AN ASSESSMENT OF THE EFFECTS OF URBAN GEOMETRY ON SPATIO-TEMPORAL VARIATION OF AIR TEMPERATURE IN KADUNA METROPOLIS, KADUNA STATE, NIGERIA

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ABSTRACT

This study investigates the effect of urban geometry on intra-urban air temperature variation in Kaduna metropolis. This is done by classifying the urban environment according to local climate zone (LCZ) system of classification. Urban geometry was determined as sky view factor (SVF), computed from digital sky view photographs taken with fish-eye lens, using BMSky View program. Temperature data were collected using temperature dataloggers (thermochron ibuttons). Results show that SVF has a range of 0.514 in the study area, higher intra-urban temperature range (4.37°C) at night, medium range (2.71°C) in the afternoon and low range (1.84°C) in the morning. Linear regression of temperature on SVF on hourly basis yielded coefficients of regression (r) and determination (r^2) values which are high during evening and first-half of the night hours and low during late night to noon hours. Higher student's t test values also indicated more significant relationship between the two parameters from late evening to mid-night and less significant relationship from late night to early evening. This indicates that urban geometry exerts more influence on urban air temperature at late evening and night times. It is recommended that in planning cities here in the tropics, storey buildings should not be closely located to avoid reducing SVF, there should be open spaces between buildings to allow for urban ventilation and green areas should be provided for their cooling effects.

Key words**:** Canyon Geometry Effect, Sky View Factor, Spatio-temporal, Urban Geometry

INTRODUCTION

The earth surface absorbs and store heat energy in form of solar radiation. At night, this energy is released back to the sky in form of long wave radiation. Thus, the sky has an important role in the earth's temperature gain and loss, and its general energy balance (Souza *et al*., 2003). Urban areas have rougher surfaces (made up of buildings and other physical structures) than their rural surroundings. Buildings are made up of materials with higher heat capacities. They also reduce wind flow and sky view, as a result, more heat accumulates due to reduced ventilation to transport warmer air away, which is known as urban canyon geometry effect (Oke, 1988a). Urban geometry refers to the dimensions and spacing of buildings within a city (EPA, 2012). Its effect is more prominent at night when due to reduced open sky, less heat escapes through convection to comparatively cooler sky. Thus, it is clear that it influences the radiation exchange between the earth surface and the sky. Urban canyon geometry can be determined as either a ratio of height of buildings to width of streets or in terms of sky view factor (SVF). SVF refers to the proportion of sky visible in 180° field of view, expressed in decimal fraction (Smith and Levermore, 2008). It ranges from 0 to 1 representing completely open and totally obstructed sky (Johnson and Watson,1984), which controls urban cooling by limiting net long wave radiation loss at street level (Oke, 1981). And it has been described as a surrogate for building density (Smith and Levermore, 2008).

Air temperature variation in urban areas have been studied in relation to many urban parameters such as; built-up ratio and distance from city centre (Bottyan *et al*., 2005), land use land cover (LULC) types (Adebayo and Zemba, 2002; Garcia-Cueto *et al*., 2007; Mohan *et al*., 2009) population size (Jauregui, 1986), city size (Oke, 1973; Sakakibara and Matsui, 2005) and anthropogenic heat release (Oke, 1988b; Taha, 1997). However, some studies suggest that city size has little influence on urban air temperature variations (Seaman *et al*., 1989; Atkinson, 2003), while Oke *et al* (1991) reveals that other factors than city size including urban geometry and vegetation were more important, and that anthropogenic heat release is more important in cold climates.

The effect of urban geometry on air temperature has been studied in some Nigerian cities, for instance; Kano (Abdulhamed *et al*., 2012), Onitsha (Nduka, 2011) and Akure (Balogun *et al*., 2012). Yet, realities of global warming, rapid urbanization and the fact that such studies in tropical cities are scanty (Roth, 2007) coupled with the need for thorough understanding of the effect of urbanization on the climate of Nigerian cities in their different climatic and physical settings (Adelekan, 2005), call for its investigation in Kaduna metropolis.

