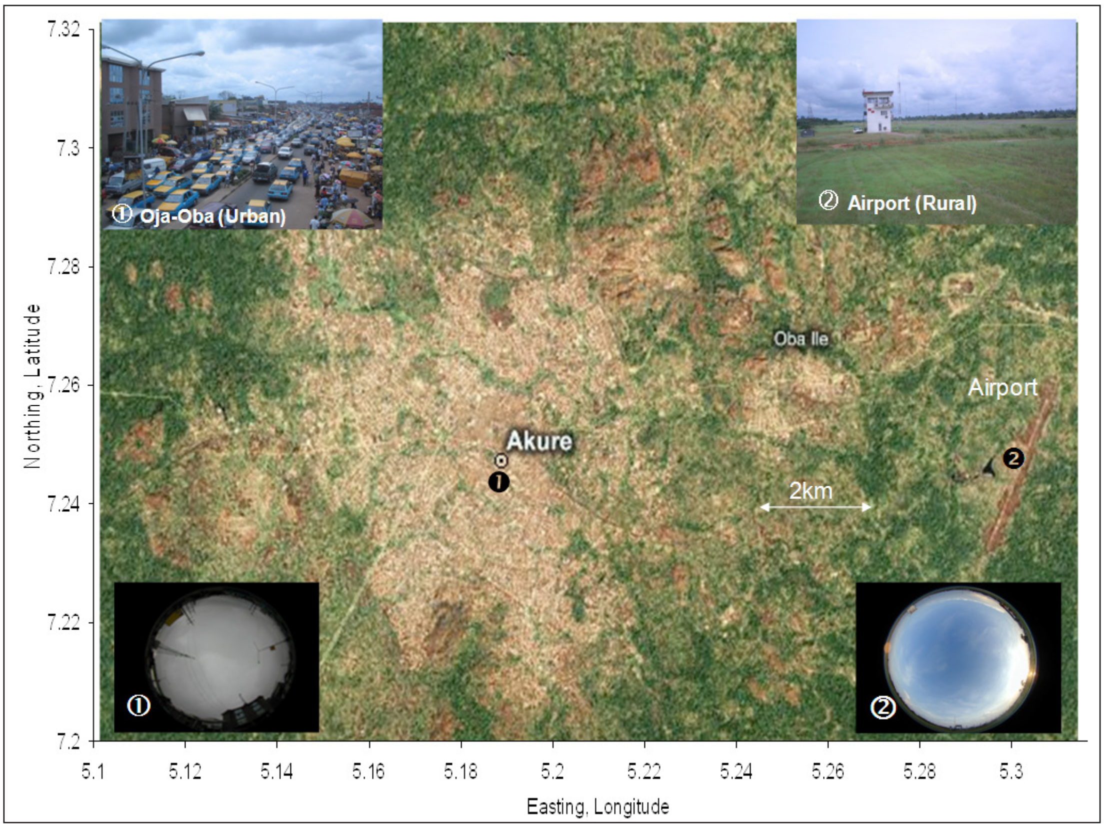

Fig. 2 Google map of Akure showing the study sites [city centre (1) and airport (2)], their eye level pictures and sky view photos taken during the experiment respectively.

ative strain index (RSI). We analysed the heat stress conditions in terms of maximum, minimum and mean hourly values of the thermohygrometric index (THI, defined by air temperature and relative humidity; *Kyle* 1994). The categories are listed in *Table 1*.

$$THI = T - (0.55 - 0.0055\ RH)\ (T - 14.5),$$

where air temperature (T) is measured in °C, and relative humidity (RH) in %. This index has been used in many bioclimatic investigations (*Unger* 1999; *Matzarakis* and *Mayer* 1991; *Toy* et al. 2005, amongst others). Descriptive statistics with a one-way analysis of variance (ANOVA) is applied to detect the significant differences at a 95 % confidence interval between the mean values of THI at the urban and rural sites.

