The Built Up Environment and Micro-Climate Variation in Lokoja, Nigeria

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Abstract

At the banks of river Niger particularly bordering the confluence of the river Niger and Benue lies the city of Lokoja. The population increase over the years had led to the increase rate of expansion of built-up areas which consequently led to the increase emission and trapping of carbon dioxide and subsequently increase in temperature. Records have shown over the years in the study area of the gradual change in micro climate which could be directly related to the rate of increase in the size of built up area. The point for temperature measurement is taken at buffered points of every 200 meters, at the core area of the city and similarly at the fringe area. A continuous fixed site micrometeorological observation is undertaken for about a year. Data for mean annual minimum and maximum temperature, average monthly humidity and rainfall was sourced from the Nigeria meteorological station. A correlation was attempted with use of Pearson correlation coefficient to measure the correlation relationship between the rate of increase in built up and 3 main elements of climate that are directly related to urban growth, the element used where rainfall, humidity and temperature . The result gave 0.531 at a significance of 0.005. This is indicative of a high correlation, which means that as the built up area increases, temperature of the city tends to increase and hence more energy is needed to cool a home. The city core will therefore need more energy to maintain a comfort cool temperature than the fringe area, since the core area indicated a warmer afternoon temperature than the fringes. This result may be contrary to the normal heat oases effect. suggestion is therefore given to curb this anomaly

Key words: Micro-climate variation, urban heat island, cooling degree day, urban design

1:0 Introduction

At the banks of river Niger particularly bordering the confluence of the river Niger and Benue lies the city of Lokoja. This area could be described as a prototype of a rapidly urbanizing area around river banks. The population increase over the years had led to the increase rate of expansion of built-up areas which consequently led to the increase emission and trapping of carbon dioxide and subsequently increase in temperature. Higher concentrations of population have been linked to higher energy use and demand in developing countries, this scenario had continue to play itself in the study area (OECD,2006)

The rising heat emission and the impact of the increase built-up area on the heat budget, the emission of green house gases(GHG) is increasing while the physical geography of the area stands as a challenge because the area is juxtaposed between the patti ridge(over 400m asl)and the river Niger . These pose a tremendous impact on heat transfer and a dramatic effect on the micro climate. This could be compared to the global trend elsewhere. Rouillon (2000) and Rouillon (2001) explained the irreversibility of global warming or urban warming that if measures were not put in place to reduce the incidence may lead to natural disasters. Kimitoshi (2008) reveals an exponential trend in temperature change in the recent decade where urban activities have the tendency to increase the level of atmospheric gasses such as the Green house gasses (GHGs) such as CO_2 , methane (CH_4), Chlorofluoro Carbons (CFCs). Such urban activities are generated by urban residents either directly from fossil fuel based transport, domestic activities or indirectly through electricity use and consumption of industrial and agricultural products, further more high density of people in the cities makes them possible focal points of potential vulnerability to the impact of temperature increase.

Epileptic power supply has also contributed to the use of generator sets of different kinds and dimensions and consequently adds to the amount of CO_2 and other green house gases in the atmosphere and a resultant increase in temperature.

Other contributing factors to temperature increase could be traced to high population density and exclusion of nature .Since the natural vegetation has been cleared for construction and consequently an alteration of biodiversity (Gidley, Fien, Smith, Thomsen and Smith, 2011).

Records have shown over the years in the study area of the gradual change in micro climate which could be directly related to the rate of increase in the size of built up area, similar issues have also been documented in other parts of the world, where there is a considerable change in the global climate with tremendous health, economic and environmental consequences (Monjur, 2011).

This research attempts to investigate the effects of built-up development on the temperature variation at the core and the periphery of the city and to suggest strategies for building energy efficient and resilient neighborhoods in the city. Attempts will be made to find out the impact of increase proliferation built up in the city by comparing the temperature change at the core and peripheral areas.

1:2 The role of built-up environment in rising environmental temperature

Literature on development control in the study area, all reveal that the practice and policies of built up processes do not consider the impacts of the emission of GHG in building plan approval (Alabi, 2012).

