DIURNAL VARIATION OF URBAN CANOPY HEAT ISLAND IN THE DRY SEASON IN BENIN CITY, EDO STATE, NIGERIA

BY

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ABSTRACT
This study assessed the diurnal variation of Urban Canopy Heat Island (UCHI) in the dry season in Benin City, Edo State, Nigeria. LCZ system of classification was used to classify Benin City into climate field sites. DS1921G – F5 thermocron iButton data loggers were used for collecting the temperature data from the stations. The result of the analysis showed that the highest temperature in the dry season was 29.70°C, while the lowest was 27.72°C. FS has the highest UCHI with 3.03°C followed by TM with 3.01°C and PS and BR with 2.98°C each. Maximum diurnal UCHI values were recorded at WR (6.34°C), TM (6.21°C) and BR (6.08°C) at 15:00 hours local time while the minimum diurnal UCHI were recorded at PS (0.03°C) and WI (0.18°C) at 12:00 hours and 05:00 hours respectively. The high development of UCHI and variation in diurnal characteristics were closely attributed to the nature of the impervious surfaces and anthropogenic activities that reduces the amount of ambient heat through evaporative cooling**.** The study therefore recommended the use of climate-sensitive planning and design schemes, adoption of planning methods of green city, and green roof approaches.
Key words: Diurnal variation, Heat island, Temperature, Urban canopy

INTRODUCTION

The climate in cities and other built-up areas is altered most by the modifications humans make to the surface of the earth during urbanization. City surfaces are typically rougher and often drier as naturally vegetated surfaces are replaced by buildings and paved streets. Buildings along streets form urban street canyons that cause the urban surface to take on a distinctly three-dimensional character. These changes affect the absorption of solar radiation, evaporation rates, storage of heat, the turbulence and wind pattern of cities and the surface temperature (Voogt, 2004).

Montavez, Gonzalez-Rouco and Valero (2008) defined Urban Heat Island (UHI) as the temperature differences between the urban area and its rural surroundings, always assuming that the records should be similar if there were no urbanizations. Usually these differences show that cities are warmer than the surrounding rural areas. In most developed countries where the divide between compact urban areas and sparsely populated peripheries is comparatively clear and abrupt, the temperature difference between the air in the urban area and air in the rural reference area outside the settlement is significant and comprises intensities greater than 4°C (Stewart & Oke, 2012).

UHI is categorized into three main types based on scale and method of measurement. First, surface urban heat island (SUHI), which refers to the higher temperature of urban surfaces. This is determined by measuring the thermal infrared radiation emitted and reflected by the surfaces. It is normally done using satellite remote sensing and Geographic Information System (GIS) techniques. Second, urban canopy heat island (UCHI), which refers to higher temperatures obtained within the urban canopy layer. The urban canopy layer is the layer of air between the ground and treetops or roofs of buildings, where most human activities take place. Third, urban boundary layer heat island (UBLHI), which refers to higher air temperatures within the urban boundary layer. This layer is located above the urban canopy layer and its characteristics are affected by the presence of the urban canopy layer (Voogt, 2004). UCHI is the type of UHI that this study is designed to investigate.

Several studies have been carried out in Nigeria to investigate the relative warmth of cities by measuring air temperature (also known as ambient temperature). Nduka (2011) used thermochron i-Button data-loggers to assess the urban canopy heat island variation and land use/land cover in Onitsha metropolis in the hot and dry season. The study was able to establish a significant variation in both the spatial and temporal distribution of UCHI in the metropolis. Abdulhamed (2011) measured temperature data in Kano using thermochron iButton data loggersa and determined the UCHI from the data collected. The different sample stations were determined using the canyon zoning system known as the Urban Climate Zone (UCZ). The UCHI Characteristics shows a generally warm profile during the day time and night periods, suggesting that most of the stations had high temperatures. More recently, Usman (2016) investigated the effect of surface cover composition on spatial and temporal variations of UCHI in Kaduna metropolis, Nigeria. Results of this study using one-way ANOVA revealed significant spatial and temporal variations of UCHI in March and August and only significant spatial variation in January. Also, the percentage of surface elements influenced the spatial variation of UCHI.

