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Full Length Research Paper

Observed urban heat island characteristics in Akure, Nigeria

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A climatological analysis of the differences in air temperature between rural and urban areas (ΔT_{u-r}) corroborates the existence of an urban heat island (UHI) in Akure (7º 25' N, 5º 20' E), a tropical city in the south western part of Nigeria. The investigations which have been conducted out of a year-long experiment from fixed point observations focuses on the description of the climatology of urban canopy heat island in the Akure and the analysis of the results were presented. The results show that the nocturnal heat island was more frequent than the daytime heat island as it exists from less intense to higher intensity categories throughout the study period. Nocturnal heat Island intensity was observed to be stronger during the dry season. Although of lower intensity, daytime heat Island exists throughout the day except for few hours in the months of November and December that exhibits a reverse thermal contrast. The daytime heat island is observed to be intense in the wet months than the dry months, which may be caused by the evaporative cooling of wet surfaces. On the average, the urban/ rural thermal differences are positive, varying from 4°C at nocturnal hours during dry months to an approximate of 2°C around noon during wet months. This paper explain the aspects of heat islands and their relation to other causative agents such as the sky view factor (SVF) and also discusses its potential impact on energy demand.

Key words: Urban heat island, sky view factor, energy demand.

INTRODUCTION

The city of Akure has witnessed remarkable growth in its urbanisation in recent years, and its population during the past few decades has more than tripled. Urbanisation has been reported to modifiy local city climates. The resulting UHI is the characteristic warmth of urban areas compared to their outskirts. It is also often referred to as the increase of air temperature in the near-surface layer of the atmosphere within cities relative to their surrounding countryside (Voogt, 2002).

Essence of studies of the UHI are not only predicated on the necessity to gain knowledge of its numerous secondary effects when excessive, but also its practical needs in town planning, prevention of high concentration of air pollution and creation of optimum bioclimatic conditions (Rosenfeld, 1995; Balogun et al., 2010).

Built-up environment has been found to exacerbate heat stress, particularly at night, during heat waves and provides a preferential site for spread of vector borne diseases (Samuels, 2004; Svensson and Tarvainen, 2004). It has also been well documented that weather-related factors play an important role in affecting electricity consumption. For many years, utility companies and the electric power industry have been interested in the relation between energy consumption and climate, and have developed empirical weather normalization algorithms aimed at improving load forecasting subject to variations in regional climate (Sailor, 2001).

Modification of air temperature by urban areas at roof level has been reported extensively in mid-latitude cities (Chandler, 1962; Oke, 1982), but it has however been noted that transferability of results from knowledge regarding the mid latitude studies is still limited (Oke et al., 1990, 1991). Lately, the heat-island phenomenon begin to receive attention in tropical environments where

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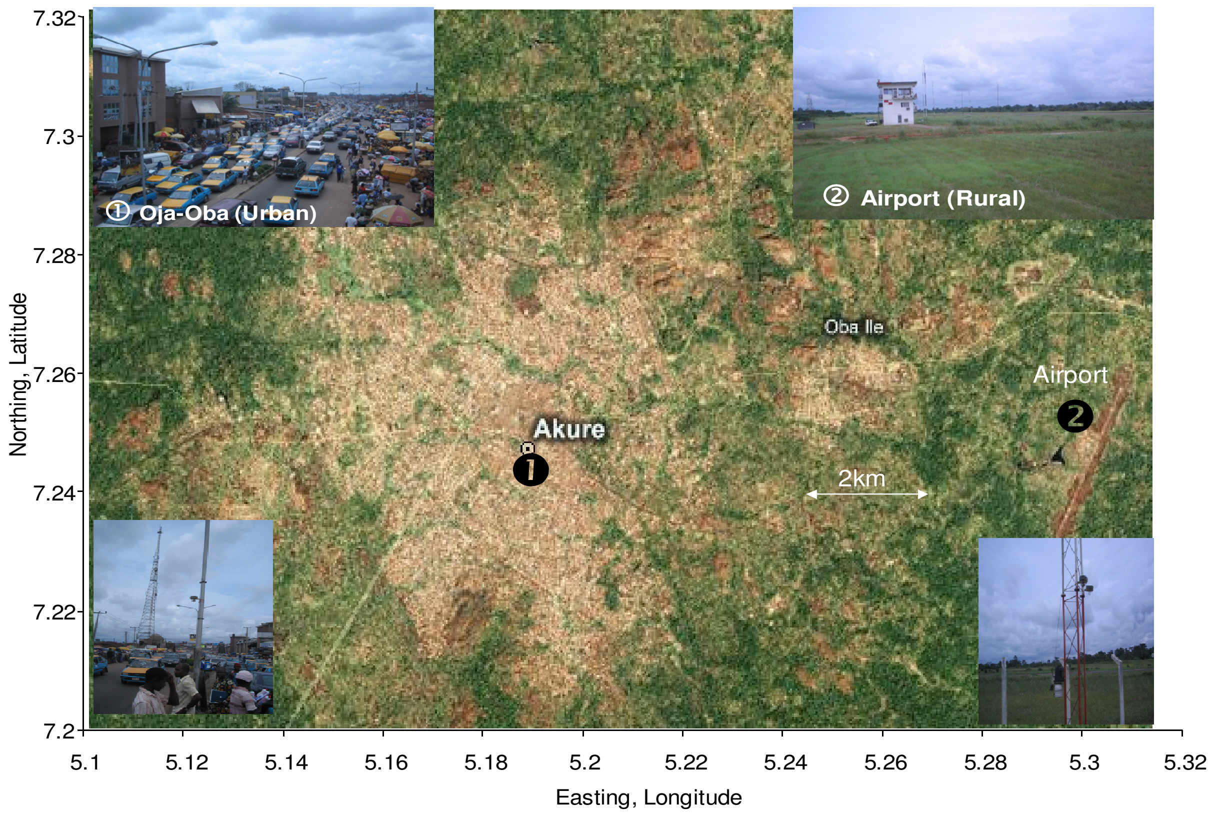