However recent developments on energy consumption related to buildings is seen to hold a very high temperature change effects in other parts of the world due to the type of construction practices. This has been attributed to urban design problems where traditional patterns which were adapted to the town’s climatic conditions have increasingly been abandoned. While most new buildings are characterized by western design, especially the roofing and even the colors of roof. The old buildings are bereft with urban design problems where every space of a plot of land is filled up with buildings in order to maximize profits, here no room is left for landscaping. So areas hitherto left as open spaces have been converted to built- environment. This consequently stifles the free flow of air. The proliferation of these built structures have been found to have led to the removal of vegetation cover and have increased surface runoff and reduction in water availability in the landscape, thereby limiting evapotranspiration (Alabi,2012).

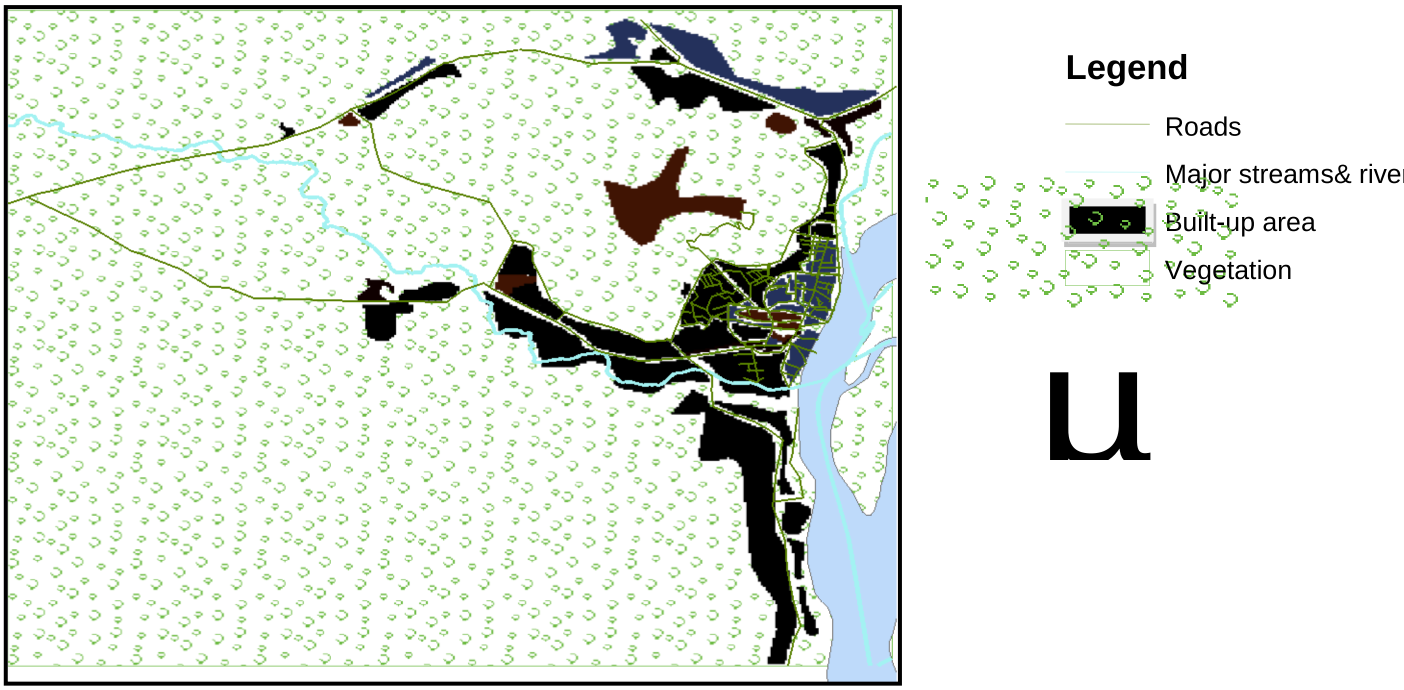
Technocratic approach which over emphasizes physical plans often fails to consider economic goals. “Mass” and “Space” regulation have been found to be continually violated in buildings construction, most buildings are sited to cover more than 60% of their plot, here energy supply systems are barely employed and the use of renewable energies is negligible (Arnfield, 2003)

The paved roads also contribute to the heating of the air because of restricted horizontal flow due to increased formation in city limits the ability for warm air within the streets (Urban canyons) to be dispersed. Research findings in the study area, show that buildings have high heat capacities and thermal conductors that can absorb and retain solar radiation in the urban fabric. The heat is then released slowly at night, increasing the surrounding temperature (air conditioning) (Alabi, 2012). All these are might result to urban heat island (UHI), which is a phenomena described as,” microscale and mesoscale in (Oke,1982). He describes microscale as the variation of the surface air and temperature , that every surface has its own temperature and so its own microclimate on it and in its immediate vicinity , that typical scales of urban microclimates relate to the dimensions of individual buildings , trees, roads , streets , gardens .while the mesoscale is the influence on weather and climate by a city at the scale of the whole city .

