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Cooling Effect of urban shade trees on roads and Roadside Built forms _An Analysis on Organic Urban Fabric of Dhaka

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Abstract

Dhaka, the capital city of Bangladesh, has grown spontaneously without any prior or systematic planning. The city has very enriched quality of urban fabric with a lot of possibilities to turn down many environmental issues. Mounting empirical evidence shows that the roadside urban vegetations are effective in mitigating the heat emission and pollution of built environment. The shade plants have impact on the built forms, in terms of radiative cooling, pedestrian thermal comfort, temperature control and reduction of air pollution by absorption of the pollutant. The existing road layout of Dhaka is developed in an organic pattern with time to meet up the need of rapid growing population. This paper focuses on cooling effect on built forms and hard surfaces alongside those roads. This analysis is based on the term 'Mutual Shading' by roadside trees. Although several studies on the cooling effect of shade trees in temperate urban areas have been reported, similar studies for the areas of Dhaka are rare. The objective of this paper is to analyze the impact of roadside trees and plants in urban air temperature including the comparison between two important primary roads with and without mutual shading and propose solution for maximizing the cooling effect. For proposed research query, temperatures under the tree canopies and an unshaded open space were measured repeatedly at mid days without precipitation and then an evidence based microclimatic software simulation is used. Finally, multiple regression analysis is done to analyze the contribution of vegetation characteristics to the cooling effect.

1. Introduction

Continuous socioeconomic development, along with growing population, has led to the sustaining urbanization and the associated changes in the Earth system, accelerating the flows of energy and materials (Batty, 2008). In particular, physical modifications via fabric and surface cover changes, as well as anthropogenic heat emissions, alter patterns of heat and water exchange within urban ecosystem (Arnfield, 2003). Changes of radiative, thermal, moisture, and aerodynamic patterns play an important role in affecting local boundary layer and emergent meteorological patterns (e.g., air temperature, air quality; Christen & Vogt, 2004; Oke et al., 2017; C. Wang et al., 2017; C. Wang & Wang, 2017). As a consequence, a series of environmental issues has arisen (Landsberg, 1981), examples including the formation of urban heat island (Grimmond, 2007), degradation of environmental quality and ecosystem services (Stone Jr, 2005), elevated energy and water usage (Breyer et al., 2012), and rise in heat-related morbidity and mortality (Harlan et al., 2006). The root of many urban environmental issues can be traced back to the exacerbated thermal environment of cities. It is therefore of crucial importance for researchers and policy makers to look for urban heat mitigation strategies to promote adaptive capacity of cities to global changes (Sherwood & Huber, 2010). In particular, the plantation of trees have emerged as a popular solution for alleviating the excessive thermal stress in cities, with other community benefits such as stormwater management (US EPA (United States Environmental Protection Agency), 2008). Trees have multiple biophysical functions in the urban ecosystem (Erell et al., 2011), among which the radiative shading and evapotranspiration (ET) are predominant in regulating the thermal environment. The presence of crowns can reduce the penetration of shortwave solar radiation and lower the surface and air temperatures in shade (Roy et al., 2012). In addition, trees can provide cooling by transpiration, especially during nighttime (Konarska et al., 2016). The evapotranspirative cooling (hereafter ET cooling), however, is highly affected by the seasonal variability in foliage for deciduous trees.

The cooling effect of trees is in general beneficial to the urban environment, leading to energy saving and improved pedestrian thermal comfort during hot seasons (Shahidan et al., 2010). Nevertheless, there are adverse effects of urban trees that should not be ignored. For example, urban trees can impede the vertical mixing inside street canopies, leading to reduced efficiency of pollutant dilution and dispersion (Gromke et al., 2008; Li & Wang, 2018; Morani et al., 2011; Oke et al., 1989). Previous studies of urban trees were mostly based on empirical evidence using field measurements (Shashua-Bar et al., 2011). There are only very few numerical simulations using neighborhood-scale models such as ENVI-met (e.g., Middel et al., 2015). This study is designed to focus exclusively on the radiative shading effect of trees as a stand-alone mechanism in regulating the urban thermal environment. In addition, the impacts of radiative cooling of urban trees are evaluated in terms of changes of outdoor human thermal comfort and urban land surface energy balance.

