Towards Sustainable Urban Environment: An Investigation on the Relationship between Electrical Energy Consumption and Urban Morphology in Context of Dhaka City

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Abstract

In a city, its morphological character and complex built environment mainly control its microclimate. The street pattern, orientations, the canyon shape, built density, available green space- all are the concerning features that should be properly cared for the a sustainable urban environment. The buildings that gain heat from solar radiation are responsible for increasing the heat of the densely populated area. The evaporative cooling, which is related to land use pattern, irrigation, wind speed and rainfall, also varies in urban environments. On the other hand, the microclimates as well as morphological character of a city have a great impact on its electrical energy consumption as both have a relationship with the outdoor and indoor comfort.

With the literature review for background study, this paper gives some observation and analysis based on the collected data and field study on a selected area to understand the relationships among the energy consumption and city morphology in context of Dhaka city. Analyzing with meteorological data, this study also gives some indications to understand the important factors of sustainable urban design to reduce energy consumption within the city.

Keywords: *Sustainable Urban Environment, Energy consumption, morphological characters, microclimate, meteorological data.*

1 Introduction

The Urban morphology which includes street pattern and its orientations, the canyon shape, built density, available green space is responsible enough in creating urban heat island effect within a city (Smith, C. & Levermore, G., 2008). With considering global warming, if the heat produced within any city is not reduced, the pressure will be created on the overall national energy demand, as more heat needs more electricity for cooling the indoor spaces of the buildings. Now-a-days Dhaka has become a densely populated city with high concentrations of various types of buildings and built spaces. This paper focuses on study of the electrical energy consumption in an area of Dhaka city and analyses the relationship with the climatic data as well as morphological characters of the same part of the city. Particular emphasis has been given on important findings which can be considered for reducing the electrical energy consumption of Dhaka city.

2 Objective and Scope

The objectives of the study are as follows:

a. To develop a relation of electrical energy consumption with climatic data of Dhaka city
b. To study the morphological characteristic of part of the city and to identify the dominant factors those affect the electrical energy consumption.

The study is conducted through analyzing the electrical energy consumption and morphological characters of specific area in the climatic context Dhaka city. This study is limited to evaluating the 'Segunbagicha' Division (a demarcated area among 32 divisions according to PDB) which includes three wards of Dhaka city (Figure 7) to limit the scope of work.

3 Methodology

Some literature reviews are done to gather general background knowledge about city morphology and the climatic context of Dhaka city within the research. The corresponding climate data are collected from the Met Office in Dhaka. Also all the energy consumption data are collected from the main office of the Power Distribution Board (PDB). For morphological analysis of the studied areas; GIS maps, photographs, measurements and other information are gathered from Dhaka City Corporation, URP Department of BUET, internet and extensive field surveys. Statistical Analysis is done to find the relationship among these issues. For statistical as well as software analysis of the collected data, Microsoft Excel 2007, Ecotect v5.2 and Rayman v1.2 software are used as Supporting tools. The research is conducted through analyzing the electrical energy consumption and morphological characters of specific 3 wards in context of Dhaka city.

4 Background of the Study

4.1 City morphology and its effect

Among the three levels of studies, distinguished as urban planning, urban morphology and building design (Goulding, Lewis and Steemers, 1986), urban morphology is the study of the form of human settlements and the process of their formation and transformation. The study seeks to understand the spatial structure and character of a metropolitan area, city, town or village by examining the patterns of its component parts and the process of its development. This can involve the analysis of physical structures at different scales as well as patterns of movement, land use, ownership or control and occupation. Typically, analysis of physical form focuses on street pattern, and building pattern, sometimes referred to collectively as urban grain. This urban morphology interacts with people behaviour and with the local climate. The development of cities parallels the growth in energy consumption with quite simple laws derived from physics and thermodynamics. At the neighbourhood scale, the heterogeneities of structures within the urban canopy (i.e., the layer between the surface and the tops of the buildings) exert a strong influence on the urban boundary layer wind and thermodynamic structure and a subsequent effect on the pollutant dispersion and resulting air quality predictions (Goulding, Lewis and Steemers, 1986).

An urban canyon is caused by streets cutting through dense blocks of structures, especially skyscrapers, which cause a canyon effect. The sky view factor of urban streets is also important because the proportion of the street and building geometry controls the solar heat gain and others factors Smith, C. & Levermore, G., 2008). Urban canyons have an impact on various local conditions:

- Wind speed, as moving air is channeled and accelerated
- Temperature, which can be elevated 5-10 degrees F (2-4 degrees C) and contributes to the urban heat island effect
- Air quality, where locally stagnant air concentrates pollutants near ground level.

So for any city the microclimate can be controlled through proper developing the morphological components which controls also the energy consumption.

4.2 The Context of Dhaka

Dhaka is located in the central position of Bangladesh at, on the eastern banks of the Buriganga River. The city lies on the lower reaches of the Ganges Delta and covers a total area of 59.40 sq miles. It consists of 7 principal thanas: Dhanmondi, Kotwali, Motijheel, Paltan, Ramna, Mohammadpur, Tejgaon, Sutrapur and 16 auxiliary thanas. In total, the city has 130 Wards and 725 Mohallas (http://en.wikipedia.org/wiki/Dhaka). Vegetation and moist soils characterize the land, which is flat and close to sea level. This leaves Dhaka vulnerable to flooding during the monsoon owing to heavy rainfall and cyclones.