The discomfort index (DI) method of classification of thermal environment in summer proposed by *Matzarakis* and *Meyer* (1991), presented in *Table 2,* was adopted to obtain a more definite percentage of inhabitants under different heat stress conditions. The DI was originally proposed by *Thom* (1959) as

$$DI\ (°F) = 0.4\ (td + tw) + 15\ .$$

Thom's discomfort index (DI), often referred to as the thermohygrometric index (THI), is secured by a simple linear adjustment applied to the average of the simultaneous dry-bulb (td) and wet-bulb temperatures (tw). Alternative versions of THI proposed utilise

Tab. 1 The categories of the thermohygrometric index (THI) (Kyle 1994)

THI category	Temperature (°C)
Hyperglacial	< –40
Glacial	–39.9 to –20
Extremely cold	–19.9 to –10
Very cold	–9.9 to –1.8
Cold	–1.7 to +12.9
Cool	+13 to +14.9
Comfortable	+15 to +19.9
Hot	+20 to +26.4
Very hot	+26.5 to +29.9
Torrid	> +30

Tab. 2 Classification of the thermal environment in summer according to the discomfort index (= THI; Matzarakis and Mayer 1991)

DI classification	DI range (°C)
No discomfort	DI < 21
Under 50 % population feels discomfort	21 ≤ DI < 24
Over 50 % population feels discomfort	24 ≤ DI < 27
Most of population suffers discomfort	27 ≤ DI < 29
Everyone feels severe stress	29 ≤ DI < 32
State of medical emergency	DI ≥ 32

Tab. 3 The Relative strain Index (after Kyle 1994)

RSI Values	Implications
0.1	100 % unstressed (everyone comfortable)
0.2	75 % unstressed
0.3	0 % unstressed (upper limit of comfort)
0.4	75 % distressed
0.5	100 % distressed (everyone uncomfortable)

temperatures measured in °C and relative humidity. The THI was used originally to determine the discomfort due to heat stress and has been evaluated over a much wider range of conditions. *Unger* (1999) reports their similarities; there are no significant differences between the two classifications.

We also considered the RSI (defined by air temperature and vapour pressure) in determining bioclimatological conditions as it accommodates the effects of clothing insulation and net radiation. The RSI for a "standard man" (i.e. a healthy 25-year-old male, un-acclimatised to heat, in business clothing) under specified conditions (i.e. internal heat production of 100 Wm^{-2}, wind speed of 1 ms^{-1} and no direct solar radiation) is given by the following:

$$RSI = (t - 21) / (58 - e)$$

where *t* is the air temperature (*°C*) and *e* is the vapour pressure (*hPa*). The RSI table after *Kyle* (1994) is presented in *Table 3*. The RSI has been used over temperate regions (*Unger* 1999; *Emmanuel* 2005). *Unger* mentioned that an RSI of 0.2 is the upper limit of comfort for the elderly and people with ill health.

The three indices adopted for this research are based on the available parameters, and the differences observed in the indices obtained from the urban and rural sites were used to establish the influence of urbanisation on human bioclimatological conditions in Akure.

4. Results

4.1 Urban Heat Island

The existence of UHI in Akure has been reported in our earlier studies (*Balogun* et al. 2010; *Balogun* et al. 2012). *Figure 3* shows the variation of urban heat island intensities over Akure and its environs in two