Figure 1. Google map of Akure showing the city centre (1) and Airport (2) sites. Inset (left and right) are photos of the sites and measurement systems respectively.

cities have been witnessing rapid growth in a chaotic manner (Imamura, 1988; Adebayo, 1991; Balogun et al., 2009a, b). Most of the studies on mid-latitude were undertaken during the summer, when prevailing cloudless skies and calm or light winds allow full development of the phenomenon. Since the above conditions are not often present during winter, with some exceptions (Munn et al., 1969; Unwin, 1980), rather few studies were attempted to describe the seasonal behavior of the heat island during an annual cycle. Findings regarding relationships between the intensity of the urban heat island and various parameters such as population of a city and sky-view-factor have been investigated (Yamashita, 1988; Park, 1987; Tumanov et al., 1995).

Urban microclimate studies of tropical regions are still rare, the few workdone in Nigeria have used mean monthly climatological data or 2 to 3 hourly interval short term manual measurements (Adebayo, 1991; Balogun et al., 2009a) and these have limited the studies to daytime conditions. This paper intends to provide additional insights on the descriptive aspects of the heat island phenomenon characterizing a tropical urban environment and discusses its relative impact on energy demand of the city and its enviroment. The importance of weather related parameters in determining the amount of energy required to achieve desired human comfort needs to be harnessed, particularly during periods that are associated with high frequency of heat island and warmer nights which are also expected to vary in severity by different landuse types. This can be translated into economic value and also serve as a basis for policy formulation in urban planning and climate mitigation measures.

EXPERIMENTAL MEASUREMENT AND METHODS

The experiment was conducted from the period of October 2008 to September 2009. Figure 1 shows the location of the urban and rural stations used. The site at Oja Oba (meaning King's market), representing the urban is located at the city center in a densely mid-rise built-up area characterized with dense population, intense transportation and commercial activity. The rural reference site is situated at the meteorological service observatory of the seldom use local airport located about 15 km east on the outskirt of the city, and is characterized by massive grass-covered open plots, few bungalow office buildings and the control tower shown as inset picture in the Figure 1. The Oja urban site (1) and the rural reference site (2) are classified as Built climate zone (BCZ5) and Agricultural climate zone (ACZ3) respectively (Stewart and Oke, 2009). The sites were selected for fixed point observations and data were obtained from shielded portable Lascar EL-USB-2 temperature/humidity data loggers, sampled at 5-minute intervals that were mounted on a lamp post above head height (3 m) in the city urban centre and on a mast at the same height in the local