2. Background

Dhaka has grown mostly without adequate planning interventions; substantially organic in nature. The patterns of areal expansion and the urban form of Dhaka have been largely dominated by the physical configuration of the landscape in and around the city, particularly the river system and the height of land in relation to flood level. [Islam, 1996: 191] Human settlement in Dhaka can be traced back as early as the 12th century (Ahmed, 1986). It is likely that the fertile land of the delta brought human settlement on this land. There are two dominant general patterns in the historical evolution of urban (Nilufar, 2010), old Dhaka or the historic core and new Dhaka or northern expansion. The growth of Dhaka from 1949 to 1989 largely followed the limits determined by the Mughals (i.e. towards north up to Tongi, up to Mirpur in north-west, up to Postagola in south-east). They recognized the importance of the land and established a city in the early seventeenth century (Karim, 1989). It was the geographical location of Dhaka, the topographic advantages of being situated on higher ground in a low-lying region, and above all its strategic position on the water-routes of the country which convinced the Mughals to establish their capital (Chowdhury and Faruqui, 1989) South East Asia.

The physical changes that Dhaka went through were not only in terms of vast territorial expansion, but also through internal physical transformations. The urban built-up area of Dhaka increased by 88.78% in the past 20 years from 1989 to 2009. The city went through phases of growth and decline from its beginning as a city with a small population to its current state as a tremendously expanded megacity. Figure shows the physical development of Dhaka City at different stages of its growth.

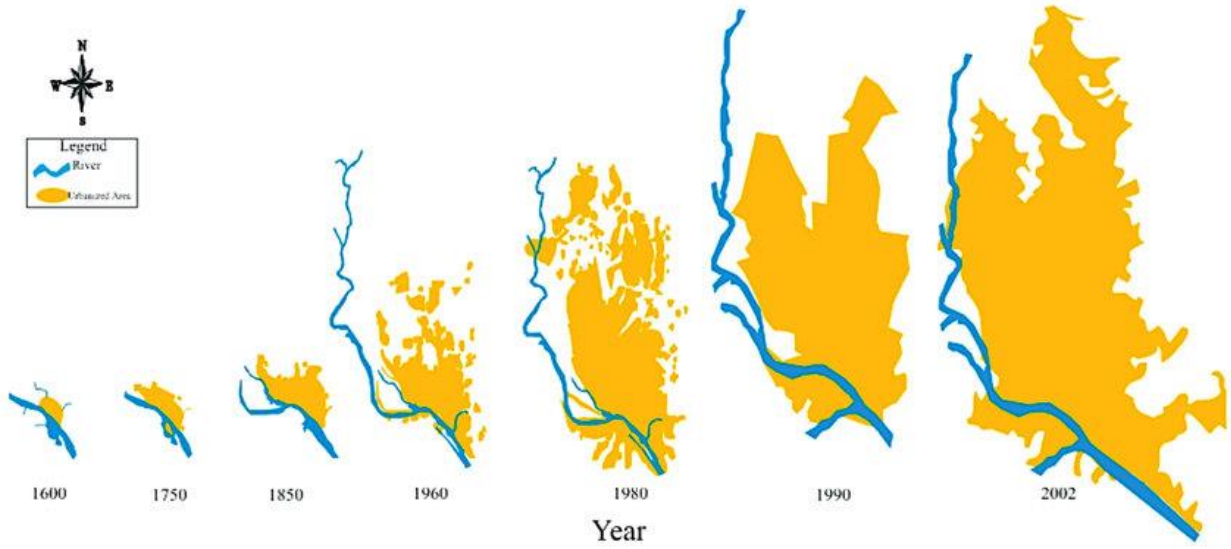


Figure 1. The historical growth of Dhaka City (not to scale). Source: Urban Planning Department, Dhaka City Corporation, 2007.