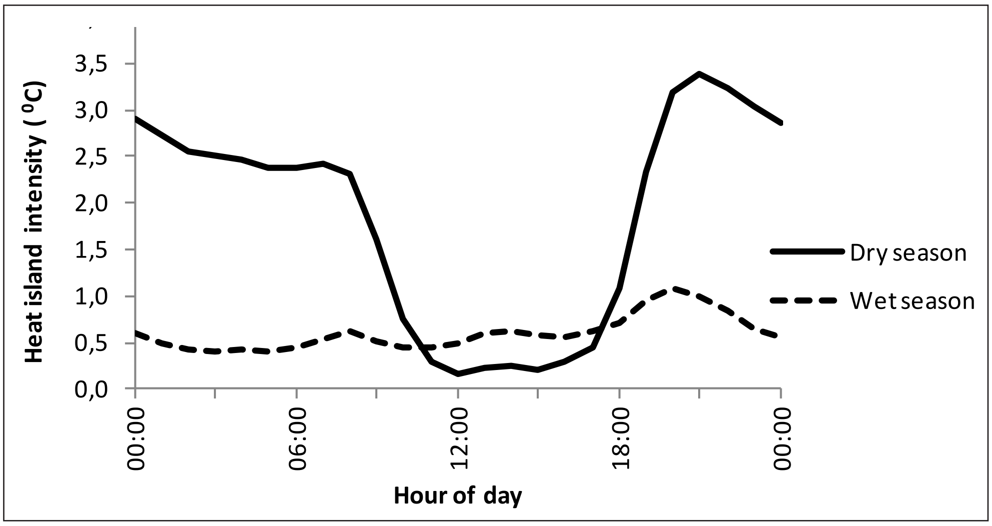

Fig. 3 Diurnal variation of the heat island intensities during the dry and wet season in 2010

prominent seasons of the year experienced in the locality. The figure reveals that the maximum UHI intensity occurs at night between 19:00 and 22:00 local time and that the magnitude and intensities of the urban heat island is a function of the season of the year. The mean UHI intensities are reaching higher up to 3.5°C during the dry season and about 1°C during the wet season. *Figure 4* shows the variation of urban and rural THI and the UHI intensity for the dry and wet seasons. The magnitude of the differences between the THI in the city centre and at the rural airport indicates that there is larger variation between the THI of both stations during the dry season and particularly during the nocturnal hours. During the wet season, the less intense nocturnal UHI observed in the city has a reduction impact on the urban-rural differences in bioclimatological conditions. Regardless of whatever season of the year, at daytime, precisely from few hours after sunrise till around sunset, the urban-rural differences in bioclimatological conditions are quite small compared to the nocturnal hours.

4.2 Bioclimatic conditions

Data analysis over the 1-year period under investigation reveals that the urban site was far less comfortable than the rural airport. Only five out of the THI categories presented in *Table 1* can be identified in this study region: 'cool', 'comfortable', 'hot', 'very hot' and 'torrid'. Results of the mean, maximum and minimum THI study indicate that hot conditions were predominant at both sites (*Fig 5a, b* and *c*). Only the urban site has records of torrid conditions in the mean and minimum THI values.

Generally, the urban city centre did not register any cool conditions at all but has more very hot and torrid afternoons than the rural airport. Although comfort-