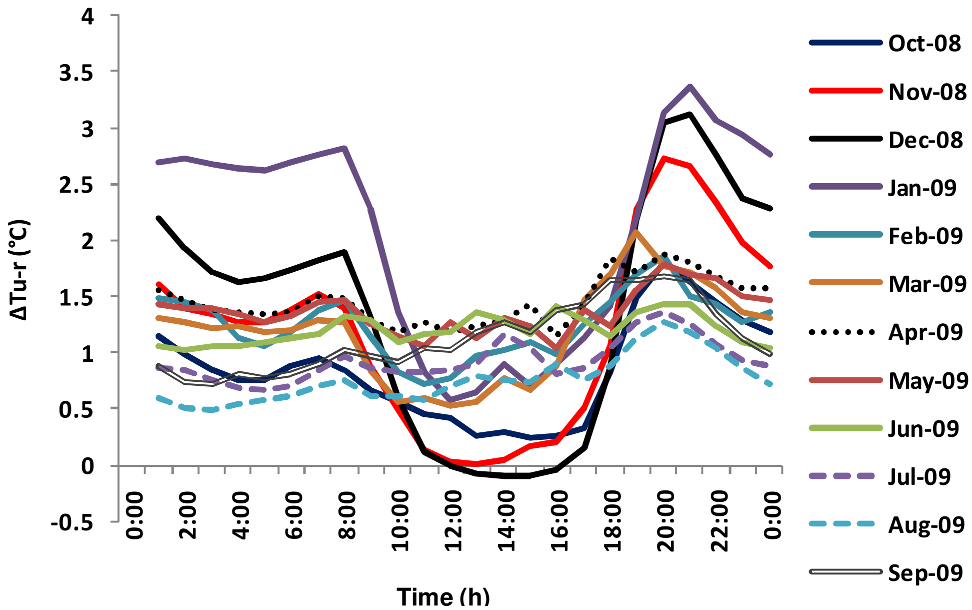


Figure 2. Diurnal variation of mean monthly urban – rural air temperature differences.

Airport. Position of the sensor at the urban site was carefully selected to prevent elevated heat sources such as rooftops. Afternoon air temperatures at 3 m above roof level are about 2°C higher than at 2 m above street level (Sakaida and Suzuki, 1994).

The difference in temperatures between the city and the out-of-town stations, Tu-Tr, is the most commonly used index of the intensity of the UHI. In this paper the quantity of this difference is accepted as a measure of the city's influence on thermal conditions. Cooling degree days are values complied daily to assess how much energy may be needed to cool buildings. In determining the CDD, average temperature value is calculated for a given day. If it is greater than the standard base, the standard base value is subtracted from calculated average temperature to yield the CDD. This is compiled for daily and totaled for entire month. The CDD is calculated using the following formula; $CDD = \Sigma\ (ti - T)$ where ti is the daily mean temperature and T is the required room air temperature (25°C). The rationale behind this technique is that whenever average temperature exceeds the comfort range, some cooling will be required, the requirement for cooling increases with increasing.

The Hemispherical images are taken using a digital camera (Nikon Coolpix 950 with a 183-degree field of view fisheye lens) and the sky view factor was calculated from the hemispherical images using a method outlined by Chapman et al. (2001).

RESULTS AND DISCUSSION

Diurnal and annual course of the UHI intensity

It is evident that the daily course of the temperature fluctuations between the urban and rural site are function of the season of the year. The most essential feature of the annual course of urban canopy heat island in the city is that the greatest differences occur in the dry season reaching 3.5°C and the smallest difference occurs during the wet season. The results regarding the urban rural air temperature differences (ΔTu-r) at both sites are presented in Figure 2. It shows that the UHI exists in Akure throughout the day except in November and December where urban cool island (UCI) is observed for few hours in the afternoon in both months. Daytime heat islands may be positive or negative depending on the particular characteristics of the urban area and their surroundings. Highest UHI values observed in the dry season agrees with Balogun et al. (2009b) that reported UCI at 1500 in October and November and higher UHI values in January and February in Akure. However, results from this study slightly differ as the higher UHI values are observed in November through January but with January recording the highest value in overall. During the wet season, the UHI formed at night is preserved and almost unchanged throughout the day while 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. Annual course of the UHI at the time of the morning observation depends more on the time of sunrise relative to the time of observation, than on any factual dynamics of the weather conditions. The figure further shows that the maximum UHI occurs at night between 1800 to 2200 h local time having its peak around 2100 h. The peak period, on the average, might be linked to the release of sensible heat from "rush hour traffic" occurring in the city as a result of closing hours and evening market transactions from about 6 to 9 pm thereabout. Thereafter, the heat island continues to develop through the early morning hours due mainly to the rural site net radiative energy loss to an unobstructed sky and less polluted atmosphere prior to sunrise. After this time, the solar