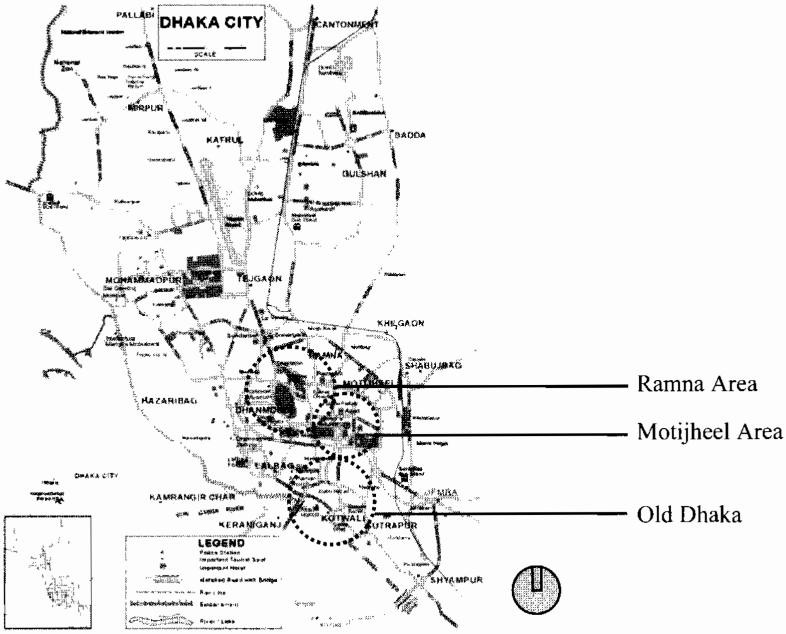


Figure 1: Map of Dhaka City (Source: www.dhakacity.com.bd/dhaka_city_map)

Dhaka experiences a hot, wet and humid tropical climate. The city is within the monsoon climate zone, with an annual average temperature of 25 °C (77 °F) and monthly means varying between 18 °C (64 °F) in January and 29 °C (84 °F) in August. Nearly 80% of the annual average rainfall of 1,854 millimetres (73 in) occurs between May and September. The Land use pattern (Figure 2) shows that among the built areas (without agricultural land) residential land is high in area. Commercial land use is low in respect to that. If the greater Dhaka is considered with its surroundings, it can be found that about 27% (figure: 2) of land are occupied by residential building. Also it is notable that the agricultural land is also high but they are all at outside of Dhaka metropolitan. Estimated number of housing plots in DCC is about 186,000 (plot size 4.5-7.5 decimals) out of which 80% plots (i.e., about 148,800 plots) are already used for housing. As a result there are very limited green open spaces in Dhaka city.

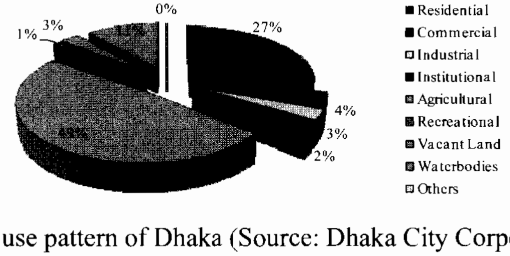


Figure 2: Land use pattern of Dhaka (Source: Dhaka City Corporation)

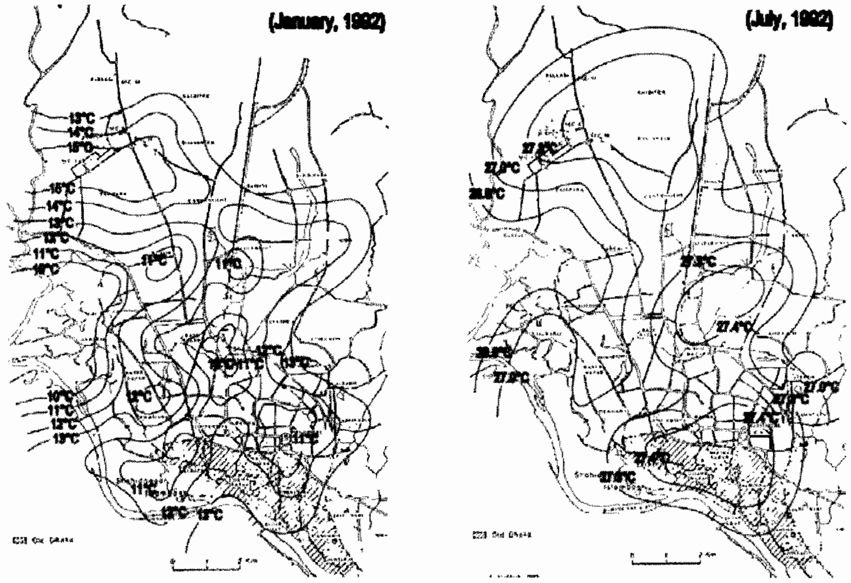


Figure 3: Effect of hard and green surfaces on Temperature distribution of Dhaka city (Source: Ahmed, K. A., 1996, newly drawn by the author)