Increases in temperatures in the city in comparison to adjacent rural regions and resultant adverse consequences for local and global communities” is seen as the consequence of vegetation removal (Oke, 1982), (Timothy, Smith.Phillip, O’Toolec, Matthewsa, Thomsena, Inayatullaha, Fiend and Graymore, 2011). Anthony (2007) agrees with this also and he further stated that that the main cause of urban heat island is the modification of the land surface by urban development which uses materials which efficiently maintain heat. That waste generation is also a secondary contributor. Hence as the population increases this afore mentioned activities increases and a greater area of land is modified leading to a continuous increase in average temperature.

2.0 The study area

Lokoja is located between latitude 7° 45' N, 7° 51'N of the equator and longitude 6° 41' E 6° 45'E of the Greenwich Meridian. It is bounded in the west by the River Niger at an altitude of 45-125metres above sea level. It is also surrounded by pockets of hills of which the highest in the Patti ridge. (figure1), the flat area is generally undulating at an altitude of 107metres below sea level.



Scale: 1:100,000
Figure 1 Study area

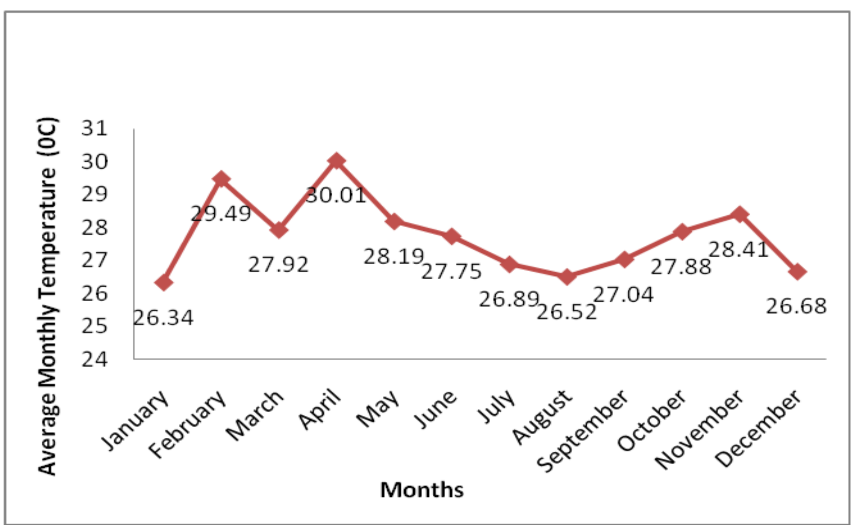


Figure 2 Average monthly temperature pattern (January –December 2010)

The study area is categorized to be within the guinea savannah belt, even though what we really have now is derived savannah, only resistant vegetation still remains dominant due to anthropogenic activities of bush clearing and burning , lumbering , most of area consists of secondary regrowth. The climate described as the tropical wet and dry climate of the Koppen's classification. It is characterized by wet and dry season. The rain begins in May and ends in October. With a maximum temperature of 37.9 ^{0}C, maximum temperature between December and April, average annual rainfall of about 1000mm and a relative humidity at 60% (figure 2), (appendix).

2.0 Methodology

The point for temperature measurement is taken at buffered points of every 200 meters, at the core area of the city and similarly at the fringe area. A continuous fixed site micrometeorological observation is undertaken for about a year. Data for mean annual minimum and maximum temperature, average monthly humidity and rainfall was sourced from the Nigeria meteorological station, Lokoja (Appendix).

The concept degree days is utilized to estimate temperature variation, since it can also be used to find the corresponding bench mark for building s expected performance as against other buildings of similar characteristics, to set also energy budget. It can also be used to estimate the corresponding CO_2 emissions due to space cooling or heating in buildings (Kadioğlu, Şen, and Gültekin ,1992)(Ucar and Balo,2010). The degree days is also used to monitor and analyze weather related energy consumption and corresponding CO_2 emissions of buildings based on historical data ((figure 3). The spearman correlation coefficient is then used to find the correlation between rate of growth of the built-up and microclimatic variation (table- 2).