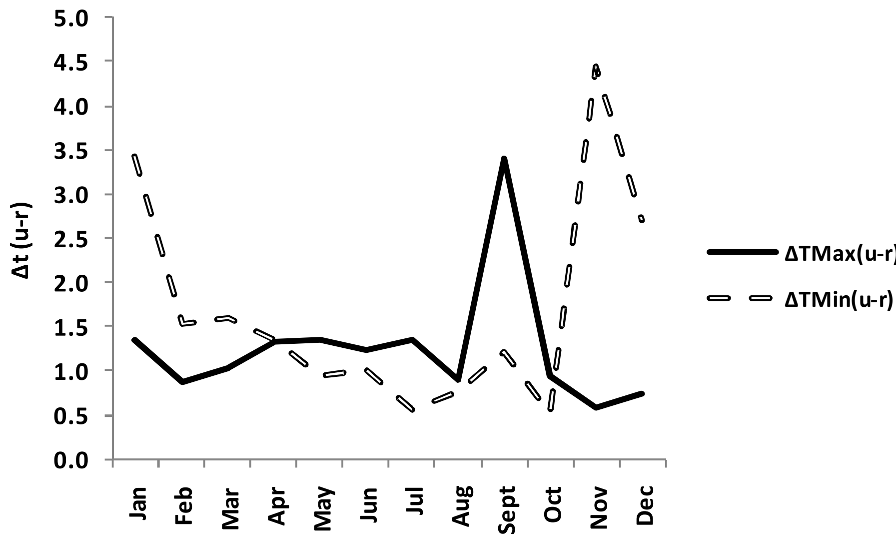


Figure 3. Seasonal variation of urban heat island using mean monthly differences between maximum and minimum temperatures during the period (October 2008 to September 2009).

heating generates a turbulent mixed layer over both the urban surfaces and its environs, so thermal contrasts decline until around the end of the afternoon. Our result is however different from earlier reports that indicate that the maximum UHI occurs during the day time. The difference observed in months of highest value of UHI and the disagreement with time of maximum UHI occurrences exists because the earlier studies were restricted to daytime periods using the convectional mercury in glass thermometer. This result therefore provides new information on the diurnal characteristics of the UHI in Akure.

Seasonal variation of the maximum and minimum UHI

The seasonal variations of the urban-rural thermal differences at two critical hours of the day are presented in Figure 3. It shows the mean monthly values of thermal contrasts at the time of maximum and minimum temperature for the study period (October 2008 to September 2009). The variations observed may be as a result of different main causes of the UHI phenomenon explained by Oke (1982). Critical properties governing thermal contrasts during the night are the radiation geometry and the surface thermal properties, thermal admittance in particular while the dominant processes responsible during the day are turbulent sensible heat flux obtained from increased absorption of shortwave radiation and anthropogenic heat sources which are mainly industrial and vehicular.

The distinct seasonal variation which is peculiar to both the nocturnal and daytime phenomena is associated with the seasonality of weather controls. It ranges from clear, calm nights in the dry season to unstable weather conditions with clouds and rain during the wet seasons (April to October). Therefore, as seen in Figure 3, the largest mean nocturnal heat islands (4.5°C) occur in the dry season when differences in urban/rural thermal admittance are more distinct, declining to a minimum (as low as 0.5°C) during the wet months of July and October when soil in the rural site is near saturation. The mean daytime heat island intensity is less intense reaching a maximum in September (3.5°C) (as a result of rural evaporative cooling from rainstorm), declining to a minimum (0.6°C) in November. The figure gives a clear indication that the urban-rural thermal contrasts, on the average always remain positive throughout the year and at all hours of the day for the 1-year period under study

In order to establish period of pronounced heat island occurrences, our target involves only days that well marked urban temperature excedance of greater than or equals to 1°C are being maintained over several hours. Data were available for 315 days only. Result obtained justifies our observation in Figure 2 that the nocturnal (1900 to 0600 h) heat island is far dominant than the daytime heat island (0700 to 1800 h) particularly intense during the dry months. It overtakes in all the months except June and September. However, it is noticed to be weaker and having a narrow margin with the daytime heat island throughout the wet season (April to September) especially during the monsoon, but prevailing from the transitional month of October through the dry season. The daytime heat islands (0700 to 1800 h) were mostly observed during the wet season and almost out of existence in the dry season.