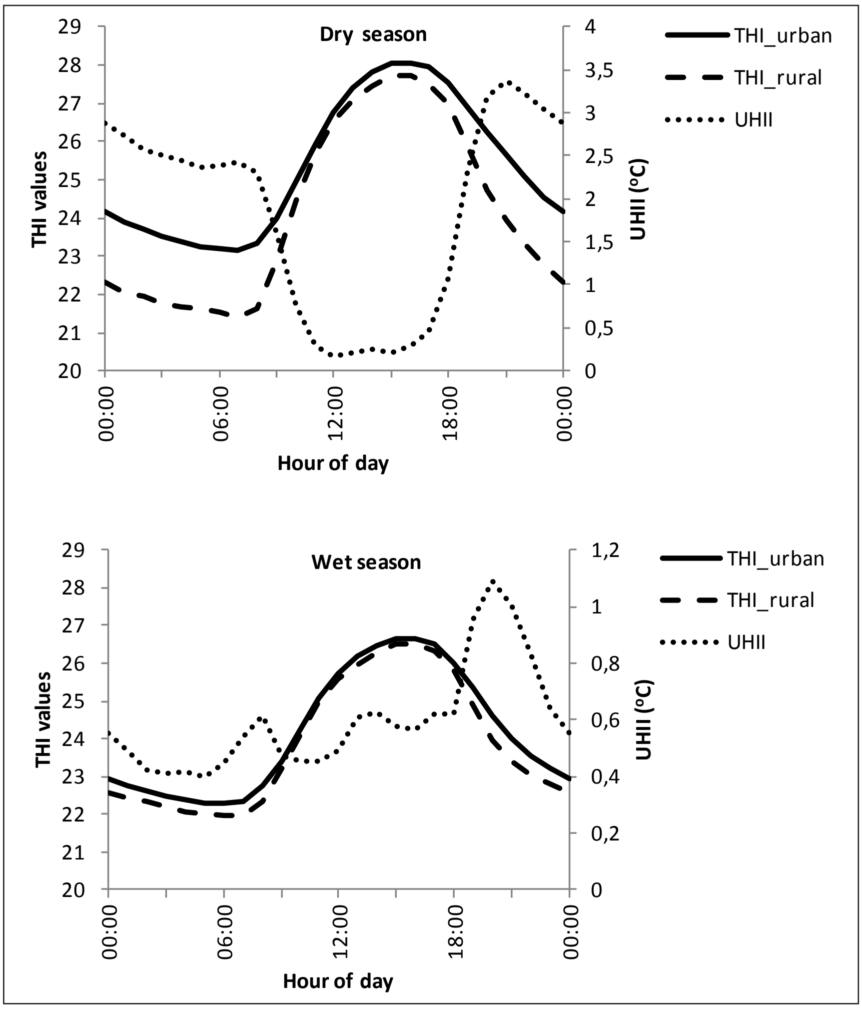

Fig. 4 Diurnal variation of mean seasonal urban and rural thermohygrometric index (THI) and the urban heat island intensities (UHII) for (a) dry season and (b) wet season.