This study therefore assesses the effect of urban geometry on spatio-temporal variation of air temperature in Kaduna metropolis through determining the; (i) local climate zones (LCZ) in the study area, (ii) SVF among the LCZ classes, and (iii) Variation of temperature among the LCZ classes

STUDY AREA

Kaduna metropolis is located between latitude 10^o21^IN to 10^o37^IN and Longitude 7^o22^IE to 7^o31^IE (see figure 1), in the high plains of the north central highlands of Nigeria. It covers more than 196 square kilometers (Akpu and Tanko, 2012) and is about 912 kilometres north of Gulf of Guinea and about 390 kilometres south of the Nigeria's northern border, with a population of about 1 million people. It has a tropical continental climate (Aw) with distinct wet (April to October) and dry (November to March) seasons. These seasons reflect the oscillation of Intertropical Convergence Zone (ITCZ) or Intertropical Discontinuity (ITD) over the region. ITCZ or ITD is the point where the tropical maritime air mass (mT), which originates over the Atlantic Ocean, meets the tropical continental air mass (cT), which originates over the Sahara Desert. Northward incursion of ITCZ brings in rainy season, while its southward retreat brings in the dry season. The city has mean monthly minimum and maximum temperatures of 15.9^{o}C and 35.35^{o}C, and an average annual rainfall of about 1530mm.

MATERIALS AND METHODS

The land use land cover of the study area was classified according to Stewart's (2009) Local Climate Zones (LCZ) classification (see figure 2). This classification is based on sites metadata such as SVF photos, built fraction, Google Earth satellite imageries, traffic density and street level photos. From these, eleven zones were identified; B1, B2, B3, B4, B5, B6, B7, B8, B9, B10 and N5 (see table 1). The first ten represent the built series, while one (N5) represents the natural series (low plant cover). A temperature recording site is chosen within each zone, from which round the clock temperature data was recorded for the month of March, 2011 (hot dry season), using temperature data loggers (thermochron ibuttons) at 2m height above ground level.