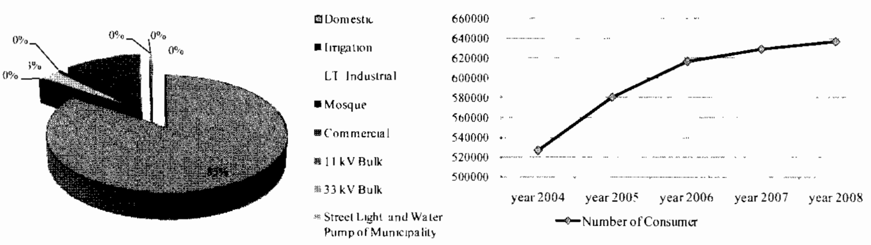


Figure 4: Energy consumption pattern of year 2005 and yearly consumer data of Dhaka city (Source: Data from Power Distribution board)

If the temperature distribution diagram (figure: 3) is analyzed, temperature of Dhaka varies with morphological (buildings, roads, green parks, water body and others) character of the city. The hard surfaces of roofs and roads gain more heat and are the cause of urban heat island effect

On the other hand, energy consumption Data (figure: 4) shows that domestic data is the highest in value. So the residential buildings as well as commercial buildings consume a lot of energy in Dhaka city. The numbers of consumers are increasing (Figure 4) as same as population, but the electrical energy import is limited. So, saving electrical energy of Dhaka city is very important for its sustainability.

4.3 Area of the investigation

In Dhaka city there are some circles (zones) according to the electricity coverage area of PDB. Each circle includes 4~ 5 divisions or demarcated areas. The area of Segunbagicha division is randomly selected from Ramna circle. This division (figure: 6) consists of Ward No 36, 56 and 57 (figure 7). Considering vegetation, this division has significance as primarily as numbers of studies have established the positive environmental impact of plants and vegetative surfaces in cities (Reza et al, 1991). The important characteristic of this area is its extensive vegetative surfaces (Figure: 5) and it has a distribution of large number of mature trees. On the other hand, it has also hard surfaces with multi storied buildings.

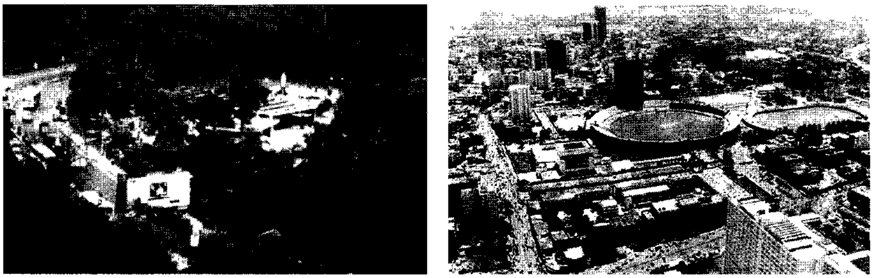


Figure 5: Green and Hard surface area in Segunbagicha division (Source: http://bsapk.tripod.com/id13)

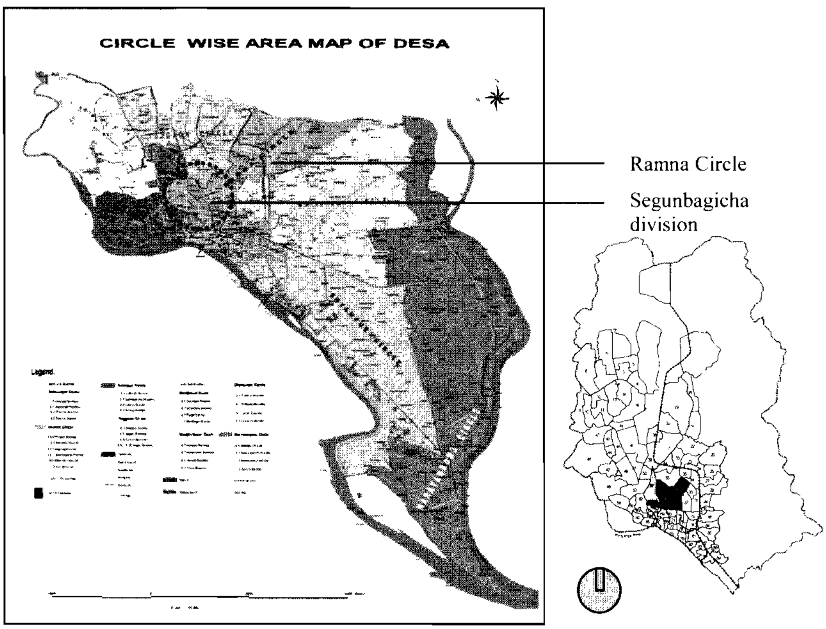


Figure 6: Circle wise area map of DESA (Source: Collected from Power distribution Board, Dhaka)