Benin City and its surrounding areas have experienced changes in their morphology over the years. In Benin City, there are some areas where the buildings are tall, for example Akpakpava, G.R.A, Airport Road, Mission Road and Sapele road. The City has also experienced dramatic changes in building patterns, moving from single-storey buildings to multiple-storey buildings, zinc to aluminum roofing sheets and louvers to sliding windows that trap solar radiation during the day and emit heat in the night. These have markedly altered the surface properties of the area and hence modified the energy and water balance of the area, which result in increased temperature of the urban canopy of the City. Commercial activities in Benin City also add human metabolic heat into the atmosphere, these include the various markets where there is a high concentration of people. These have markedly altered the surface properties of the area and hence have modified the energy and water balance of the area, and resulted in increased temperature of the urban canopy of Benin City (Omogbai, 1985; Efe, 2006).

The continuous growth of population and urbanization in Benin City has left in its wake emerging development of infrastructures and housing patterns which have given the urban fabric of the city a new look. These infrastructures and housing patterns have led to the development of Local Climate Zones (LCZs) in conformity with the delineations outlined in Stewart and Oke (2012) which have an impact on the socio-economic and thermal comfort of the inhabitants. These impacts can no longer be neglected. Therefore, this study examines the temporal variation of urban canopy heat island in Benin City in the dry season using the following objectives; identifying the local climate zones (LCZs) in the study area, determining the nature and spatial variations of the

UCHI in the wet season and assessing the diurnal variation of UCHI in the dry season in the study area

THE STUDY AREA

Benin City serves as the principal administrative and socio-economic centre for both Oredo Local Government Area and Edo State in Nigeria. The City is a humid tropical urban settlement that comprises three Local Government Areas namely Egor, Ikpoba Okha and Oredo. It is located within Latitudes 6°18´55″N to 6°58´39″N and Longitudes 5°35´18″E to 5°. It broadly occupies an area of approximately 112.552km^2. This extensive coverage suggests spatial variability of weather and climatic elements (Figure 1).