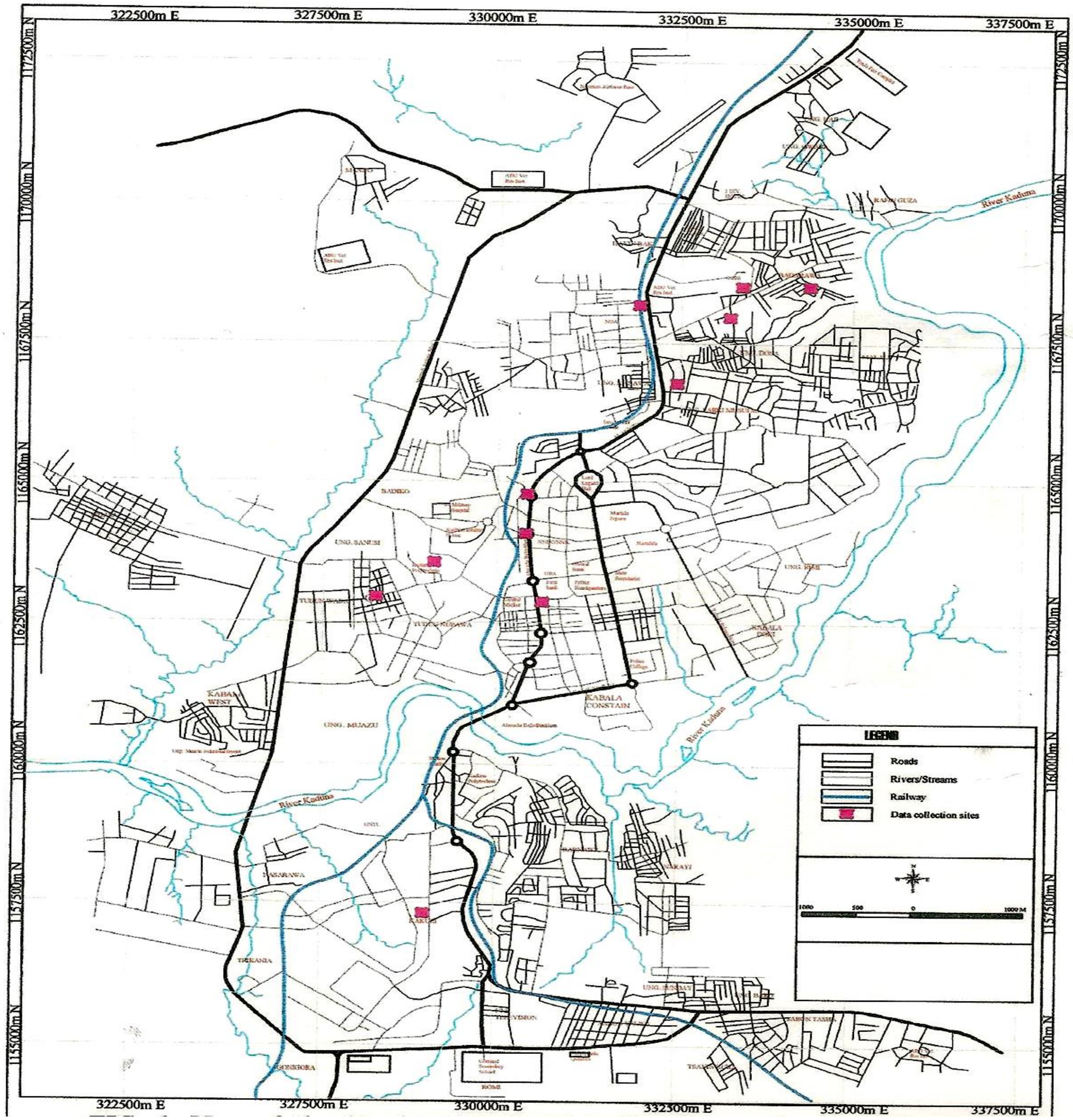

Figure 1: The study area showing data collection sites

SVF values were computed from digital fish-eye lens photos of the study sites using BMSky View programme. This software works in windows environment and computes SVF values directly from digital photos of sky taken with fish-eye lens (Rzepa, 2009). Comparison between day and night conditions forms the main focus of this study. The choice of day and night periods is based on information from literature. Analysis of variance was used in order to test if there is significant difference in near surface temperature among the LCZ classes.

Regression statistics (SPSS 20 package) was used to test (at 0.01%) significant levels the correlation (r) and coefficient of determination (r^2) of the effect of urban geometry (determined as SVF) on the near surface temperature pattern in the study area during the day and night times.