3. Literature Review

The unplanned growth of Dhaka city has induced many problems such as It presents UHI(urban heat island effect), deforestation, flash flood, lack of recreation sites or natural parks and playgrounds, unclean air etc. Many of these problems can be mitigated to a great extent by strategic planning at the national level, decentralize administration and implementing green infrastructure. Originally, the term green infrastructure was used to describe a network of green spaces that were connected, offering multiple ecosystem services. In the last decade, green infrastructure benefits have expanded beyond stormwater management and urban runoff mitigation to include other ecosystem services.

Green Infrastructure is a strategically planned network of high quality natural and seminatural areas with other environmental features, which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. [1](Cities, green infrastructure and health A paper for the Foresight Future of Cities project by Dr Val Kirby FLI and Stephen Russell, Landscape Institute, July 2015) . England's National Planning Policy Framework (NPPF) does so: it defines GI as a network of green space, both new and existing, both rural and urban, which supports natural and ecological processes and is integral to the health and quality of life of sustainable communities.[2] (Department for Communities and Local Government, National Planning Policy Framework (NPPF) March 2012) Even modest increases in tree canopy cover can significantly reduce the urban heat island effect via evapotranspiration and shading, as well as improving air quality. Tall and mid height shade trees alongside the roads provide mutual shading that can play a vital role in mitigating air temperature and create a green infrastructure in urban fabric. In this paper possibilities of implementing Green Infrastructure will be discussed.

4. Statement of Problem

In the quest of meeting the great demand of urbanization, the city has been developing her infrastructure as well as built environment by continuous ignorance of nature. Comparing with rural surroundings, this built environment of Dhaka city is mostly uncomfortable to her dwellers' experience. Expansion of unplanned urbanization and built structure results cutting a large number of trees and converts the urban land full of concrete surfaces. A minimum 25% of forest cover is suggested for a healthy living (Mowla, 1984) where at present in old Dhaka (old part of the city) only 5% and new Dhaka (new part of the city) 12% of land is green and open (Mowla, 2011). Vegetation has potential to reduce environmental temperature. Its form and configuration influence solar radiation, temperature, air humidity and wind flow of an urban setting.

There is a huge number of roads and pavements in Dhaka city and the amount of hard surfaces they create is really high. Use of excessive exposed hard surfaces like brick and concrete pavements, pitched road are responsible for raising urban air temperature. The Roads, paved ways or footpaths of a city are considered more vibrant when it can allow more people for outdoor activities. So it is important to create attractive and welcoming pedestrian level activity for the public, where outdoor comfort can be an important criterion. Again, air temperature is a vital aspect for this outdoor comfort. It is found that when meteorological data of average air temperature for a road with shade trees is 20 C then the average air temperature of the road without trees is 25 C (Field Study). Vegetation is an important element of nature. Being an organic element, vegetation has some impact on local microclimate as well as global climate. That is why this study is focused on the impact of vegetation on roadside built environment in dhaka, in terms of air temperature.

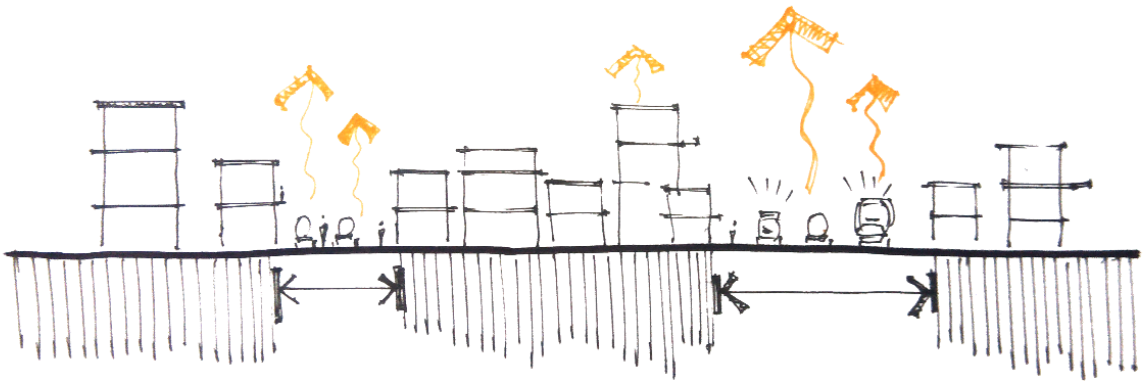


Figure 2. Hard saufaces and builtform are emitting heat which increases air temperature.