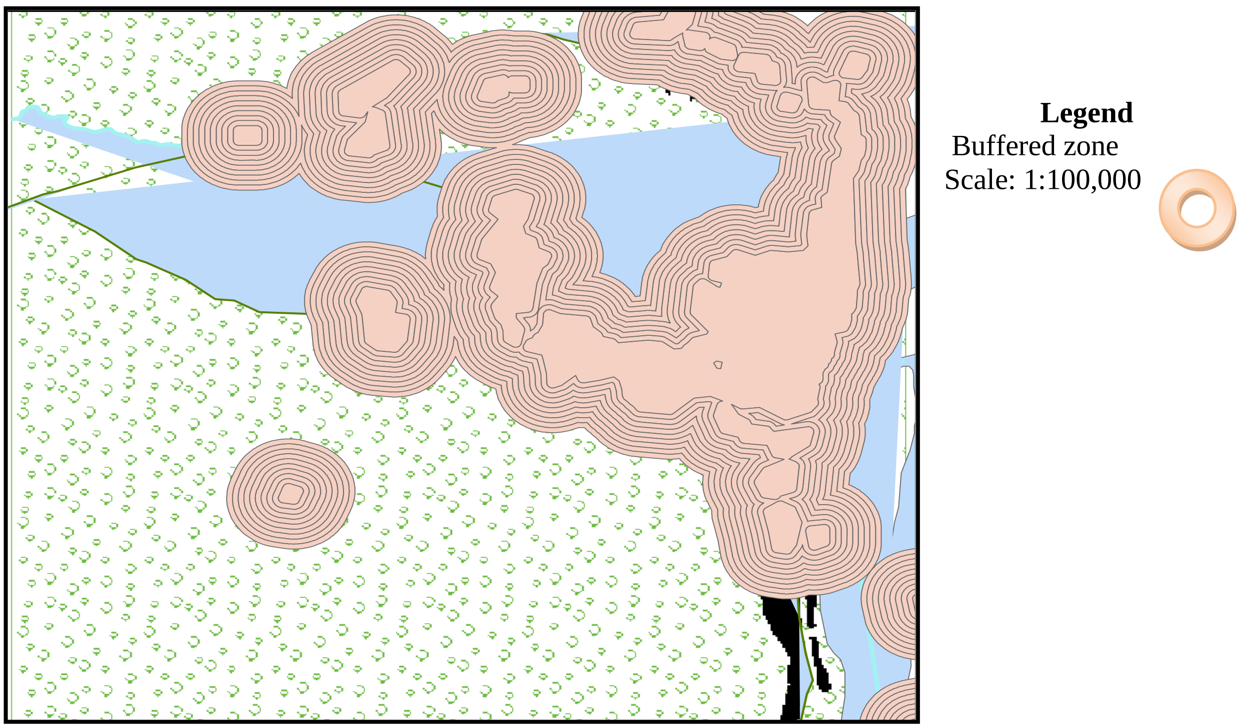


Figure 3 showing the buffering of study area at interval of 200meters

2.1 Calculating degree days

Degree days can be defined as the summation of temperature difference over time, between a reference temperature and the outdoor air temperature. It shows both intensity and duration of the outdoor temperatures .The reference or base temperature is also referred to as the balance point temperature, which is the outdoor temperature at which the cooling or heating system does not run in order to maintain comfort conditions in a building. For this research there will be a need for the cooling system to operate when the outdoor temperature is above the cooling base temperature, this is so because the study area is in the tropics with high humidity. These could be summed as Cooling Degree Days (CDD). Cooling degree day (CDD) is a measurement designed to reflect the demand for energy needed to cool a building. it is derived from measurement of outside air temperature .The cooling requirement for a given structure at a specific location are considered to be directly proportional to the number of CDD at the location. Contrarily heating degree day HDD reflects the amount of energy used to heat a home. The most appropriate base temperature for any particular building depends on the temperature at which the building is cooled and the nature of the building (including the heat generated by occupants and equipment within it).