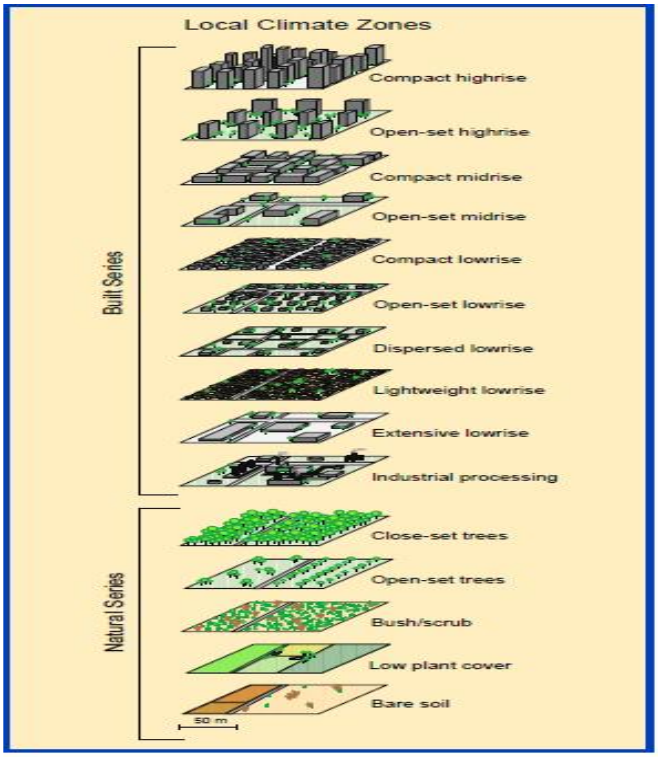

Figure 2: Stewart's (2009) Local Climate Zone classification

RESULTS AND DISCUSSION

LCZ Classification and temperature recording site selection

Table 1 presents the local climate zones identified in the study area, their locations and the site numbers assigned to each temperature recording site (one per LCZ).

Table 1: LCZ classification and selected temperature recording sites

LCZ	Code	Location	Site number
Compact highrise	B1	NEPA Round about area	Site 1
Open-set highrise	B2	Lagos round about area	Site 2
Compact midrise	B3	Leventist area	Site 3
Open-set midrise	B4	Kaduna polytechnic (Main campus)	Site 4
Compact lowrise	B5	Tudun Wada	Site 5
Open-set lowrise	B6	Kaduna Polytechnic (Staff Quarters)	Site 6
Dispersed lowrise	B7	Lgislative Quarters (Unguwan Dosa)	Site 7
Lightweight lowrise	B8	Rafin Guza	Site 8
Extensive lowrise	B9	State House area (Kawo)	Site 9
Industrial processing	B10	Nigerian Breweries (Kakuri Ind. Area)	Site 10
Low plant cover	N5	Part of Sardauna Memorial College	Site 11

SVF Analysis

Result of canyon geometry analysis is presented in figure 3. From this figure, site 11 has the highest SVF value of 0.997. It means that over 99% of sky is visible (i.e. less than 1% obstructed by buildings or vegetation). This is followed by sites 6 and 8, with values of 0.921 and 0.913 indicating lower building densities. Site 1 has the lowest SVF value of 0.483, which implies that only a little over 48% of sky is visible (i.e. about 52% is obstructed by physical structures) at this site. Next in lower SVF values are sites 3 and 2, with values of 0.613 and 0.651. The study area has a range in SVF of 0.514, which clearly indicates that there is a remarkable variation in SVF (building density/canyon geometry) in the metropolis. The mean SVF value is 0.775, meaning that in general, about 77.5% of sky is visible in the study area. This result is lower than that of Abdulhamed (2011) for Kano (0.839) while so close to that of Nduka (2011) for Onitsha (0.778).

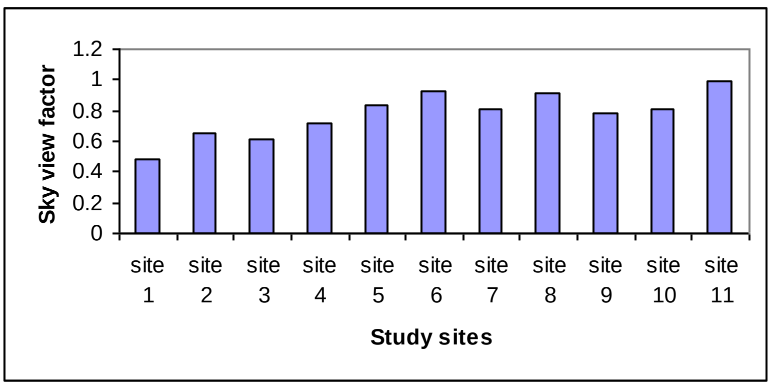

Figure 3: SVF values of the study sites

Diurnal and Nocturnal Temperature Variations

Three periods (mid-morning, afternoon and night) were chosen in order to investigate day and night changes in temperature pattern in the metropolis. The choice of these periods is based on information from previous studies (e.g. Svensson and Eliasson, 2002; Chow and Roth, 2006; Balogun *et al*., 2009).