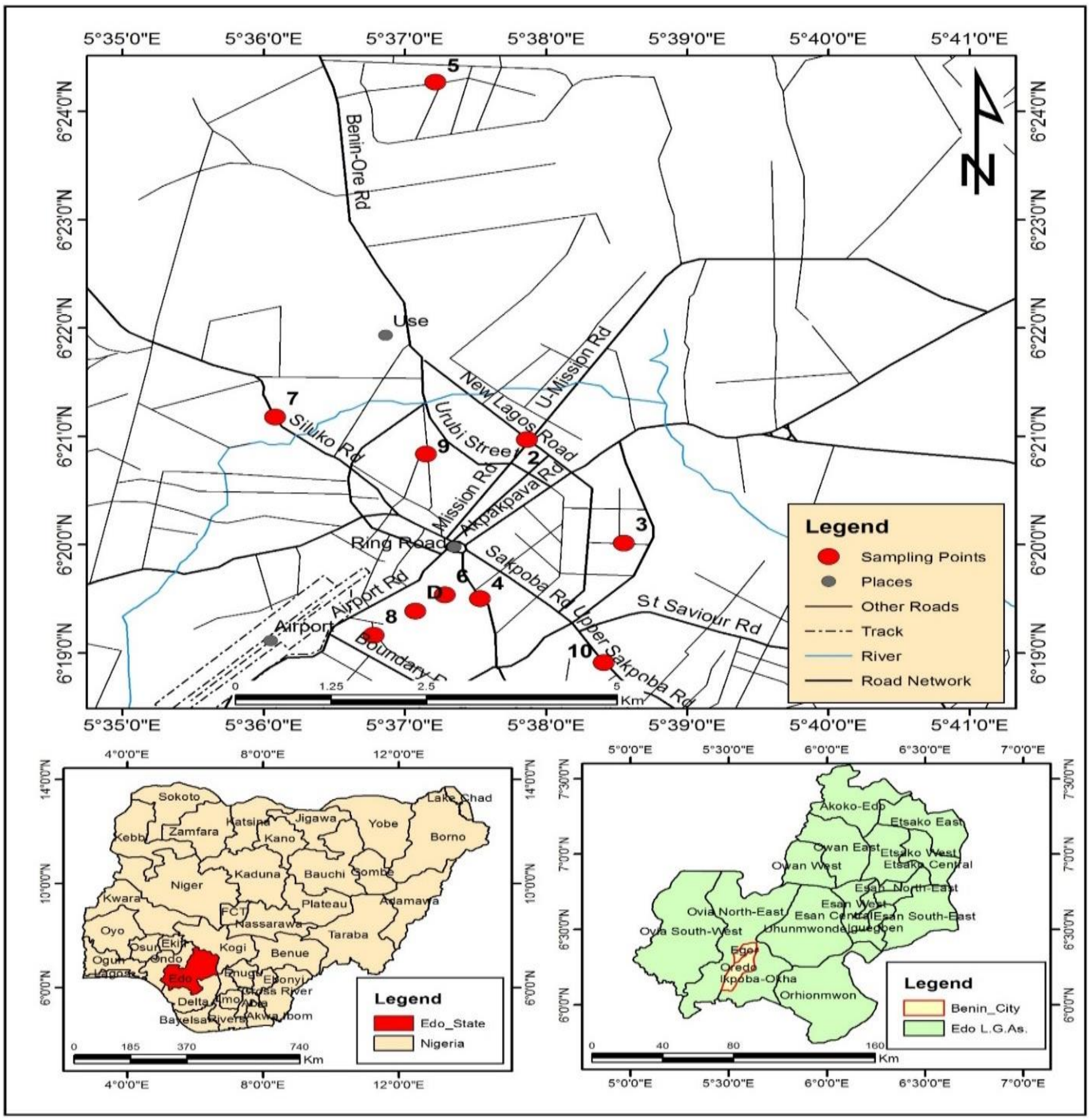


Figure 1: The Study Area showing Selected Sites
Source: Adapted and modified from Benin City Map 2011

The study area has a tropical climate characterized by two distinct seasons, the wet and dry seasons. The wet season covers the months of March to October with an annual rainfall amount usually up to 2000 mm and a mean temperature of approximately 27°C (Odekunle, 2004). The month of March is the warmest in the study area due to increasing cloudiness during the transition from the dry season to the wet season, while July is one of the months of peak rainfall since rainfall is bimodal with September being the second month of peak rainfall (Atedhor & John-Abebe, 2017). As observed during the assessment of the urban troposphere using sensitive rain gauges of American origin, the rainfall amount, its intensity, duration as well as its distribution throughout the city are determined by the prevailing maritime winds, changing clouds, temperatures, and circulating pressures (Atedhor & John-Abebe, 2017).

Benin City has a total population of 1,086,882 based on the 2006 census. The City has a radial network of roads which converge in the city centre. Economic activities are dominantly commercial and are largely concentrated in the city centre. These commercial activities generate huge waste that sometimes constitutes a nuisance due to poor refuse evacuation. The high vehicular traffic coupled with pockets of industrial activities remain sources of effluents.

MATERIALS AND METHODS

For LCZs classification, metadata was used in preparing datasheets for all the probable zones. Each datasheet was then compared with the general properties of the site it represents in the LCZ classification datasheets of Stewart and Oke (2012). Then the best match or best fit for each site was identified (a site whose metadata are fairly aligned with those in the data sheets containing the general properties) and selected. In addition to the identification of the LCZ, a temperature recording site was also located in each LCZ.

The other forms of data used for this study include geo-coordinates, elevation, satellite imageries, and the eye-level photograph of sites and temperature data (Stewart & Oke, 2012). Both the geo-coordinate and elevation data were recorded using a hand-held Garmin GPS receiver. Other data collected that were relevant to this research include the nature of traffic flow and the predominant function of the area (residential, commercial, industrial, educational, etc.). Traffic flow was graded as heavy, medium or light (Table 1).