5. Objectives

The objective of this paper is to show how roadside shade trees can affect the temperature of roads, pavements and nearby built forms. The impact of roadside urban vegetation in air temperature is stated here and the possibility of vegetation configuration are explored to maximize the cooling effect on pedestrian level in Dhaka city. This paper aims to determine the issues with some field survey data analysis and simulation. Parallelly the criteria of vegetation and how they determine the shading properties will be discussed.

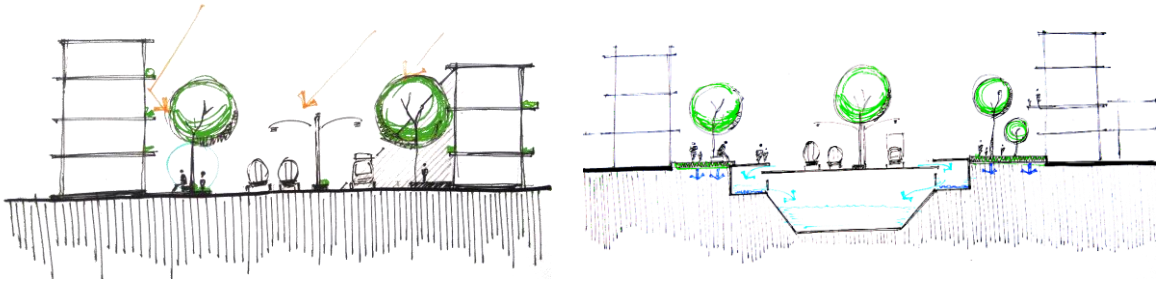


Figure 3 &4. Roads with trees can create pedestrian level activity more comfortable by reducing air temperature.

5. Methodology

The methodology of this study can be described in three steps and these are:

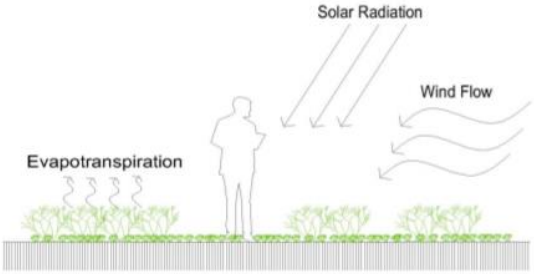
Step 1: **Literature Review and Theoretical Basis:** Study the relationship between vegetation and basic four environmental components and the impact of vegetation on the open spaces from different paper, journal, books, articles etc.