However relating to any particular building CDD is often made available with base temperature of 16 C or 18 C, which is approximately appropriate for a good proportion of building depending on the climatic condition of the area. For this reason degree-days will be calculated in this research at variable base temperatures ranging from 16 °C to 25 °C for cooling at an interval of 0.5 °C. Therefore to calculate the cooling degree days for a particular day, find the day's average temperature by adding the day's high and low temperatures and dividing by two. If the number is less than 65, there is no cooling degree days that day. Subtract this average from 65 to find the number of cooling degree days. For example, if the day's high temperature is 60 and the low is 40, the average temperature is 50 degrees. 65 minus 50 is equal to 15 cooling degree days.

The calculation for cooling degree days hourly weather data is given as:

$$D_{c,d} = \frac{\sum_{i=1}^{24}(\theta_{o,i} - \theta_{b,c})}{24} \quad \text{for } (\theta_{o,i} - \theta_{b,c}) > 0$$

Where Dc,d is the daily cooling degree-days for one day (°C day), θb,c is the cooling base temperature (°C) and θo,i is the outdoor air temperature at the ith hour of the day (°C).

Monthly cooling, Dc,m for a particular month are the sums of daily cooing .Similarly, annual cooling Dc,a are the sums of monthly degree-days over the twelve months of the year. In cases where hourly meteorological data are not available, degree-days can be calculated from reduced datasets such as mean daily temperatures or mean monthly temperatures. The standard method of calculating degree-days varies around the world, like in the USA, published degree-days are calculated from mean daily temperatures Arnfield (2003) and Monjur (2011). However for this research based on data available, the monthly cooling degree days (Dc.m) will be applied.

3.0 Results

Table: 2 Result of Pearson Correlation Coefficient for Relation Between built-up growth and Microclimate Variations

	Built up growth	rainfall	humidity	temperature
Built up growth	1	0.228* (0.523)**	0.735* (0.16)**	0.532* (0.115)**

*****-- Person and ******--0.05 Confidence Level

A correlation was attempted with use of Pearson correlation coefficient to measure the correlation relationship between the rate of increase in built up and 3 main elements of climate that are directly related to urban growth, the element used where rainfall, humidity and temperature . The result gave 0.531 at a significance of 0.005. This is indicative of a high correlation, which means that as the built up area increases, temperature of the city tends to increase and hence more energy is needed to cool a home (Figure 4, table 2).

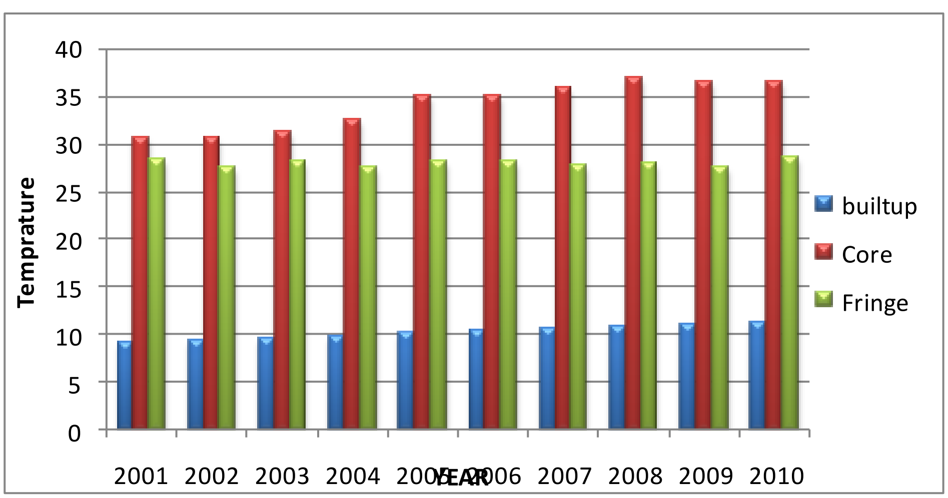


Figure 4 Built-up change and average temperature at the core and fringe area from 2001 to2010

The figure 4 above shows the growth trend of the built up area and the corresponding temperature change. It shows that the rate of temperature increase is directly proportional to the rate of growth of the built-up area. Where as in 2001 the area covered by the built-up was 9.17 kilometer square increased to 11.24 by 2010. This have correspondingly increased the average temperature of the core area form 30.37 in 2001 to a gradual gradation to 36.62 ^{o}C in 2009 and then 36.55 ^{o}C in 2010 . Similarly temperature trend at the fringe area shows certain trend where average temperature in 2001 indicates 20.30 ^{o}C and increased to 28.52 ^{o}C in the year 2010 .Even though there are fluctuations over the years which might be due to other attributes of urban air such as cloudiness, absolute humidity, and wind velocity. However it can easily be observed that the core area is being slightly more heated up than the fringe which signifies the occurrence of urban heat island, it is more correctly described as being over heated.