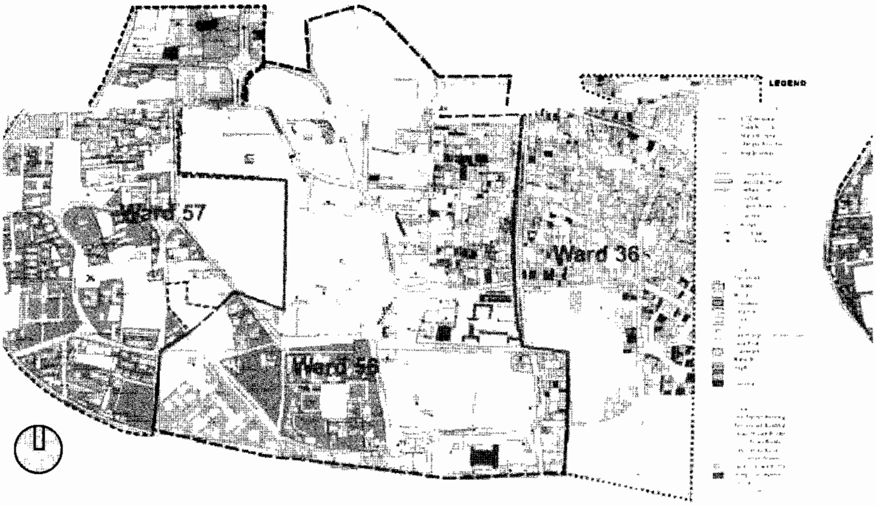


Figure 7: Map of Segunbagicha division including 3 Wards (Source: GIS MAP, Collected from Dhaka City Corporation)

5 Observations and Findings

The total area of Segunbagicha division is 46931031 sft (4.36 sq km) population is about 118,710 (figure 7). Among these three wards, the ward no 56 is larger in area and population is also high. Comparing the land use pattern it can be seen that the ward 36 which covers the Topkhana and Paltan area has higher density than the others. The ward 56 has greater green area (figure 8) which includes the Ramna Park, Sahrawardi Udyan, Osmani Udyan and other. And the ward 57 has mainly the educational and government institutes.

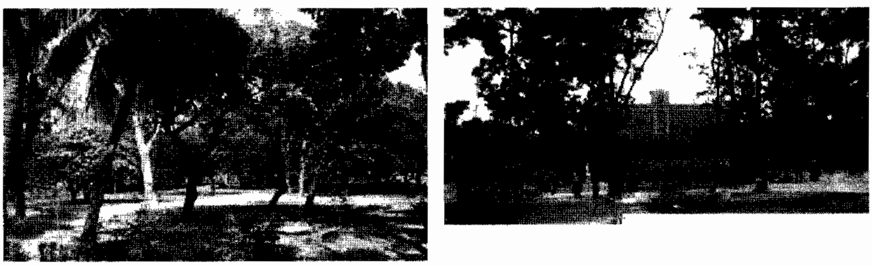


Figure 8: Sahrawardy and Osmani Udyan (Source: photography by author)

The green area creates a micro climate in the area through evaporative cooling. The water bodies are only covered in the ward 56 which includes Ramna Park Lake, Karjan Hall water body (figure 9), Osmani Udiyan's water body and others.

Figure 9: Water bodies: Karjan Hall and Ramna park lake (Source: photography by the author)

These water bodies have an impact on its local microclimate. Comparing with other wards it is clear that the ward 56 has some basic morphological difference with other area. These park areas can be considered as a northern most boundary of area with high distribution of vegetal covering. Large number of trees in this area had a considerably impact on the micro climate. Although, being surrounded by areas devoid of vegetation, the ambient temperature on this site is close to the values of meteorological station (Ahmed K.S., 1995, pp.164).

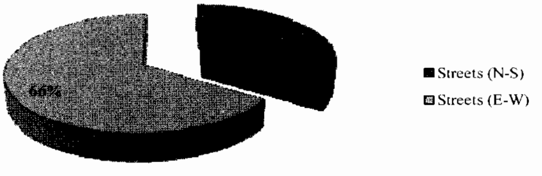


Figure 10: street orientation ratio (Source: DCC GIS map)

The E-W streets are high in number (figure 10) in Dhaka city and these streets gain more solar heat from sun especially on the months from April to July. The average canopy heights and sky view factors can be shown as follows:

Table 1: street orientation ratio (Source: DCC map)

	Commercial Zone	**Residential Zone**	**Educational use Zone**
Average road width (W)	50'	30'	60'
Average building height (H)	60'	40'	60'
Average sky view factor (H/W)	1.2	1.3	1.0

In table 2, the Abdul Gani road (figure 13) is E-W oriented and it is in the south-eastern perimeter. In this kind of wider canyon, there is considerably more radiation influx in comparison with a canyon of narrow section, resulting in a marked rise in canyon air temperature (Ahmed, 1994) (Salleh, 1994). The Edge of the Ramna Park is influenced by the cooling effect of the green vegetation and the water body (figure 9). The tree lined streets produces thermally agreeable climate and the air temperatures are close to meteorological data of Dhaka (Ahmed, K. S., 1995, p.170). Also, the Relative Humidity at this studied area is higher than the met data and the radiant temperature is found to be lower than the air temperature. (Ahmed, K.S., 1995, p. 264)