Table 1: Selected Sites, their Corresponding LCZ Designations and Code for Temperature Recording Station in each LCZ

Site	Name	LCZ	Designation	Station code	Traffic
1	New Benin	LCZ 2	Compact midrise	NB	Heavy
2	Textile Mill Road	LCZ 3	Compact low-rise	TM	Moderate
3	Permanent Secretariat	LCZ 4	Open high-rise	PS	Moderate
4	Faculty of Social Science	LCZ 5	Open midrise	FS	Low
5	G.R.A Benin	LCZ 6	Open low-rise	GR	Low
6	NIFOR	LCZ D	Low plants	NI	Low
7	Welu, Igor Axis	LCZ 7	Lightweight low-rise	WI	Low
8	Kada Plaza	LCZ 8	Large low-rise	KP	Heavy
9	Wire Road	LCZ 9	Sparsely built	WR	Low
10	Nigerian Brewery	LCZ 10	Heavy industry	BR	Moderate

Source: Field Work, 2019

DS1921G – F5 thermocron iButton data loggers were used for collecting the temperature data simultaneously from the ten (10) stations that were set up within the study area. The sites for temperature measurement were selected according to Stewart and Oke (2012) local climate zones (LCZ) system of classification. Only nine of the sites outlined in Stewart and Oke (2012) were identified in the study area as built up while NIFOR served as the control site. The thermochron iButton is a 17.25mm diameter by 6mm thick instrument. The data loggers were programmed to record air temperature at 30 minutes intervals throughout the study period. According to Balogun, Ahmed, and Zachariah (2011), the calibration of the iButtons will make it effective for the area under study. This study covers the period of 1st to 31st January 2019 (Dry Season).

Data Analysis

Quantitative and qualitative statistical methods were employed to analyze the information collected from the field. Firstly, the average temperature value for every hour of the study period was calculated from the recorded temperature data of each site. It is from this hourly temperature data that UCHI was computed. In this study UCHI was determined as follows:

$$UCHI = T_{LCZn - LCZD}$$

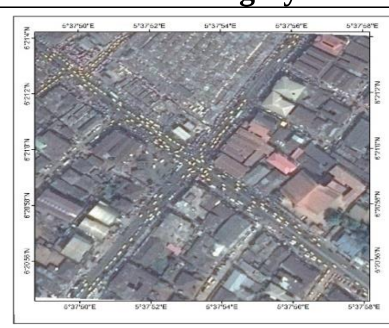
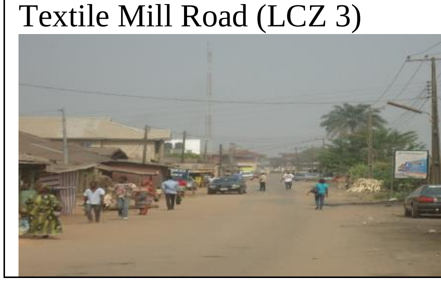
Where:
T = temperature of a sample station, LCZ = local climate zone, n = built type zone from 1 to 10, D = land cover type zone (low plants)
Secondly, the mean UCHI for each LCZ type was calculated.

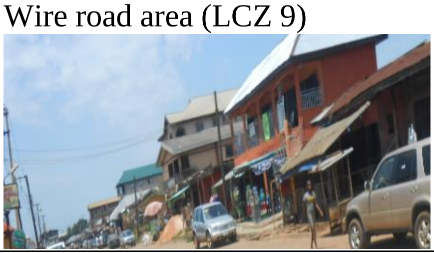
RESULTS AND DISCUSSION

Characteristics of LCZs

The characteristics of each LCZ was defined based on Stewart and Oke (2012) and the best fit urban fabric was selected to match each LCZ (Table 2)

Table 2: Characterization of LCZs

Eye-Level Picture	Coordinates	Site Satellite Imagery
New Benin Market Area (LCZ 2) 	6°20′58″N - 5°37′52″E	
Textile Mill Road (LCZ 3) 	6°21′32″N - 5°36′54″E	

Permanent Secretariat (LCZ 4) 	6°24′16″N - 5°37′13″E	
Faculty of social science (LCZ 5) 	6°19′30″N - 5°37′32″E	
GRA, Benin (LCZ 6) 	6°19′32″N - 5°37′17″E	
Welu, Igor axis (LCZ 7) 	6°21′32″N - 5°36′58″E	
Kada Plaza (LCZ 8) 	6°19′32″N - 5°37′31″E	
Wire road area (LCZ 9) 	6°20′50″N - 5°37′9″E	