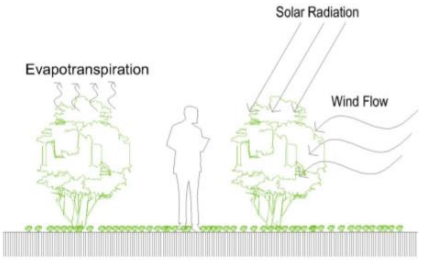
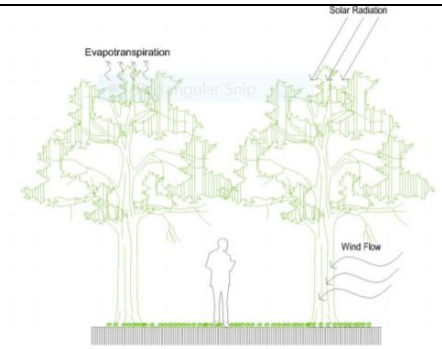
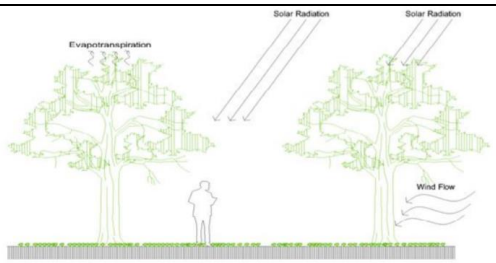
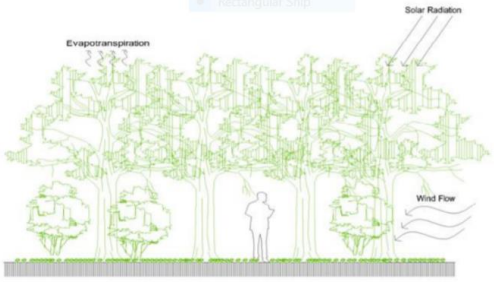
Step 2: **Field Study:** A short field survey (at two major primary roads) has been done in the current situation of Dhaka. This part is very important for this research because this research is based on field study and the output provides the current microclimatic data of the study area. Two roads are selected for this study. Road 01 is North South road and road 02 is Azimpur road. Both the roads are laid in north south direction and consist of both pitched surface and pavement. The only difference is that there are tall trees on both sides of azimpur road when the roadsides of north south road is full of built forms. This step will find out the answer of the query, whether is there any variation of air temperature happened for presence of green vegetation and urban pave. For data collection, 5 Points (spot) have been taken (in almost equal distance) on an imaginary line along the centre (north-south direction) for the both cases for measuring the air Temperature. Here for Azimpur road and north south road, lump sum 500 ft distance has being taken, where after every 100 ft one data point has located. All data have been taken on that imaginary line above 1m ground level with the Kestrel 3000 Pocket Weather Meter. The data was being taken on January, 2018 on morning 10.00 am, noon 1.00 pm and evening 4.00 pm.

Step 3: **Simulation:** Microclimatic simulation has been done by ENVI-met software to compare with the survey results. Two roads are considered for ENVI-met modeling. Input data are found from field survey and weather data of Dhaka.

6. Types of vegetation

Table 1. Impact of Vegetation and Climate Components

	Classify plants	Solar Radiation, Air Temperature, Air Flow and Relative Humidity	Comments
In General	Herb	 **Figure 5. Impact of Herbs**	_Direct solar radiation and Air temperature is higher than other cases in open spaces. _ Uninterrupted wind flow. _ Relative humidity depends on density of green. _ Reduces dust and no visual barrier.

	Shrub	 **Figure 6. Impact of Shrubs**	_ Sometimes small shaded area or sometimes direct solar radiation in open spaces. _ Shrubs hinder the natural wind flow in human level, but a large or smaller shrub allows air flow in human level. _ Relative humidity is high in human level. _ Sometimes filters air and create barrier. _ Flowering shrubs are good in terms of aesthetics.
	Tree	 **Figure 7. Impact of Trees**	_ Create shaded spaces. _ Allows gentle wind movements in human level, and filters or guiding the movements in. _ Sometimes ground cover do not grow in the soil because of large shading tree and lack of solar radiation. _ Air temperature is less in the shading area. _ Relative humidity is high under the tree.
	Low (SDI < 280)	 **Figure 8. Impact of Low Density Green**	_ Allows direct solar radiation. _ Allows gentle wind flow. _ Air temperature is less than a paved area. _ Relative humidity is moderate. _ Allows ground cover in the soil.
	High (SDI >280)	 **Figure 9. Impact of High Density Green**	_ Do not allow direct solar radiation. _ Hinder wind velocity sometimes allows tunnel effect. _ Air temperature is less than other situation _ Relative humidity is high. _ Sometimes do not allow good grass on ground and Create dark shade.