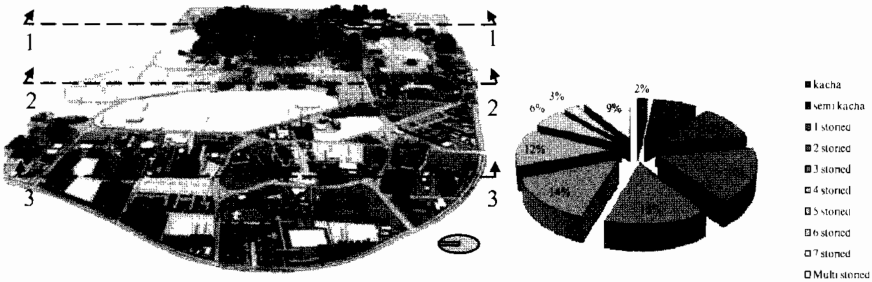


Figure 11: The morphology of the studied area (Source: Drawn by the author from the data Dhaka City Corporation GIS MAP)

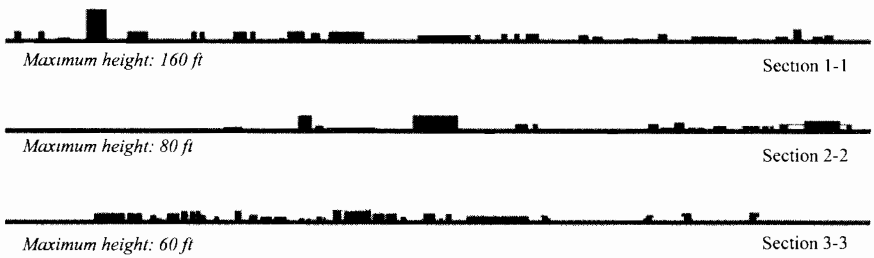


Figure 12: Morphology (Urban Canopy Height): Segunbagicha division (Source: Drawn by the author)

Table 2: Analysis of 6 Urban Canyons of Segunbagicha division (field survey and Ray man Software analysis)

Road Location	**Orientation**	**Road Width**	**Vegetation**	**Average SVF**	**Major Construction Materials**
Segunbagicha Road	N-S	50'-0"	Low	1.6	Plaster, Concrete
Suhrawardi Udyan Road	N-S	60'-0"	Moderate	0.17	Concrete
Bijay Nagar Avenue	N-S	60'-0"	No Vegetation	2.67	Glass, Plaster, Concrete
Abdul Gani Road	E-W	80'-0"	Moderate	0.4	Concrete
Pilkhana Road	E-W	60'-0"	High	0.12	Concrete
Topkhana Road	E-W	80'-0"	No Vegetation	1.87	Glass, Plaster, Concrete