Nigeria Brewery Benin (LCZ 10) 	6°20′48″N - 5°39′54″E	
NIFOR (LCZ D) 	6°33′27″N - 5°37′27″E	

Source: Field Work (2019) and Google Earth Imagery

Spatial Air Temperature Variation in the Dry Season

Mean temperature values of January for each of the observation sites in the study area are presented in Figure 2. From Figure 2, it can be seen that near-surface air temperature is not evenly distributed within the study area. It is evident that FS has the highest temperature value of 29.70^{o}C while TM, BR, PS and WR followed with 29.69^{o}C, 29.66^{o}C, 29.65^{o}C and 29.61^{o}C respectively. The lowest value was recorded in NI with a value of 27.72^{o}C.

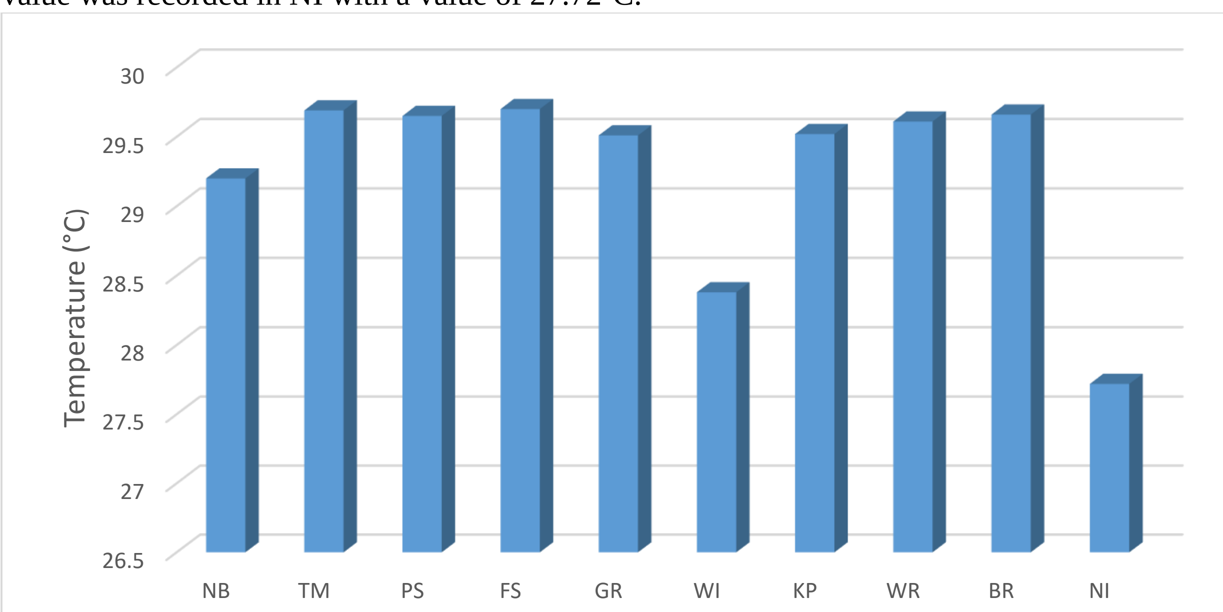


Figure 2: Mean Spatial Air Temperature Variation for January (Dry Season)
Source: Author's Analysis (2019)

The result of the mean spatial variation in the study area slightly differs from the work of Abdulhamed (2011) as the highest mean value recorded (29.70^{o}C) in January is higher than what was obtained at Kano (26.21^{o}C) for January. However, the mean range of temperature here is

2.95ºC which is less than what was recorded at Kano for the month of January (4.1ºC) by Abdulhamed (2011) and Akure (3.5°C) by Balogun et al. (2011).