The average and extreme values of the heat island

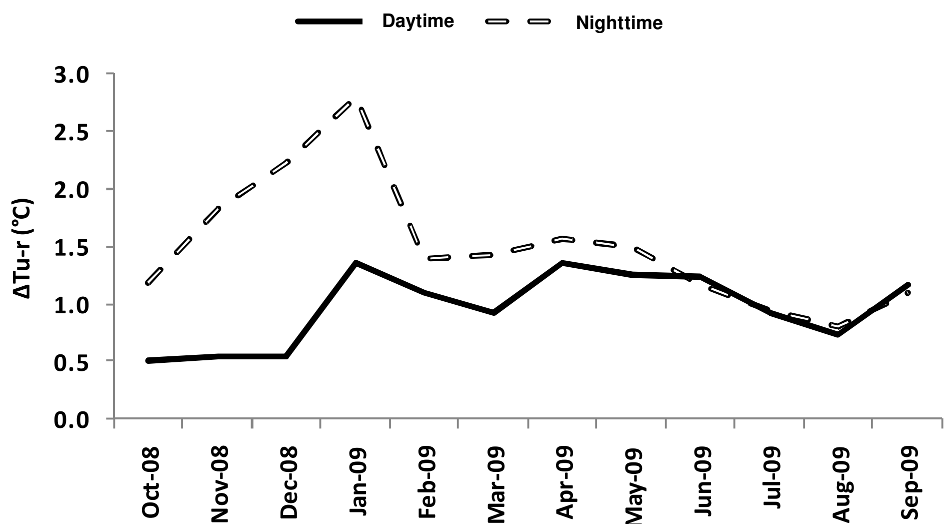


Figure 4. Average and extreme values of heat island intensity for the daytime and nocturnal hours during the period of observation (October 2008 to September 2009).

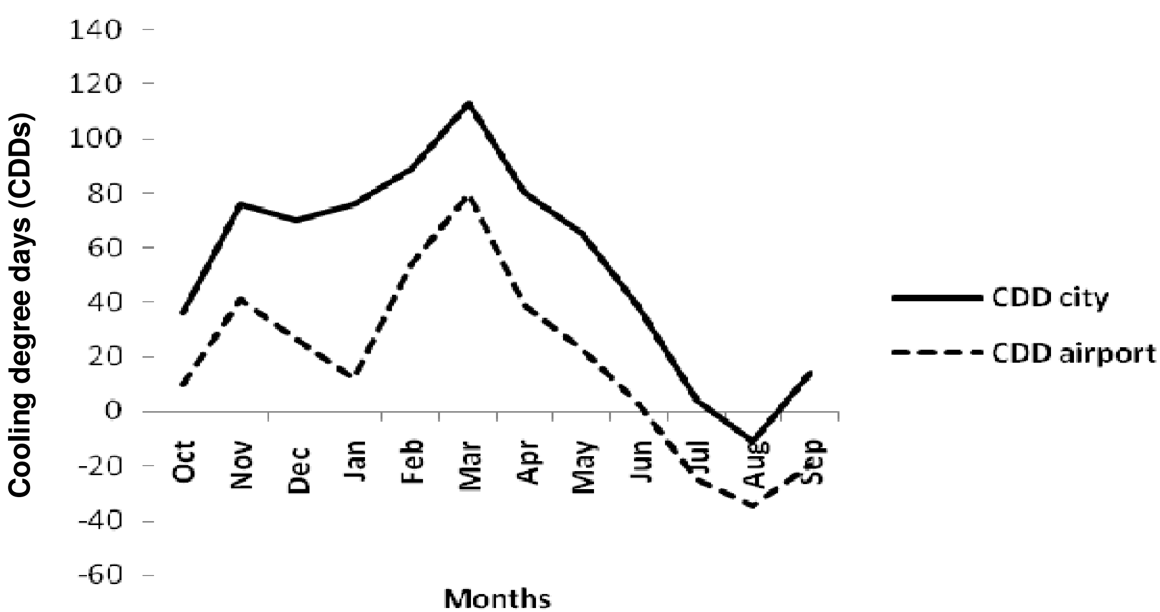


Figure 5. Seasonal variation of the cooling degree days at the urban and rural sites.

along the 1 year period of observations are illustrated in Figure 4. While the mean heat island intensity for nocturnal events is about 1.5℃, reaching as much as 2.5℃ during the dry season and lowest during wet season (1℃). The mean daytime events have somewhat lower intensities in both dry (0.8℃) and wet seasons (1±C) and less variability of extremes. It further shows that there is hardly existence of daytime heat island from October through December. The average and extreme values of both daytime and nocturnal period of the day are nearly constant throughout the wet months from June to September (period of the peak rainfall). When they occur, the daytime heat islands have about the same intensities as the night-time.