3:1 Over heating

Table 4. Monthly cooling degree-days, Dh,m, in the fringe area of town,2011

month	Monthly cooling degree-days, Dc,m (°C-day)		
	cooling base temperature, θb,c (°C)		
	16	20	25
January	268.77	144.77	-10.23
February	296.96	180.96	35.96
March	308.92	184.92	29.91
April	330.45	210.45	480.90
May	281.95	157.95	2.95
June	281.10	146.10	-3.90
July	261.94	133.35	-17.21
August	255.91	131.91	-23.10
September	270.60	150.60	0.60
October	292.64	168.64	13.64
November	748.2	130.36	- 15.5
December	754.39	134.39	-20.62

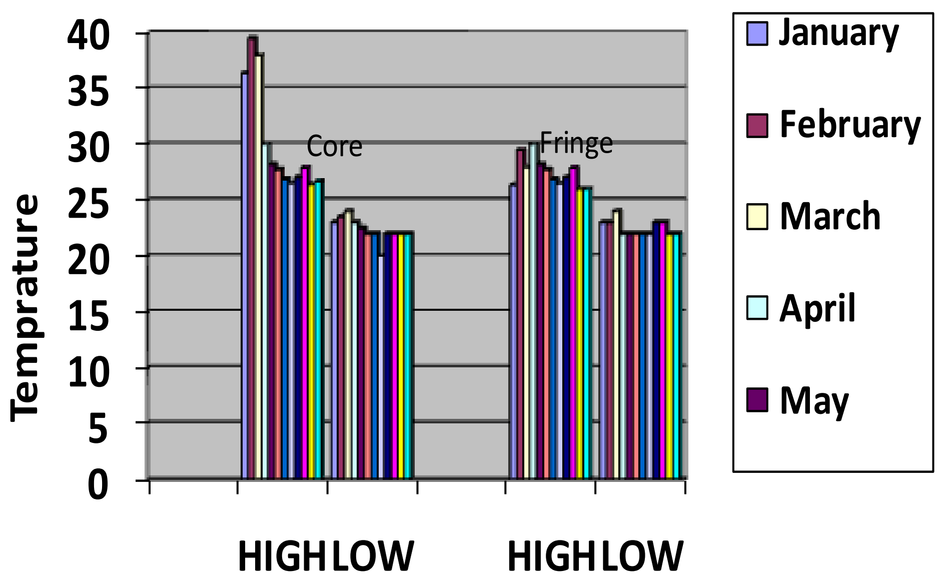


Figure .5 Monthly cooling temperatures for the core and the fringe area, 2011.

The table 4 above and the corresponding figure 5 below, shows the core area of the city experiencing overheating , even though there have not been agreement by scholars of what overheating is, various approaches have been applied in the past to define over heating , these were based on the definition of acceptance threshold of thermal comforts.

It was agreed that the exceedance of certain temperatures for certain durations (Kadioğlu, Şen, and Gültekin 2001) were to be used as an indicator of overheating. In the U.K study on overheating, the comfort threshold temperatures of 25 ^{o}C and 28 ^{o}C have been used (CIBSE, 2006) In Nigeria conditions of excessive discomfort has been given as 35-37 ^{o}C. The point where the use of air conditioning or fans could be needed ranged from 31-33 ^{o}C, this is when the internal temperature should not exceed 31 ^{o}C for more than 5% or exceed 33 ^{o}C for more than 1% of the occupied period in the year (However in this research the comfort thresholds for the study area should be as low as 26-30 ^{o}C as per the researcher's disgression, due to the low tolerance of high temperature in the area, and because the internal temperatures are often higher than external temperatures in most buildings which contributes to rise in indoor temperature. This also agrees with the threshold used in Evans ,1980 .The figure 4 also indicates that the core area is perpetually being over heated from 2001 to 2010 as compared to the fringe or peripheral area of the town whose temperature falls below the threshold for mechanical cooling and therefore less energy will be needed for cooling at the periphery throughout the year.