These differences in air temperature in the dry season could be a result of variation in urban fabric morphology which determines the thermal properties of each LCZ. Also human activities influence the thermal characteristics of each zone. This is seen as FS has the highest percentage of paved surface (impervious surface) and high human activities, being an academic institution which results in higher absorption of heat energy from solar radiation which when released, warm up the overlying air. There is no significant difference between the mean temperature of FS and TM. Another possible reason for the high temperature in FS and TM is heat emission from cars as a result of the compact nature of the urban layout, high vehicular movement etc.

Since pervious surfaces have higher moisture holding capacity as a result of which a large fraction of sensible heat is lost as latent heat of vapourisation through the process of evaporation, the lowest temperature value recorded at NI (27.72ºC) could be attributed to the prevalence of pervious and vegetated surfaces found in the area**.** This result agrees with the work of Enete and Alabi (2012) in Enugu where a downtown-centered heat island was observed both day and night and the variations were strongly correlated to the amount of tree shading and thermal properties. Also, significant reductions as a result of vegetation cover were also recorded at Uxbridge, UK and Cuiaba (Maciel et al, 2013) and in Hong Kong (Tan and Ng, 2014).

Spatial Variation of UCHI

The spatial variation of UCHI in the dry season was calculated from the mean hourly temperature values of the dry season. The resultant mean UCHI is presented in Figure 3

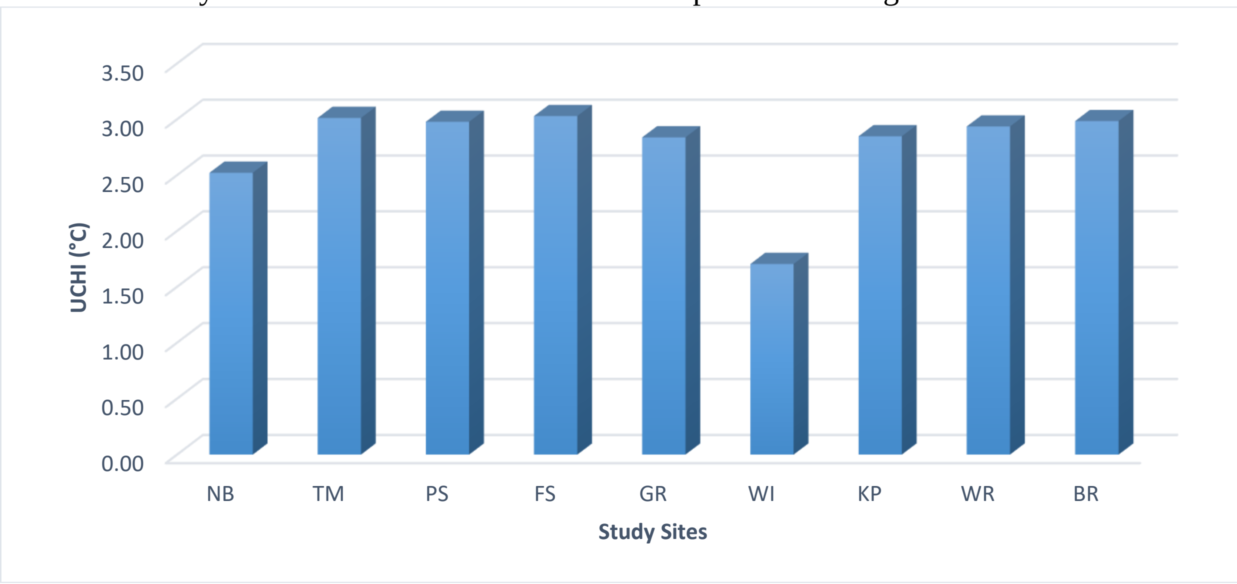


Figure 3: UCHI Variation in the Dry season
Source: Author's Analysis (2019)

From Figure 3, it can be seen that FS has the highest UCHI with 3.03°C followed by TM with 3.01°C and PS and BR with 2.98°C each. The lowest value of UCHI in the dry season was recorded in WI with 1.70°C. The high development of UCHI in FS and TM is closely attributed to the nature of the impervious surfaces and anthropogenic activities which reduces the amount of ambient heat through evaporative cooling. The pattern of UCHI development in the study area closely agrees with the work of Efe and Eyefia (2014) in Benin where higher UCHI was observed in the central business district area due to higher impervious surface while the rural control stations revealed lower UCHI due to higher pervious surfaces.