Mid-morning temperature variation

The time chosen to represent this period is 09:00. This is a time when the sun is well up in the sky and the warming process of surfaces has started. This is in order to investigate the relative responses of different LCZs to the progressive warming effect of the rising sun. The rationale behind the choice of 09:00 is that urban areas in the tropics tend to have slower rates of cooling and warming than do the surrounding rural areas, which causes both the day-time and nocturnal heat islands to develop later than in the mid-latitudes (in the mid- latitudes heat islands start to develop around sunrise) (Jauregui, 1997).

The result is presented in figure 4, and from this figure the highest temperature (32.27^{o}C) was recorded at site 1 and the lowest (30^{o}C) was recorded at station 11, the range was 1.84^{o}C. This narrow range could be attributed to the fact that this is a time when the thermal inertia of the respective sites has barely been overcome. In other words, it is a time characterised by active absorption of heat by both the artificial and natural surfaces. Thus, it is too early for reasonable heating of overlaying air to have taken place. This is so because increase in near surface air temperature is not caused directly by incoming solar radiation, rather by the heat emitted by surfaces in form of long wave radiation. This result is lower than that of Nduka (2011) for Onitsha (4.77^{o}C).

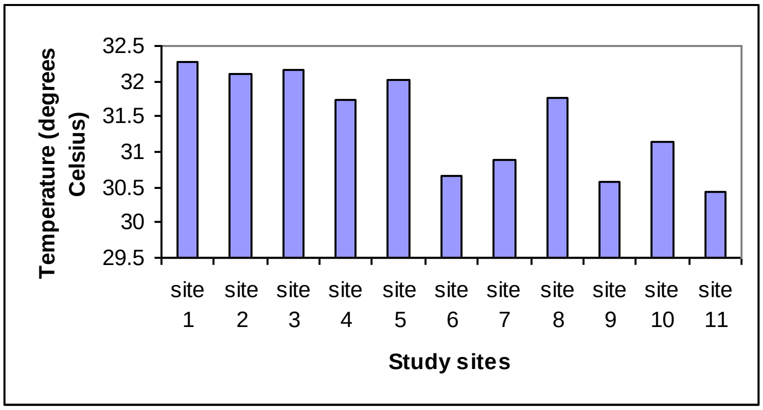

Figure 4: Temperature distributions among the LCZ at 09:00 hours

Afternoon temperature variation

This period is represented by 14:00 hours (2 hours after mid-day). This is in order to investigate the combined effects of mid-day sun and anthropogenic heat release on near surface air temperature in the study area. It is a period when the highest possible amount of solar radiation has been absorbed by surfaces. And a great deal of heating of near surface air has been achieved through the processes of radiation, conduction and convection, so also the heat released by automobiles and industrial processing plants.

The result is presented in figure 5, and from this figure, site 3 has the highest value of 41.53^{o}C and site 11 has the lowest value of 38.28^{o}C. The temperature range is 2.71^{o}C, which is lower than those of Mohan *et al* (2009) for Delhi (3.8^{o}C), Wong and Chen (2009) for Singapore city (4.01^{o}C), Abdulhamed (2011) for Kano (10.35^{o}C) and Nduka (2011) for Onitsha (4.33^{o}C). Site 6 has a value of 38.91^{o}C, which is just about the same as that of the low plant cover zone (38.82^{o}C). Possible explanation could be due to abundance of vegetation. Because research has shown that an average tree during a sunny day can evaporate 1460kg of water and consume about 860 MJ of energy (Moffat and Schiler, 1981) meaning that the amount of energy converted to latent heat through plants is enormous. Thus, the energy being stored and later released as sensible heat where there is no vegetation, on the other hand is being converted into latent heat where there is vegetation. *Night-time temperature variation*