3.2 Degree days

The table 4 and figure 5 compares the cooling degree days for the core area and fringes. The monthly variation in change shows an uneven trend at different base temperatures .Monthly cooling degree days for the core area increases from January to march and reduces to nothing at the other periods of the year at base 16 ($\theta_{b,c}$ = 16 °C), this however does not depict the reality rather the reality is well depicted when base 25($\theta_{b,c}$ = 25 °C) is used . The chart, figure 5 shows temperature increase above low base from October to march which coincides with period of dry season and then the reduction in temperature at the advent of the rainy season due to increase moisture in the atmosphere, not only that this is the period of highest temperature at the tropics, it is also the period when the sun is at the northern hemisphere, a period of intense insolation. Energy demand may have to be met through the use of electricity power, and the use of generating set, where the supply of electricity is not efficient. This a carbon intensive form of energy which will have the effect of increase GHG emissions. This consequently increases the atmospheric temperature.

As we go into the rainy season from April to September the temperature reduces. However the at the fringes the temperature is almost at the threshold due to the modifying effects of vegetation and greeneries , here roofing and housing materials modify the cooling effect on the environment. The area is characterized by thatched roofs, corrugated iron sheets and sometimes mud buildings with brick walls and vast open spaces. The result of this scenario is less energy demand for cooling.

4.0 Conclusion

The ongoing discussion shows that the city core will need more energy to maintain a comfort cool temperature than the fringe area, since the core area indicated a warmer afternoon temperature than the fringes. This result may be contrary to the normal heat oases effect .Imura (1992) in his findings shows that the afternoon temperatures are warmer inside the city core than the suburbs. This contrast could be attributed to other factors such as atmospheric pollutants, surface albedos and that of building materials used. Like the use of corrugated iron sheets (zinc materials). African cities are known to have albedos ranging from 0.3 to 0.45 (Taha, 1990). Urban design problem of the buildings could also be an attribute. This could be summed up as the factor of the built environment. These heating problems can be eliminated by considering the environmental design of the area. Various studies have advanced three primary mitigation strategies such as urban forestry, cool roofs, and cool pavement. The urban forestry is to plant trees so as to increase evapotranspiration while providing day time shading (Alabi,2012), (Oke, 1982). Reflective paving has also been suggested, two mechanisms for creating cool pavements are increased surface reflectance which reduces the solar radiation absorbed by the pavement and increased permeability which cools the pavement either through increased convection, lower thermal storage or evaporation of water. The cool roofing approach has been used to model the impact of increasing albedo of roof tops. Building configurations have also been found to influence the cooling demand by producing shaded areas (Arnfield,2003).

The orientation of building also has a large effect on the cooling demand by up to 3% and heating demand by up to 16% compared to unfavorable orientation. Building configuration have also been found to influence the cooling demand by producing shaded areas .The orientation of each building has the largest influence on energy demand.

The predominant north–south orientations of the buildings have been found to reduce the cooling in Dhaka(Seelig S ,2011) .This idea can also be exploited in the building construction in the study area. Culturally adapted building typologies can also reduce heating. it is suggested the encouragement of courtyard house, because it supports ventilation and permits cooling , while reducing direct exposure to insolation .The courtyard house have been found to be culturally sensitive building form because it creates private and introverted spaces in dense urban form.

Finally it is suggested that building practices that is concerned with" green construction" be encouraged i.e. building construction that will focus design on efficient energy use , reducing the amount of energy a structure needs in the long term and using sustainable building materials that are none toxic.

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Appendix

Average annual Temperature of Lokoja

Month	Temperature(o C)
January	26.34
February	29.48
March	27.93
April	30.03
May	28.19
June	27.74
July	26.89
August	26.51
September	27.04
October	27.88
November	27.62
December	28.55

Source: Lokoja meteorological station

Average monthly rainfall

Month	Average rainfall(mm)
January	22.5
February	67.3
March	101.2
April	1186.7
May	1672.2
June	1475.4
july	2329.9
August	2076.8
September	2049.4
October	14.01
November	22.1
December	0

Source: Lokoja meteorological station

Average monthly humidity

Month	Average humidity
January	51.4
February	49.2
March	52.8
April	57.6
May	63
June	66
july	67.4
August	68
September	67.9
October	59.4
November	48.5
December	53.1

Source: Lokoja meteorological station