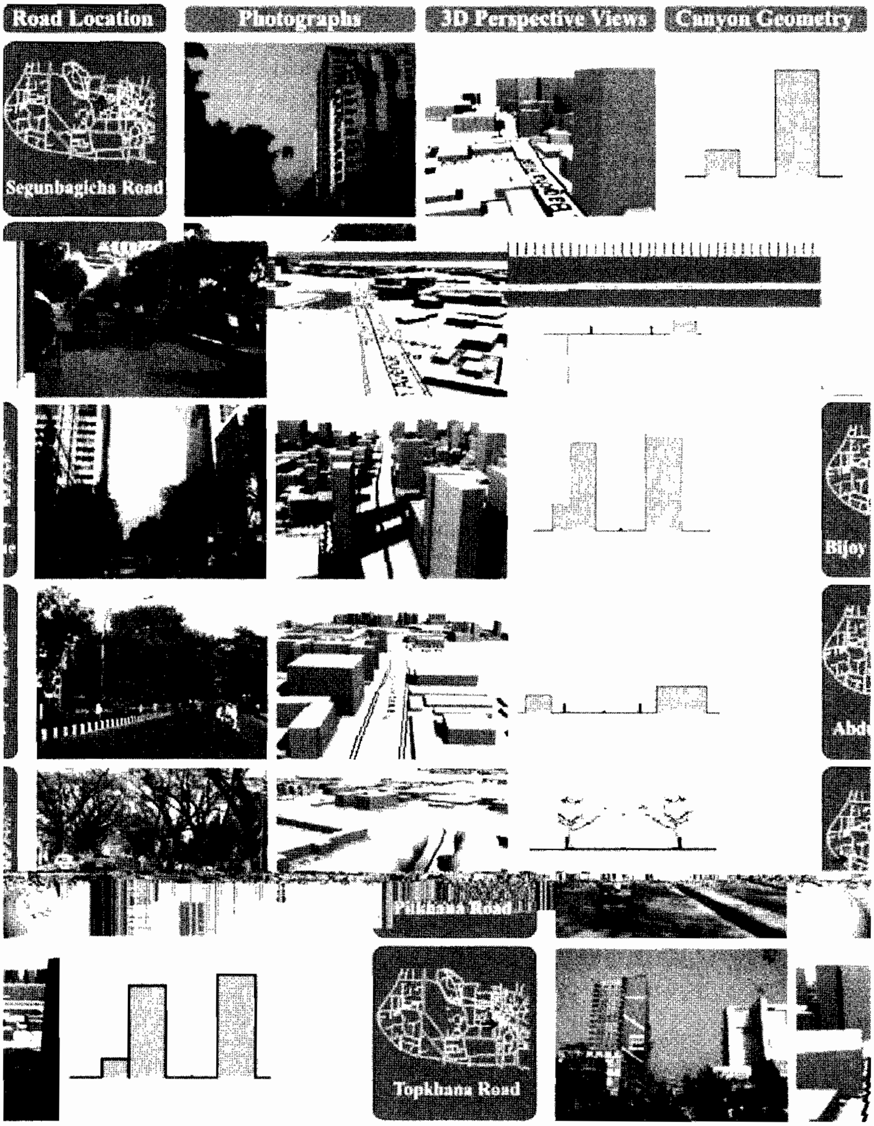


Figure 13: Graphical analysis of 6 Urban Canyons of Segunbagicha division (Source: Drawn by the author and field survey, use of Ray man Software)

Comparing all the data from table 2 with figure 11, 12 and 13, it is notable that both the width of the road and height of the buildings contribute to make urban canyon effective. As Orientation of the road also an important factor for gaining solar radiation in the canyon, the total morphological character of the canyon can be also responsible for extra electrical energy consumed by these buildings adjacent to the canyon.

6 Analysis and Findings

Firstly, analyzing only the meteorological data some relationships among each other can be found. In the figure 14, the average ranges of dry bulb temperature are found to be higher from March to August in the year of 2005. The second and third graph of this figure shows the relationship among average Relative Humidity, dry bulb temperature and average wind speed in the same year. But from May to October, there is an opposite relationship between sunshine hours and cloud in octa.

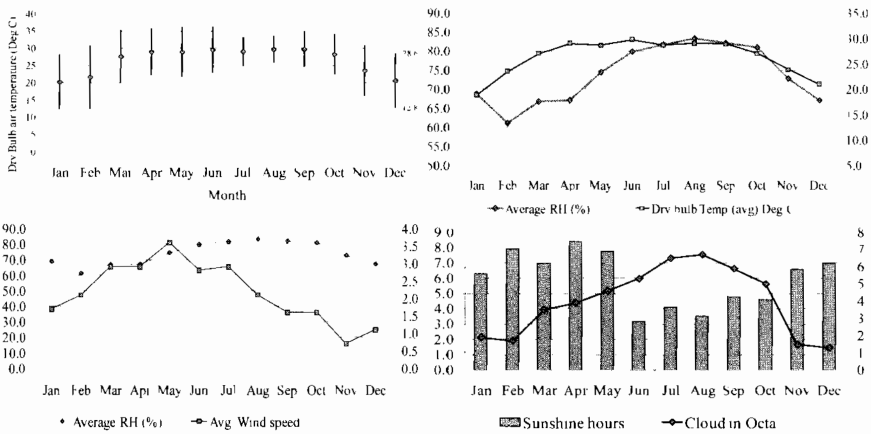


Figure 14: mean air temperature and Correlation among the met data 2005 (Source: Meteorological Data 2005)

Secondly, analyzing the energy consumption data (figure 15) it can be found that the electrical energy that is imported and sold from April to August is higher in value than the rest of the year. So there is an impact of climate on energy consumption during these months in Dhaka city, as we can see similar curves of average RH, dry bulb temperature and cloud in octa in figure 14.

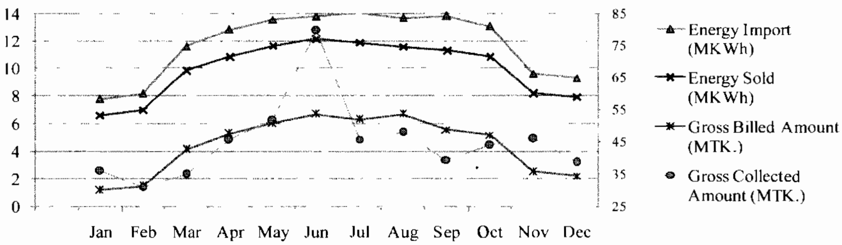


Figure 15: relations among the energy consumption data (Source: PDB)

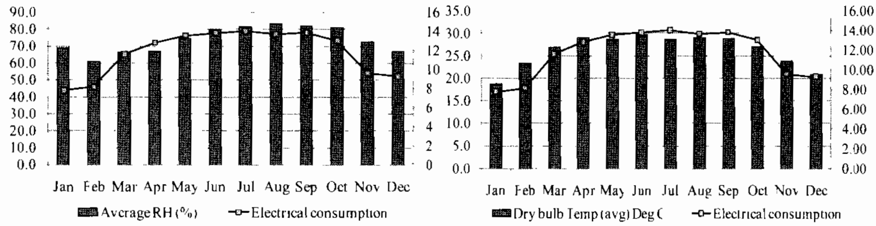


Figure 16: Relationship between Met data and energy consumption data, Year 2005 (Source: Met Data and PDB)

From comparative analysis among Meteorological data and electrical energy consumption data of the year 2005 in the charts (figure 16 and 17) it can be observed that electrical energy consumption of the Segunbagicha area has parallel relationships with Relative Humidity, Air temperatute, cloud cover and has inverse relationship with the Sunshine our, solar radiation and wind speed.