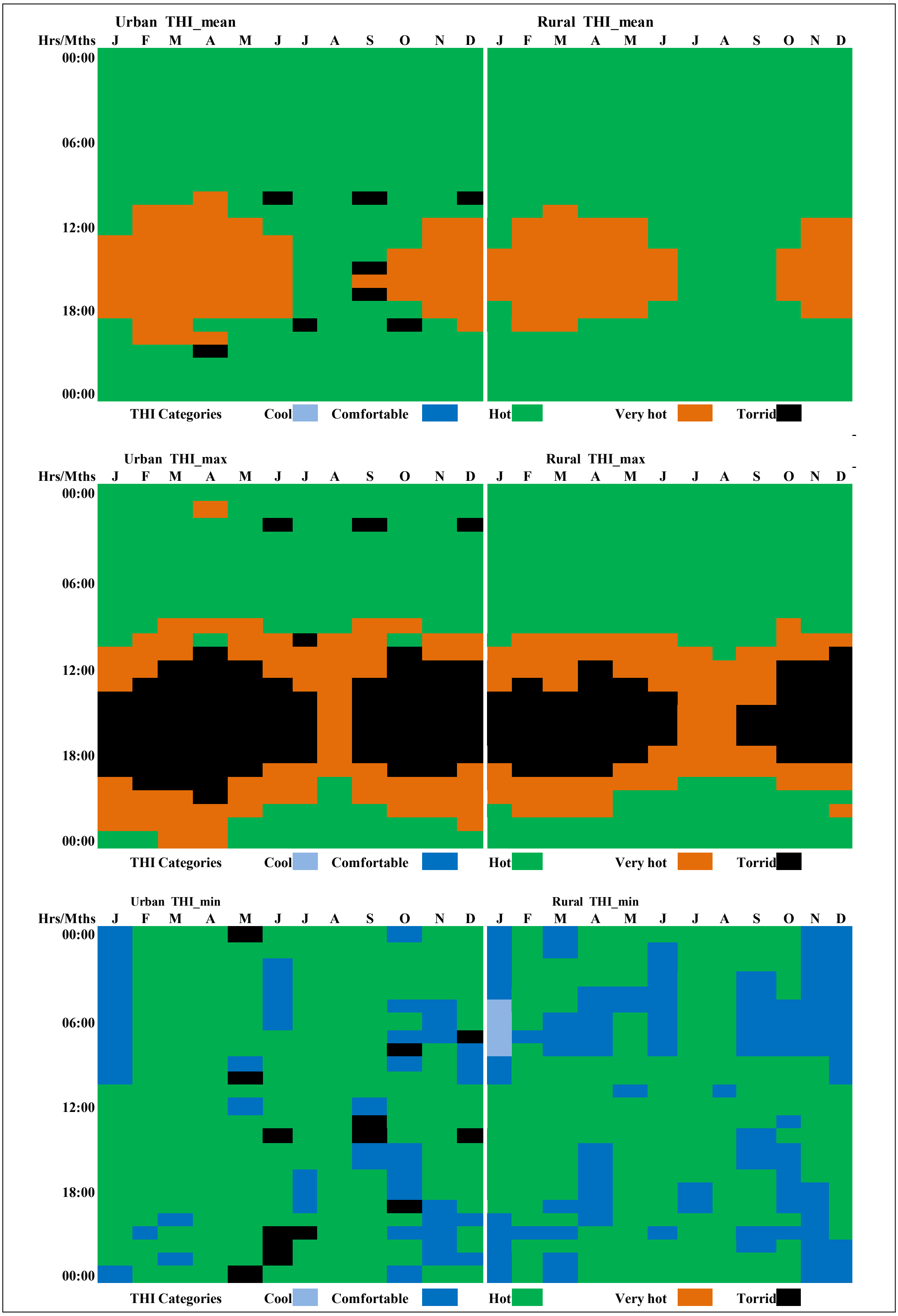

Fig. 5 Variations in the categories of the thermohygrometric index (THI) for (a) mean, (b) maximum and (c) minimum values at the urban and rural sites

able conditions were observed in the minimum THI result of both sites, most especially in the mornings and evenings of some months, the rural area has more pleasant mornings and evenings and less very hot and torrid conditions. Comfortable conditions are observed to be predominant between the months of November and January. The month of August, which is the period of the little dry season, records no torrid condition at both sites for the mean, maximum and minimum THI.

A comparison of the generated plots identifies the following main features of the differences in human bioclimatological effects between the urban city centre and the rural reference airport station: Considering a whole year as 100 %, the frequencies of the identified THI categories for both the urban city centre and the rural airport with respect to the mean, maximum and minimum values are presented in *Table 4*. Based on the mean THI values, 3 % of the year at the urban city centre is in the "torrid" THI category, whereas the rural airport records no value in this highest category. The "comfortable condition", which is referred to as most important (*Unger* 1999) is only observed in the minimum THI values. Only 16 % of the year reflects this condition in the urban city centre while the rural site enjoys this comfortable condition for about one third of the year (34 %), pronounced in the mornings and late evenings and mostly in the dry season. A small proportion of the year experiencing "cool conditions" of 1 % is observed at the rural airport for few morning hours in January.

We complement our work with the investigation of monthly mean RSI values in the diurnal observation times. Akure is located in the hot-humid tropical zone where the average bioclimatic condition is hot. The heat stress condition which is termed the 'upper limit of comfort' is observed at both sites. The index reaches its maximum value (0.30) during the dry months, with the transitional month of April, at 13:00-18:00 at both sites (15 % and 9 % occurrences during the dry season respectively). Conditions with an RSI value of 0.2 around midday till the period of sunset are prevalent at both sites, but less so in the rural environment. It is also observed that the threshold level of 100 % comfortable (unstressed) is restricted to nocturnal hours from 21:00 till about 10:00 and during most days in the wet season.

Results obtained using the discomfort index (DI) classification of the thermal environment according to *Matzarakis* and *Mayer* (1991) are also presented. *Figure 6* shows the mean monthly status of the below- and above-average discomfort status of both sites. The second category of the DI where less than 50 % of the population feel discomfort is more pronounced in the rural environment than in the urban, whereas the third category indicating that more than 50 % of the population feel discomfort is higher in the urban city centre. High frequency in the category where less than half of the population feels discomfort and the low frequency in the category where above half of the population feels discomfort marked at both sites occurred in August, during the period of the little dry season. This is the only month that did not experience any torrid condition in the result of our THI study (*Fig. 5*). Only the urban site falls within the fifth category of the DI that indicates most of the people feel discomfort, and this occurred between February and April. None of the sites appears in the severe stress and state of medical emergency category in this context of monthly assessment. However, there are cases of severe stress at certain hours of some days, and also of the state of emergency category at some hours on some days, particularly during the dry months, but these periods do not last long.