However it can also be seen that WI has the lowest UCHI in the dry season. A possible explanation for this is thermal storage resulting from lack of tall skyscrapers that would have restricted thermal radiation, reduced turbulent exchanges that allow thermal radiation to be emitted from the vertical building surfaces and prevailing wind direction at this time of the year which allows the site to constantly receive fresh and cooler wind supply from the countryside. This result agrees with the findings of Usman (2016) in Kaduna Metropolis, that upwind edges of cities tend to be cooler than city centres due to the supply of fresh air from countryside.

Test of Significance for Spatial Variation of UCHI in the Dry Season

To order to test for significance for spatial variation of mean UCHI in the dry season the result of the spatial variation of UCHI was subjected to ANOVA test. The results are shown in Table 3.

Table 3: ANOVA Result for Spatial Variation of UCHI in the Dry Season

		Sum of Squares	Df	Mean Square	F	Sig
0.05 Level of Significance	Between Groups	34.783	8	4.348	2.541	.012
	Within Groups	354.258	207	1.711		
	Total	389.041	215			

Source: Author's Analysis (2019)

From the result in Table 3, it can be seen that an F-value of 2.541 with a significance of 0.012 at 0.05 (95%) level of significance indicates that there is a significant difference of UCHI across study sites. However, this value is not significant at 0.01 (99%) level of significance. Since there is a significant difference in UCHI across the study sites, it is safe to say that there is a significant difference among UCHI intensities in the various LCZ in the dry season.

Assessment of Diurnal Variation of UCHI in the Dry season

Mean diurnal UCHI variation in the dry season (January) was calculated from mean hourly UCHI values. To investigate the diurnal variation of UCHI, four hours are chosen which are 05:00, 12:00, 15.00 and 20:00 hours. These hours represent, early morning (05:00 hours) when there is net radiative energy loss to an unobstructed sky and a less polluted atmosphere prior to sunrise (Balogun, Balogun & Adeyewa, 2011), noon (12:00 hours) which represents full sunlight. Afternoon (15:00 hours), which represents a period of peak absorption of solar radiation by surfaces and night-time (20:00 hours) about two hours after sunset which represents the period of active release of heat by urban surfaces (Usman, 2016).

The results of mean diurnal UCHI in the dry season (January) are presented in Figure 4. From Figure 4 it can be seen that maximum diurnal UCHI values were recorded at WR (6.34°C), TM (6.21°C) and BR (6.08°C) at 15:00 hours local time while the minimum diurnal UCHI were recorded at PS (0.03°C) and WI (0.18°C) at noon and 05:00 hours respectively. Also as indicated by the result, diurnal UCHI is generally low at 05:00 hours local time and highest at 15:00 hours local time.