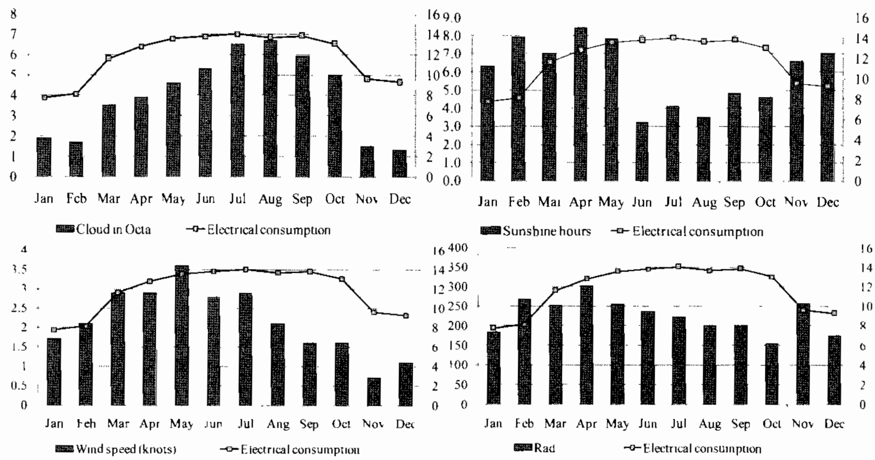


Figure 17: Relationship between Met data and energy consumption data, Year 2005 (Source: Met Data and PDB)

To justify the above comparative analysis with some definite numeric outcome, some statistical analyses like correlation, Ftest, Ttest and Linest (Table 3) is done among the detail monthly record of Meterological data and electrical energy consumption data of the studied area for the year 2005 with the help of 'Microsoft Excel' software. Here, 'Ftest' function is used to determine whether these two type of data have different variances. 'Ttest' is done to determine probability associated with these data, whereas 'Linest' is done to calculate some linear values that best fits these data. From correl statisitical Analysis (figure: 18) it can be shown that sunshine hour has inverse relationship (-0.51in value) with electrical energy consumption for Segunbagicha division. Through F-test probability analysis, it shows that only sunshine hour and cloud cover have probability relation with energy consumption. Again Through T-test it is found that probability associated with the Data are significant at all. LINEST analysis shows through value that it best fits with rain fall and solar radiation.

Table 3: Statistical Analysis of meteorological data and energy consumption and the results, Year 2005 (Source: Met Data and PDB, MS Excel)

Met. Data type	Correlation with Energy consumption	'F test' with Energy consumption	'T Test' with Energy consumption	Digression with Energy consumption (LINEST)
Dry bulb Temp (avg) Deg C	0.94	0.19	0	2.2
Average RH (%)	0.77	0	0	6.1
Rainfall in mm	0.9	0	0.03	16.7
Cloud in 'Octa'	0.92	0.55	0	0.35
Sunshine hours	-0.53	0.37	0	0.47
Solar Rad.	0.01	0	0	18.5
Wind speed (knots)	0.53	0.002	0	0.18

Now from the bar chart (Figure 19) it can be illustrated that the energy consumption of motijheel area (figure 1) is always high as from morphologial perspective, it has greater hard surfaces and no provision of cool micro climate. The studied area which is in the ramna circle have moderate energy consumption. The Energy consumption of old Dhaka (figure 1) is low as there is an effect of water body (Buriganga River) on its micro climate.

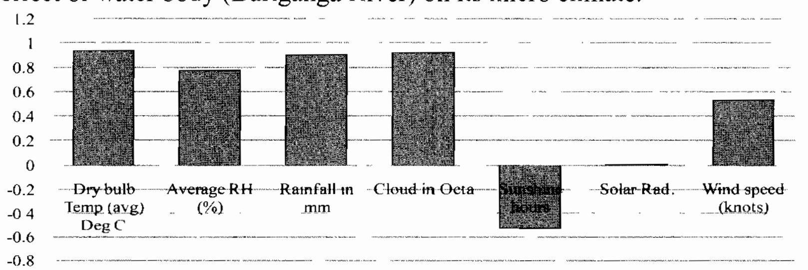


Figure 18: Results from 'Correl'Statistical Analysis of meterological data and energy consumption records, Year 2005 (Source: Met. Data and PDB, MS Excel)