The one-way analysis of variance (ANOVA) test, presented in *Table 5,* indicates that there is no significant difference ($p < 0.05$) between the mean, maximum

Tab. 4 Frequency of occurrence (%) of the observed five THI categories over the 1-year study period (January to December 2010)

THI Categories	Mean		Max.		Min.	
	Urban	Rural	Urban	Rural	Urban	Rural
Cool	0	0	0	0	0	1
Comfortable	0	0	0	0	16	34
Hot	73	80	45	54	79	65
Very hot	24	20	25	25	0	0
Torrid	3	0	30	21	5	0
Total	100	100	100	100	100	100

and minimum values of THI during the wet season. Conversely, for the dry season, the test shows that there exists a significant difference ($p < 0.05$) of 4.95 and 6.60 respectively, between the mean and minimum values of THI of the urban and rural site.

5. Discussion

The observed large differences in minimum temperature between the two sites during both the dry season and the wet season are, however, an indication of the prominent roles of cloud conditions in UHI study. The distinct seasonal UHI variation is associated with the seasonality of weather. It ranges from the abundance of clear, calm conditions, especially at night in the dry season, to unstable weather conditions with clouds and rain during the wet season (April-October). Average wind speed in Akure is 2 m/s during the dry season and 3 m/s during the wet season. Generally, the atmospheric condition is neutrally stable at nighttime and unstable during the day. The most significant factors governing heat island development during the rainy season are the changes in wind speed, cloud cover and rain (particularly at the rural site), that are associated with unstable turbulent weather (*Jauregui* 2007). During the wet season, the UHI formed at night is preserved and almost unchanged throughout the day, but during the dry season the UHI formed at night is preserved until the morning hours and significantly drops in intensity or completely vanishes during midday. The magnitude and intensities of the urban heat island dictates the extent of the THI causing both to be a function of the season of the year.

The torrid condition observed for maximum THI at the rural site in *Figure 5b* is much expected as both the urban and rural site receives insolation from the same source and apparently peaks at about the same hour of the day. It subsequently enhances the air tem-