The time chosen was 20:00 hours (i.e. 2 hours after sunset). This is in order to assess the effect of differential environmental lapse rates (cooling rates) of the various sites. The result is presented in figure 5. From figure 5, the highest temperature (32.91^{o}C) was recorded at station 3 and lowest (28.54^{o}C) at site 11. The range for this period is 4.37^{o}C. This comparatively wider range could be accounted for by low wind speed and differential environmental lapse rates among the LCZs which are controlled to the largest extent by SVF.

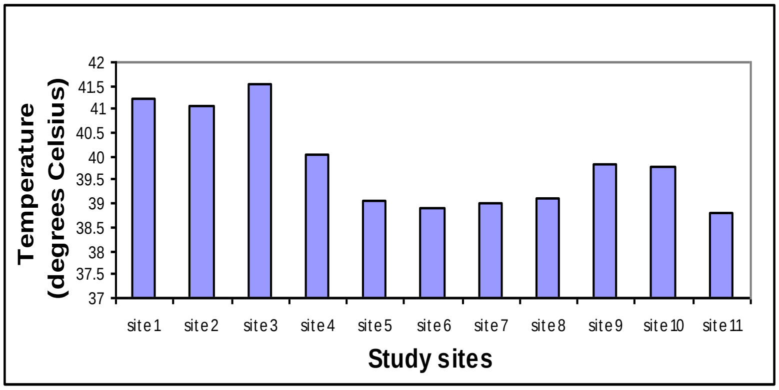

Figure 5: Temperature distributions among the LCZ at 14:00 hours

This is because this period is characterised by emission of sensible heat by surfaces in form of long wave radiation and SVF is an important factor that determines what proportion escapes to the relatively cooler sky and what is trapped within the canyon. Oke (1982) revealed that open, natural land surfaces have a relatively rapid cooling rate at sunset (typically 2^o to $3^o Chr^{-1}$). This result (intra-urban temperature range) is lower than those of Abdulhamed (2011) for Kano (7.84^oC) and higher than that of Nduka (2011) for Onitsha (1.63^oC).

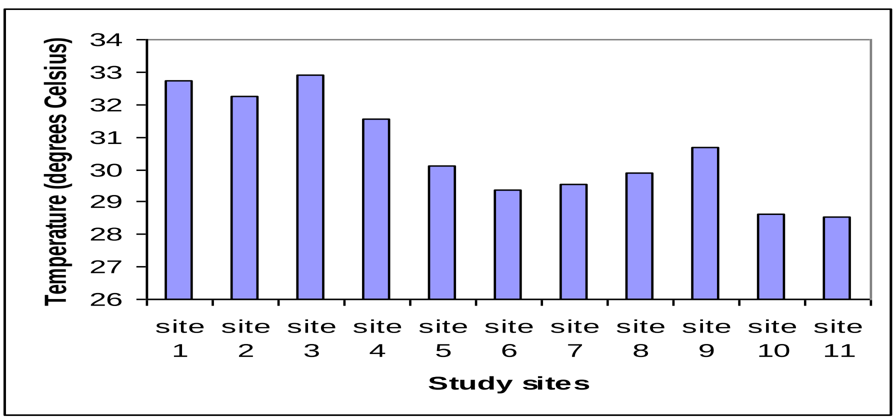

Figure 6: Temperature distributions at 20 hours

Effect of SVF on Temperature Variation

Linear regression of temperature values for all the sites at every hour on SVF values of the sites was performed. This is in order to determine the effect of SVF at 1m height on air temperature pattern in the study area. And also to detect whether there is a changing pattern in this effect between day and night conditions. The result is presented in table 1. From this table, the highest coefficients of regression (r^2) were found in the late evening, at night and in the morning, while the lowest were found from morning to middle of the day. This means that there is least thermal differentiation among the study sites from morning to noon. Possible explanation could be due to lower air stability at this period. The r and r^2 values show the goodness of fit statistics, indicating that the model for each hour is a good fit except for 08:00, 09:00 and 11:00 hours ($r<0.30$ indicates weak correlation). F ratio values also reveal values significant at 01% except for the earlier mentioned three hours. All the t values are significant at 01%, meaning that there is significant relationship between UHI and SVF in the study area.