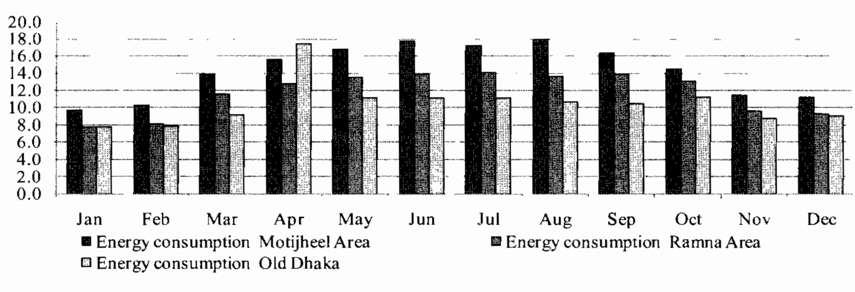
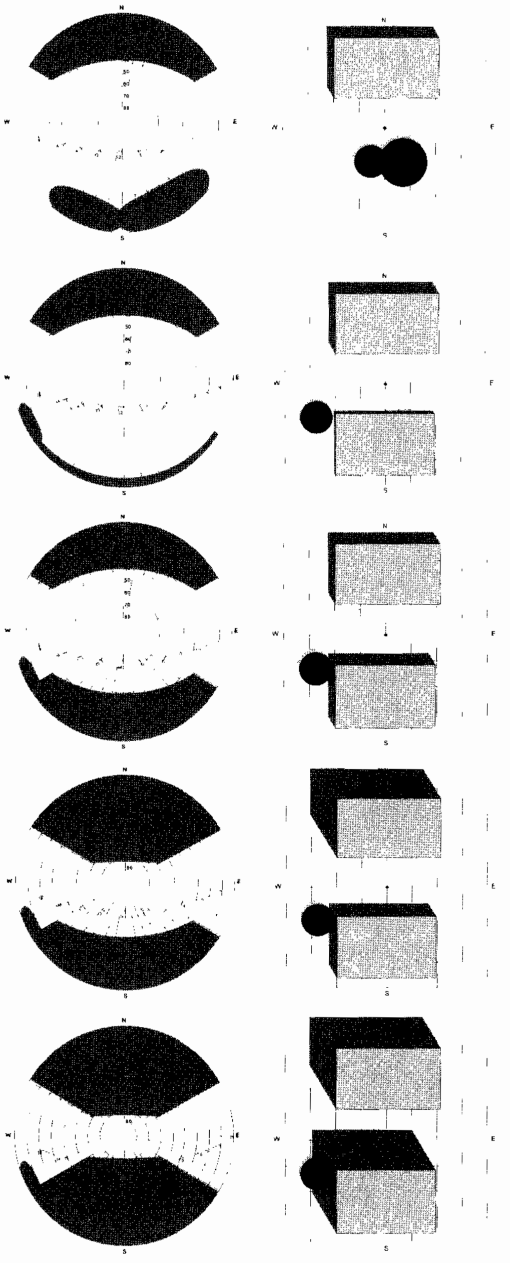


Figure 19: Comparative analysis of energy consumption of 3 areas of different morphological Character, Year 2005 (Source: PDB main office)



Canyon Type 1
(Suhrawardi Udyan Road):

Sky view factor: 0.695
Obstacle height: 40'
Deciduous tree1: 40',
Deciduous tree2: 20'

Canyon Type 2
(Katabon Road):

Sky view factor: 0.769
Obstacle height: 40'
Obstacle height: 20'
Deciduous tree: 20'

Canyon Type 3
(Elephant Road):

Sky view factor: 0.623
Obstacle height: 40'
Obstacle height: 40'
Deciduous tree: 20'

Canyon Type 4
Topkhana Road:

Sky view factor: 0.475
Obstacle height: 160'
Obstacle height: 40'
Deciduous tree: 20'.

Canyon Type 5
(Bijoy Nagar Avenue):

Sky view factor: 0.4375
Obstacle height: 160'
Obstacle height: 140'
Deciduous tree: 20'.

Figure 20: Analysis of various Canyons (Source: Rayman Software results)

The SVF variation in this urban areas and the importance of SVF in relation to other central parameters such as thermal admittance are also important. To limit the scope of the study on morphology a software analysis is done to find the relationships among the various canyons (Figure: 20) of this area with sky view factor and other climatic data found by the 'ray man' software. The spots are selected within Segunbagicha division to analyze the values of mean radiant temperature for the March, 2005. Five types of canyons are selected with constant road width of 80 feet assuming the other factors like construction materials, road orientations to be constant in order to limit the scope of the study. The objective of this software analysis was to observe the relationship between the sky view factor and the mean radiant temperature, as this temperature is one of main issues that have impact on electrical energy consumption of any area.

This software analysis (Figure 20) results that with increasing the height of the building in the canyons the sky view factors are decreasing and the mean radiant temperature decreases for the Canyon type 5. Further detail software analysis can be done in future with larger scope of work for accurate results.

7 Conclusion Remarks

According to the scope of study and its observations, analysis and results, it is clear that the urban morphology has a great impact in its microclimate. In relation to that it also directly controls the electrical energy consumption. So designing urban canyon, streets, buildings, urban open spaces- all are important to reduce the urban energy consumption and develop the quality of outdoor environment. Further detail and comparative studies can be conducted with larger scope of work to have recommended guidelines in this view.

Acknowledgement

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