6. Field Study

Road 01: North South Road

North South road is one of the major primary roads in Dhaka city. There are a number of banks, office, shops and other commercial activity zones beside this road. Building height alongside the road varies from two storied to seven storied. This is a wide one way road with a divider in the middle. There are a few trees planted in the divider which do not provide any shade. As a result temperature is higher in this road, roadside pavements and the nearby built forms. The maximum temperature here is 27.53 C and the minimum is 25.73C.

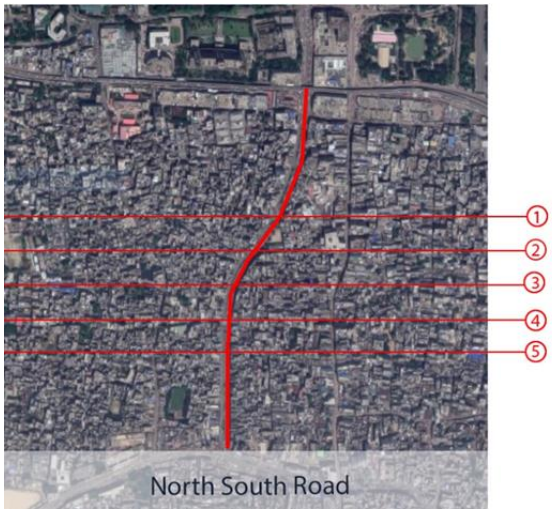


Figure 10: North South Road top view

Point 01

Point 02

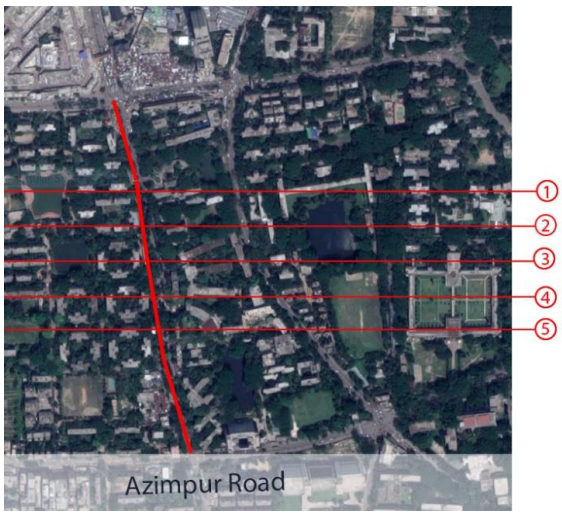
Point 03

Point 04

Point 05

Road 02: Azimpur Road

Azimpur road connects two important nodes of this area, nilkhet moor and azimpur bus stand. This is also a wide road which remains busy throughout the day. There are public institution and public housing facilities alongside the road. There are tall and mid height trees which keep the temperature of road, paves and surroundings cool. This makes the pedestrian level more comfortable there.



Point 01

Figure 11. Azimpur Road top view

Point 02

Point 03

Point 04

Point 05

ENVI-met Simulation

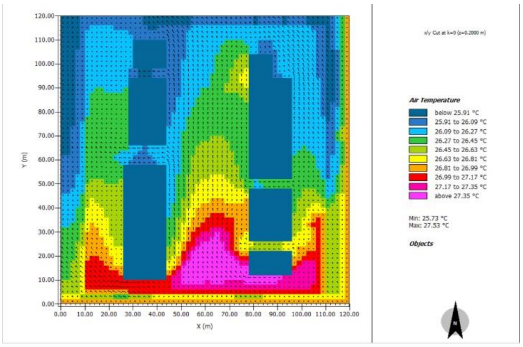


Figure 12. Thermal image of North South road

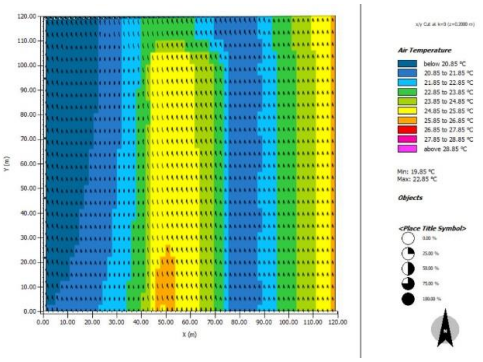


Figure 13. Thermal image of Azimpur road

Here the two thermal images of the two roads show the difference of temperature in the stated roads. The difference of temperature is almost 5-6C which is determined from the simulation.