Cooling degree days at the urban and rural sites

Figure 5 shows the monthly mean numbers of the urban (CDDu) and rural cooling degree days (CDDr). The cooling degree day is clear measure for the comparison of the cooling energy consumption. The cooling season which has two epochs is characterized by significant cooling demand, the first which exists for a very short

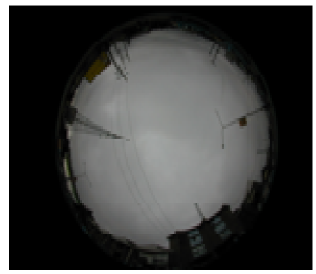
Site	Eye level photo	Sky view photo	S. V. F
1. Airport			0.98
2.Oja City			0.83

Figure 6. Study sites, its eye level picture, sky view photo and the obtained sky view factor.

period in November and the other epoch in March. These periods have peculiarities as they are both transitional months, November is the transitional month into harmattan period and March to April is transitional period into the summer monsoon. The peak cooling demand is observed to occur in March at both sites. The most significant difference appears in January (about 64°C higher in the urban than the rural site). Consequently, the effect of the city on the cooling energy demand is stronger than in other period of the cooling season. The months of July, August and September are noticed to exhibit totally different peculiarities as the three months in the both cases were absolutely typical of space heating demand rather than cooling. In this period, the summer monsoon has fully developed, resulting in reduced cooling demand due to cooling effect of monsoon winds. These are the periods discussed in the section above that both daytime and nighttime heat island intensities exhibit almost the same intensities.

Nocturnal heat island

Heat islands in the atmosphere are best expressed at night under calm and clear conditions when differential rates of radiative cooling are maximized between urban areas and their surroundings, with cities cooling more slowly than their surroundings. Mean hourly development of the heat island for days with clear skies and calm winds during the dry season was investigated and it was observed that average nighttime heat island under such atmospheric condition reaches its peak maximum value of 4.4°C at about 2100 h. This is similar to the results by Oke (1982) for mid-latitude cities where urban/rural diverging cooling rates leads to maximum heat island intensity before midnight but differs from what is observed in the tropical city of Mexico (Jauregui, 1997), where average nocturnal heat island reaches its maximum value at the end of the cooling period at about sunrise (0700 to 0800 h).

The sky view factor (SVF) obtained from the hemispherical images taken at both the urban city core and the rural reference site situated at the old seldom used airport is presented in Figure 6. Facts emanating from the SVF calculation expatiate on why the heat island is more of a nocturnal phenomenon. The SVF is used in urban climatology to characterize radiative properties. By its definition SVF varies from zero when the whole sky is obscured to one when there is no obstruction. It has been proven to be an important concept in studies on radiation and temperature in different research areas. At night time, the rural site that is free from obstructions allows for quick escape of the longwave radiation causing an enhanced radiative cooling while the city centre with reduced sky view due to its peculiar midrise buildings allows the street canyon to serve as heat storage, thereby causing a much slower radiative cooling from the urban surfaces.

Daytime heat island

Our results in Figures 2 and 7 show the existence of daytime heat island in the city of Akure. The daytime heat island is less intense during the dry season but more pronounced in the wet season (between April and