The best linear fit for the period occurs at 20:00 hours (r^2=0.897) which is slightly higher than the findings of Eliasson and Svensson (2003) (r^2=0.70). This clearly buttresses the fact revealed by previous studies that SVF exerts more influence on surface air at night (e.g. Montavez et al., 2000 in Granada Spain; Tereschenko and Filonov, 2001 in Guadaljara, Mexico).

Table 2: Result of Linear Regression Analysis of temperature on SVF

Hour	R	r^2	T	Sig	F	Sig
00:00	0.933	0.870	10.292	0.000*	53.407	0.000*
01:00	0.855	0.730	6.255	0.000*	21.658	0.002*
02:00	0.781	0.610	4.989	0.001*	12.503	0.008*
03:00	0.839	0.705	5.776	0.000*	19.088	0.002*
04:00	0.881	0.776	6.655	0.000*	27.763	0.001*
05:00	0.867	0.752	6.262	0.000*	24.229	0.001*
06:00	0.839	0.705	5.784	0.000*	19.079	0.002*
07:00	0.840	0.706	8.283	0.000*	19.191	0.002*
08:00	0.608	0.370	3.631	0.007*	4.695	0.062**
09:00	0.622	0.387	3.421	0.009*	5.043	0.055**
10:00	0.732	0.536	4.370	0.020*	9.248	0.016*
11:00	0.614	0.377	3.124	0.014*	4.850	0.059**
12:00	0.713	0.508	3.805	0.005*	8.273	0.021*
13:00	0.820	0.672	4.767	0.001*	16.365	0.004*
14:00	0.830	0.688	5.292	0.001*	17.671	0.003*
15:00	0.812	0.660	5.805	0.000*	15.573	0.004*
16:00	0.836	0.699	5.719	0.000*	18.586	0.003*
17:00	0.936	0.875	10.159	0.000*	56.244	0.000*
18:00	0.827	0.684	6.128	0.000*	17.333	0.003*
19:00	0.897	0.805	7.920	0.000*	33.024	0.000*
20:00	0.947	0.897	10.795	0.000*	69.399	0.000*
21:00	0.946	0.895	11.633	0.000*	68.076	0.000*
22:00	0.943	0.889	11.155	0.000*	63.771	0.000*
23:00	0.946	0.894	11.154	0.000*	67.805	0.000*

*Significant at 01% **Insignificant at 05%

CONCLUSION

This study has shown that urban geometry (determined as sky view factor), which is a surrogate of building density, has a considerable influence on the air temperature pattern within Kaduna metropolis, especially during hot dry season. Results showed that the air temperature varies with difference in urban geometry; temperature range of up to 4.37^{0}C (figure) has been recorded. In addition, the results when considered within the context of local climate zones classification can be compared or replicated in other tropical cities. The study indirectly also tested the ability of the temperature stations to represent urban climate field sites.

These results are of relevance to urban planning. It is recommended that urban planning and design of cities here in the tropics should always take cognizance of the background climate and microclimatic modification of built environments. In order to control reduction of SVF, there should be regulations regarding spaces between buildings (especially storey buildings) and widths of streets. Large and contiguous densely built-up areas should be avoided as this reduces urban ventilation. In addition, urban green areas which include parks, boulevards, trees in courtyards and around buildings should be encouraged, because trees have a cooling effect on their environment through evapotranspiration.

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