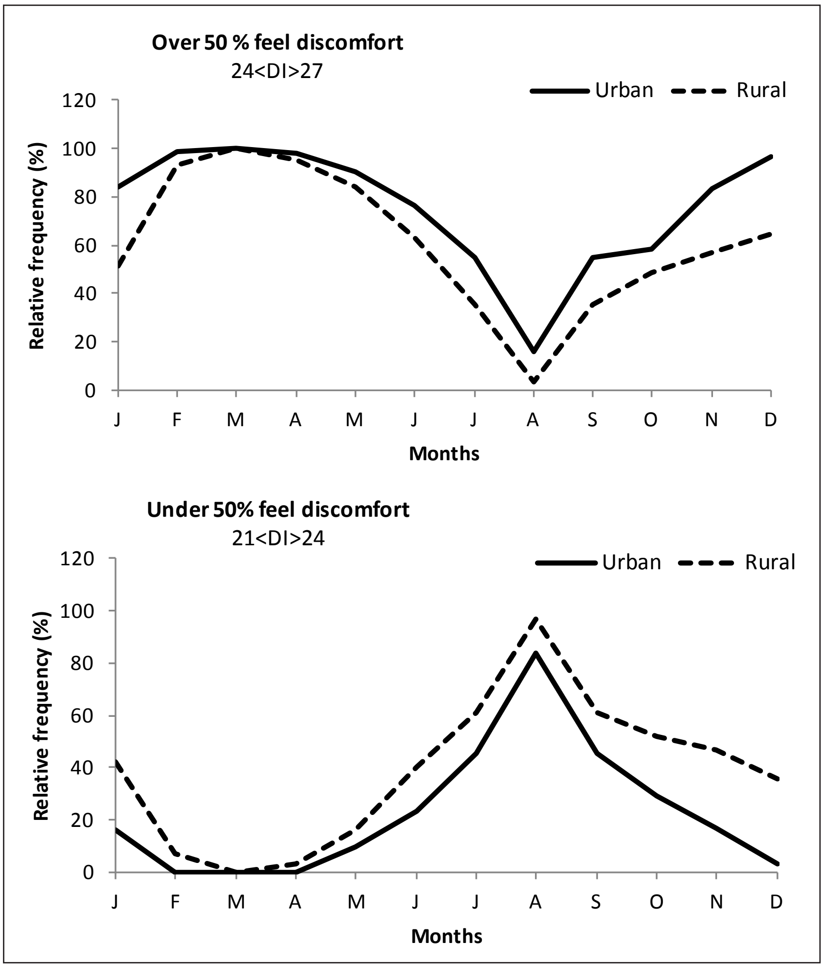

Fig. 6 Variations of monthly mean for two DI categories at the urban and rural sites, (a) when less than 50 % of the population feels discomfort, and (b) when more than 50 % feels discomfort.

perature and determines the period of maximum temperature. The solar heating generates a turbulent mixed layer over both sites, the urban surfaces and its environs, thereby causing a decline in thermal contrast until around the end of the afternoon. Contrarily, the minimum THI shown in *Figure 5c* suggests that the impact of the urban development on bioclimatological conditions is more pronounced on the city dwellers as there still exist 'torrid conditions' and reduced 'comfortable conditions' particularly during the nocturnal hours. The reductions in comfortable conditions are higher during the dry season and the cool THI category is never experienced at the urban site. The differences observed in the urban-rural bioclimatological conditions indicate that they are closely related to the UHI. The UHI has its maximum occurrence at night, between 18:00 and 22:00 local time, attaining its peak at around 21:00 and thereafter continues to develop through the early morning hours. The differences in THI between the urban and the rural site are quite large during these periods. This is due to the rural net radiative energy loss to an unobstructed sky and to the less polluted atmosphere prior to sunrise.

In the THI study, the relatively small proportion of the year experiencing "cool conditions" of 1 % observed at the rural site for few morning hours in January is attributed to the harmattan weather condition usually experienced in this region in early January. The urban centre does not enter this category as it only enjoys a "comfortable condition" at morning and late evening hours during the season.

Contrary to the results obtained for temperate cities, this measure of THI in a hot-humid tropical city suggests that the rural environment has more advantageous than disadvantageous effects on the thermal conditions of humans because of the more frequent occurrence of cool and comfortable conditions and less very hot and torrid conditions. The only period that the city may have an advantage over the rural site in this environment is for few morning hours during the period of intense harmattan, and this is when the minimum THI recorded "cool condition" for few early hours in January.

The RSI index attains its maximum value during the dry transitional month and the dry season with values exceeding the upper limit of comfort for the elderly and people with health challenges, in agreement with the work of *Unger* (1999). The prevalence of conditions with an RSI value of 0.2, suggesting that one quarter of the people are stressed, occurring around midday till around sunset at both sites, is associated with the diurnal heating pattern that attains its maximum intensities within the period. The threshold level of 100 % comfortable (unstressed) that is observed to be restricted to the nocturnal hours during most days in the wet season is linked with the weak nocturnal heat island intensities associated with the wet season (see *Fig. 4*).