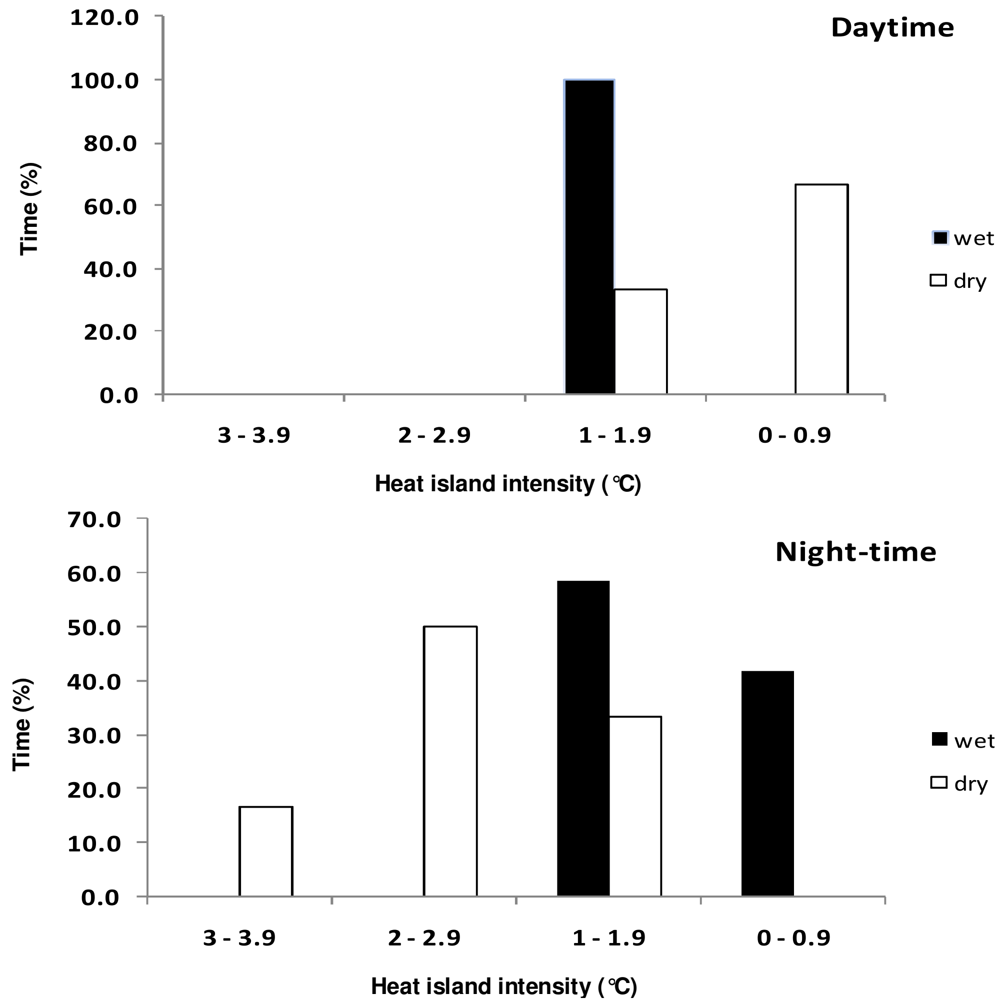


Figure 7. Frequency distribution of daytime and nighttime heat island intensity in Akure.

September) on the average of 1.5°C, and least in August (less than 1°C) during the august break usually referred to as 'little dry season'. It further revealed that the difference in air temperature between the city centre and the rural reference site in Akure in some days and particularly during November and December suggests the existence of the urban cool Island (UCI). This is similar to some earlier reports in mid latitudes and less continental cities that have been found to be cooler at certain daytime hours in summer (Chandler, 1962; Unwin, 1980). The cool island observed may be as a result of the facts explained by Oke (1982).

On the average, the mean intensities are quite small, during the dry season; it revolves around 0.8°C in the daytime and 2.4°C overnight but during the wet season, it is less intense with 1.1°C in daytime and 1.2°C in at night. The mean night-time intensity is larger than the daytime intensity in each month except for June to September (intense rainfall period) which have almost equivalent of the daytime. The daytime intensities were generally lower (0-0.9 to 1-1.9°C) than the nighttime that exists within the range (1-1.9 to 3-3.9°C) category. This is clearer in the frequency distribution shown in Figure 7, which covers the total period.

During the wet season, particularly when the summer monsoon has fully developed (June- September), the frequency of less intense heat island (1-1.9°C) is absolute during the daytime and also high at night. This suggests the observed reduced cooling demand in those periods as presented in Figure 5. The dry season is characterized with more intense heat island, ranging as much as 3- 3.9°C and this also reflects on the cooling demand as presented by the results of the cooling degree day.

Conclusion

The characteristics of urban heat island in Akure have been investigated and results reveal some interesting new findings on the diurnal and seasonal characteristics of the urban heat island in Akure. The UHI has been found to occur throughout the day and night except for a few hours after noon in November and December that existence of UCI, a reversed thermal contrast which may be as a result of relative abundance of moisture in the city compared to the rural surroundings was noticed. Weak daytime heat island exists throughout the wet season and extremely weak during the dry season accounting for reduced energy demand for cooling, but higher frequency of intense heat island at night time during the dry season is an indication of warmer nights capable of increasing the energy required for cooling. Results ascertain that the UHI is more of nocturnal phenomena in the tropical city of Akure as the highest UHI intensity occurs at night from 1800 to 2200 h having its maxima at 2100 h and also higher in the dry than the wet seasons. The elevation of temperature in the central urban areas at both day and night increases the potential for cooling of buildings. This may therefore lead to increased use of air-conditioning and hence adding more pressure to the electricity grid during peak periods of demand. This result has filled the knowledge gap on the nocturnal status of UHI in Nigeria as earlier studies were restricted to the daytime period due to lack of equipments capable of obtaining nocturnal data and has however supplemented previous attempts to fill knowledge gap of urban effects in tropical urban areas which is still insufficient as compared to the mid latitudes.