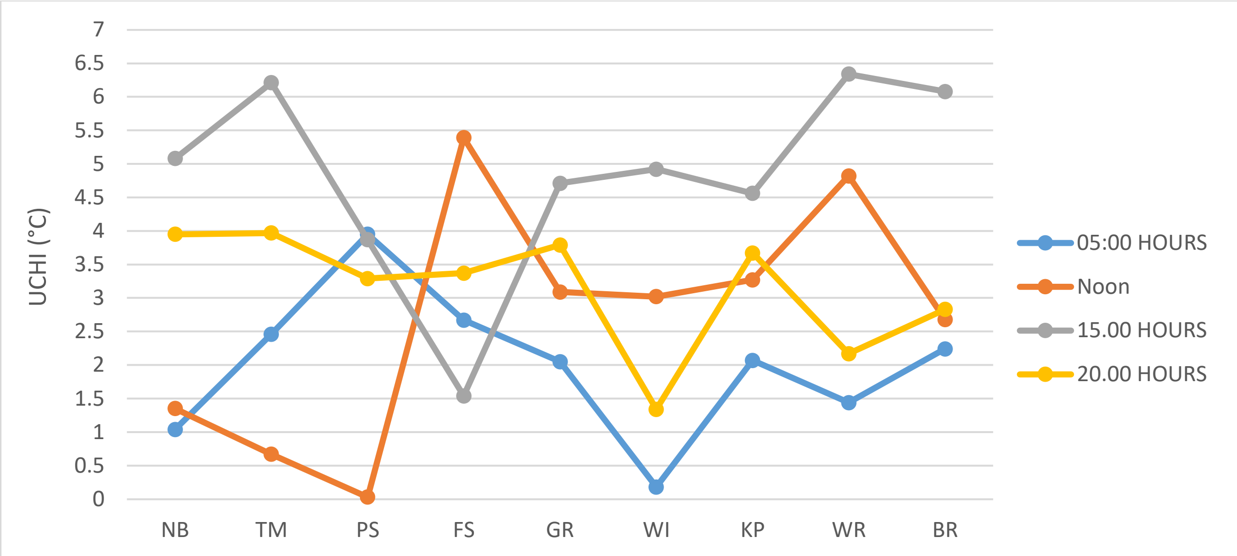


Figure 4: Diurnal UCHI Variation for Dry season
Source: Author's Analysis (2019)

The highest diurnal UCHI of 6.34°C in this study is higher than what was obtained at Kano (5.01°C) (Abdulhamed, 2011); Akure (3.5°C) (Balogun et al., 2011) and Kaduna (3.35°C) (Usman, 2016) during similar periods. However unlike what was obtained in Kaduna (Usman, 2016) and Akure (Balogun et al., 2011) where UCHI was highest in most of the stations at 20:00 hours, this study reveals that UCHI was highest in most of the stations at 15:00 hours. Possible explanations for the predominance of diurnal UCHI at 15:00 hours is the surface material colour and structure which determine the ability of these materials to absorb and release heat. Concrete, asphalt, bricks and wood absorb heat very quickly during the day while water grass and trees absorb more slowly. At night the non-vegetative surfaces lose their heat quickly and the vegetative surfaces slowly, thus raising the temperature of the air in the city at night while parks and countryside remain cool. Furthermore, the low diurnal UCHI recorded at noon in the case of PS is attributed to the modification of the microclimate by high rise building which reduces sky view factor and hence solar radiation.

Test of Significance of Diurnal UCHI Variation in January (Dry Season)

The result of UCHI within the four periods of time was subjected to statistical tests (ANOVA) to check if there was any significant difference between diurnal UCHI intensities across the study sites in the study area in January. The results are presented in Table 4.

Table 4: ANOVA Result for Temporal Variation of UCHI in the Dry Season

		Sum of Squares	Df	Mean Square	F	Sig
0.05 Level of Significance	Between Groups	38.331	3	2.777	6.989	.001
	Within Groups	58.504	32	1.828		
	Total	96.835	35			

Source: Author's Analysis (2019)

From Table 4, F- value of 6.989 and a p-value of 0.01 indicate a significant temporal variation of UCHI across the study site at 0.05 level of significance.

CONCLUSION

The study confirms the existence of urban heat island in Benin City, and thus has a strong implication on the bio-climatological aspect of the urban environment and physiological comfort of the urban inhabitants. The study also showed that there is a significant variation in the distribution of temperature within the urban canopy of Benin City. The diurnal variation of UCHI in the dry season revealed that maximum diurnal UCHI value was recorded at WR (6.34°C), TM (6.21°C) and BR (6.08°C) at 15:00 hours local time while the minimum diurnal UCHI was recorded at PS (0.03°C) and WI (0.18°C) at noon hours and 05:00 hours respectively.

The variation in UCHI in the study area was attributed to the characteristics of surface cover and anthropogenic factors since the higher the impervious surfaces, the higher the spatial variation of UCHI intensities. It is therefore recommended that:

i. there should be regulations made on the adoption of climate-sensitive planning and design schemes.
ii. there should be the adoption of planning methods of green city, green roof approach as this will help to regulate urban climate.
iii. building codes should be formulated which should provide standards for construction and discourage the use of dark coloured roofs, wall paints and pavements. This is because dark surfaces are good absorbers of heat thus, increase UCHI intensity

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