Tab. 5 Summary of one-way analysis of variance to detect significant differences (95 % confidence interval) in mean values of THI between urban and rural site

		Groups	Average	Variance	*F*	*P*-value	*F* crit
Dry Season Summary	Mean	Urban	25.3	3.3	**4.95**	0.06	4.05
		Rural	24.2	5.7			
	Max	Urban	27.9	6.3	0.57	0.45	4.05
		Rural	27.3	7.9			
	Min	Urban	21.7	2.6	**6.60**	0.01	4.05
		Rural	20.1	6.8			
Wet Season Summary	Mean	Urban	24.2	2.7	0.38	0.54	4.05
		Rural	23.9	2.9			
	Max	Urban	27.1	8.6	0.63	0.43	4.05
		Rural	26.5	7.9			
	Min	Urban	20.6	0.1	0.34	0.56	4.05
		Rural	20.5	0.2			

Results obtained using the discomfort index (DI) classification of thermal environment according to *Matzarakis* and *Mayer* (1991) suggest that the level of discomfort is higher at the urban site and this can be attributed to the urbanisation influence. The differences between these DI conditions at both sites agree with the result obtained for the THI condition, as the differences are less during the wet season than in the dry season. The relative closeness is most prevalent during the transitional months between the dry and wet season.

Considering the results of the one-way ANOVA test, the insignificant difference between the mean, maximum and minimum values of THI of both sites during the wet season indicates that there is little or no difference in demand for cooling between the urban and the rural site in this season. During the season, there will be a drastic reduction in energy demand at the urban area. During the dry season, the situation is quite different as the significant difference in mean and minimum values of THI obtained between urban and rural site suggests that the cooling energy demand to attain desired human comfort at the urban area will be much higher than that of the rural environment. This indicates that the urbanisation influence on the human bioclimatological conditions in this hot-humid tropics location is more pronounced during the dry season and also prevalent at nocturnal hours considering the THI minimum values.

6. Conclusion

The consequential modification of urbanisation on the main climatological elements of the city centre within the general climate of a hot humid tropical city has been established in this study. Most of the previous studies carried out in the temperate regions concluded that the urban atmosphere has more advantageous than disadvantageous effects on the human bioclimatologic comfort (*Unger* 1999; *Robaa* 2003; *Toy* 2007). This is not so for hot-humid environments like the city of Akure where higher warmth of the city is a significant thermal heat stress risk. Although, the most dominant bioclimatic type in both locations is the 'hot' one, the measure of THI has established that the rural environment has more advantageous than disadvantageous effects on the thermal conditions of humans because of the more frequent occurrence of 'cool' and 'comfortable' conditions and less 'very hot' and 'torrid conditions'. This suggests the need for urban greening by creating urban city parks and urban trees. The dry season has the lowest frequency of 'torrid' and 'very hot' conditions at both sites, while the wet season recorded the highest frequencies of both conditions. The study of the relative strain index reveals that the heat stress condition termed the 'upper limit of comfort' exceeding the upper limit for elderly and ill-health people is observed at both sites during the dry months (15 % and 9 % occurrences during the dry season respectively). However, the discomfort index reveals that the category of severe stress and state of medical emergency was never observed in the monthly values at both sites.

The results of the one-way ANOVA test that indicate no significant difference ($p < 0.05$) between the mean, maximum and minimum values during the dry season, suggest that there will be little or no difference in energy demand for cooling between the urban and the rural sites in this season. However, during the dry season, there exists a significant difference ($p < 0.05$) between the mean and minimum values of THI of the urban and rural site. In this period, the cooling energy demand that will be required to attain desired human comfort at the urban area will be much higher. This clearly indicates that the urbanisation influence on the human bioclimatological conditions in this hot-humid tropical location is much higher during the dry season. This has an implication for thermal comfort planning and decision-making in the city. Higher frequencies of high temperatures observed in the city centre suggest a significant heat stress and health risk in this hot-humid city. Hence measures that are capable of mitigating impacts of the increasing temperatures associated with the UHI are required in order to improve the health, safety and productivity of the city dwellers. More research is needed to achieve a better understanding of these bioclimatological conditions using recent indices that accommodate variables such as wind speed, radiative processes and other subjective parameters that could add more scientific merit to the field of human bioclimatology; but lack of research facilities and funding are major limitations to such research in Nigeria. The availability of research facilities that are capable of measuring basic environmental factors of thermal comfort will advance urban climate research in Nigeria.

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