7. Vegetation Characteristics

It is found from road 01 and road 02 that air temperature in a shaded road with road side shade trees is remarkably less than a paved road with no shade trees in Dhaka city. In Case Studies Average Air Temperature in shaded roads varies from 19.85 to 22.85 where in roads without shade trees varies from 25.73 C to 27.53 C. There are some other issues that can be described as following:

Shade: The shaded area of the road 02 is much cooler than road 01. A few examples of trees that provide shade in our city areas are Mehagoni, Gorjon, Koroi, Jarul, Shishu, Segun etc. They provide shade on most of the day time and keeps the road surface on moderate temperature.

Types of vegetation :This is another important issue because all types of plants will not provide proper shade that is needed for cooling effect. Both of the roads have some herbs and shrubs but as a matter of fact they do not provide shade on roads. But they help to reduce environmental pollution and make the air quality better. Considering the temperature of the pavements and the roads, tall trees serves best to reduce air temperature.

Vegetation Density: Vegetation density also effects the cooling. Denser vegetations increase Evapotranspiration, which reduces the air temperature. Road 02 has dense trees which provide full shade during day time for a long time of period. For this reason this road has a less average temperature than the other one.

Surrounding Vegetation and Presence of Built Objects: Surrounding area has also an impact in the air temperature. Here surrounding area is not considered enough. For both the roads there are built forms beside the road. Number of built objects is higher in road 01 when the amount of trees and green spaces is higher in the area of road 02.

8. Observation

Vegetation has tremendous impact on local microclimate. Presence of vegetation minimizes direct solar radiation and reduces microclimatic air temperature (5C - 6C) in an urban space. As wind flows from south east in Bangladesh (generally), vegetation locating in south can help to reduce the air temperature on the pave locating in the north. Large and dense trees create shade. Air temperature is less in the shaded space than an exposed area (2C – 3C). Even air temperature in the shaded pave is less than the pave exposed to the sun. Air temperature also depends on types of vegetation used in a space. Types and configuration of herbs, shrubs and trees are important for local air temperature. Density (trees) is also an important component for reducing air temperature. Dense vegetation helps to reduce air temperature by screening solar radiation.

9. Conclusion

In general, urban trees are found to be effective in alleviating urban thermal stress via radiative cooling effect, more prominent during nighttime. This cooling effect is beneficial to outdoor thermal comfort by reducing the summer heat index for cities located in tropical and subtropical climates. Over a long run, the presence of urban trees has opposite effect on the land surface energy balance: it reduces the shortwave radiation during daytime but enhances the terrestrial radiation during nighttime. As a response, this change of surface energy balance leads to significant reduction of long-term mean sensible heat toward the land surface, while leaving the long-

term ground heat storage comparatively intact. We reiterate that the proposed WRF-urban modeling framework only incorporates the radiative heat exchange between trees and urban facets, leaving out other biophysical functions of trees such as ET in the current study. Much work is left to be done for more comprehensive and realistic representation of urban trees and their interactions with the built environment. Nevertheless, the findings of this study on radiative cooling effect of trees can be informative to researchers and policy makers. For instance, most of the current urban mitigation strategies focus, almost exclusively, on reducing the daily maximum temperature, but largely ignore the nighttime thermodynamics of cities. A famous example is the widely advocated use of highly reflective (white) materials on roofs (aka cool roofs). White roofs cools the urban temperature above the canopy layer during daytime, but become unserviceable during nighttime in the absence of solar radiation. In planning for sustainable development of future cities, this one-sidedness needs to be avoided. Toward this end, the use of urban green infrastructure in general (trees included) emerges as an attractive option.

8. Acknowledgement

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