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REFERENCES

Adebayo YR (1991). Heat island in a humid tropical city and its relationship with potential evaporation. Theor. Appl. Climatol., 43(3): 17-30.

Balogun AA, Balogun IA, Adefisan AE, Abatan AA (2009a). Observed characteristics of the urban heat island during the harmattan and monsoon in Akure, Nigeria. Eight Conference on the Urban Environment. AMS 89th Annual Meeting, 11 – 15 January, 2009, Phoenix, AZ. Paper JP4.6, http://ams.confex.com/ams/pdf papers/152809.pdf.

Balogun IA, Balogun AA, Adeyewa ZD (2009b). A note on the effect of urbanization on air temperature and humidity of Akure, Nigeria. Proceedings of the seventh International Conference of Urban Climate, 29th June - 3rd July 2009, Yokohama, Japan.

Balogun AA, Balogun IA, Adeyewa ZD (2010). Comparisons of urban and rural heat stress conditions in a hot-humid tropical city. Global Health Action, 3: 5614. DOI: 10.3402/gha.v3i0. 5614.

Chandler T (1962). London's urban climate. Geogr. J., 128: 279-298.

Chapman L, Thornes JE, Bradley AV (2001). Rapid determination of canyon geometry parameters for use in surface radiation budgets. Theor. Appl. Climatol., 69(1/2): 81–89.

Imamura I (1988). Comparisons between observations at a mid-latitude city and two semiarid tropical cities. Int. Conf. Trop. Meteorol. Air Pollut., Indian Inst. Tech., Delhi, India.

Munn RE, Hirt MS, Findlay B (1969). A climatological study of the urban temperature anomaly at Toronto. J. Appl. Meteorol., 8: 411-422.

Oke TR (1982).The energetic basis of the urban heat island. Quart. J. Royal Meteorol. Soc., 108(45): 1-24.

Oke TR, Taesler, R, Olsson L (1990/1991). The tropical urban climate experiment. Energy and Buildings 15-16: 67-74.

Park HS (1987). Variations in the urban heat island intensity affected by geographical environments. Environmental Research Center Papers, Environmental Research Center, University of Tsukuba, 11: 79.

Rosenfeld AH, Akbari H, Bretz S, Fishman BL, Kurn DM, Sailor D, Taha H (1995). Mitigation of urban heat islands-materials, utility programs, updates. Energy Buildings, 22: 255-265.

Sailor DJ (2001). Relating residential and commercial sector electricity loads to climate-evaluating state level sensitivities and vulnerabilities. Energy, 26(10): 645–657.

Sakaida K, Susuki M (1994). Microclimate of an urban canyon with thick street trees. Geographical Review of Japan, 67 Series, A8: 506-517.

Samuels R (2004). Urban Heat Islands. Australian House of Representative Standing Committee on Environment and Heritage Sustainable Cities 2025 Enquiry.

Stewart I, Oke TR (2009). Classifying urban climate field sites by “Local climate zones” The case of Nagano, Japan. Proceedings of the seventh International Conference of Urban Climate, 29th June - 3rd July 2009, Yokohama, Japan.

Svensson D, Tarvainen L (2004). The Past and Present Urban Heat Island of Beijing, B416 Projektarbete Goteborg, Earth Sciences. Goteborg University, Sweden.

Tumanov S, Stan-Sion A, Soci C, Lupu A, Oprea C (1995). Local and mesoscale influences of the metropolitan areas on some meteorological parameters and phenomena to the city of Bucharest. Romanian J. Meteorol., 2: 1-18.

Unwin DJ (1980). The synoptic climatology of Birmingharn's urban heat island 1965-1974. Weather, 35(2): 43-50.

Voogt JA (2002). Urban heat island. In: Munn, T. (Ed.), Encyclopedia of Global Change. Wiley, New York, pp. 660–666.

Yamashita S (1988). Some studies of heat island in Japan with special emphasis on the climatological aspects. Geogr. Rev. Japan Series, B61: 1-13.