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COOLING EFFECT OF ROADSIDE URBAN SHADE TREES
An analysis on urban fabric of Dhaka

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Abstract
The rapidly growing population and consequent unplanned and uncontrolled urbanization of Dhaka, the capital city of Bangladesh, has resulted in the gradual loss of green spaces in the city. However, the city possesses enriched quality of urban fabric contributing towards varied forms of environmental benefits. Mounting empirical evidence shows that the roadside urban vegetations are effective in mitigating the heat emission and pollution of built environment. The shade trees 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. This study focuses specifically on the 'cooling effect' of the roadside trees and plants of Dhaka city, analyzes their impact on air temperature under the shaded and unshaded areas on roads including the comparison between two important primary roads with and without mutual shading, and proposes solutions for maximizing the cooling effect. For proposed research query, temperatures under the tree canopies of a shaded road and an unshaded road 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.

Keywords: *Urban vegetations; roadside trees; air temperature; cooling effect; vegetation characteristics.*

1. Introduction

Rapid urbanization and population growth have led to the change in the earth system, accelerating the flows of energy and materials. Changes in meteorological patterns (e.g., air temperature, air quality) creating alteration of heat and water exchange within urban ecosystem. As a result, various environmental issues have arisen including the formation of urban heat island and degradation of environmental quality. To promote adaptive capacity of cities to global changes, it is of crucial importance for researchers to look for urban heat mitigation strategies. The plantation of trees has emerged as a popular solution to control temperatures and to mitigate the effects of the "urban heat island" by alleviating the excessive thermal stress in cities. Among multiple biophysical functions of trees in the urban ecosystem, radiative shading and evapotranspiration (ET) are predominant in regulating the thermal environment.

At any point near the ground the air temperature is dependent upon the amount of heat gained or lost at the earth's surface and any other surfaces that the air is directly in contact with. During the day as surfaces are heated by solar radiations, the air nearest to the ground acquire the highest temperature. In calm condition the air within two (02) meters of the ground remains stratified in layers of differing temperature. However, trees and vegetation form an intermediate layer between the earth's surface and the atmosphere. By covering the ground with vegetation, the surface of contact can be elevated by four to twelve times. By means of shading and transpiration, plants can significantly reduce air temperature. They also increase the humidity whereas it is already too high. In a hot and humid climatic condition, the ideal situation is to have a high canopy of trees for shade, but no low plants that could block the breeze.

2. Statement of Problem

From the very beginning of urbanization, the built environment and infrastructure of Dhaka city has been developed in a way where the environmental issues were barely addressed. As a result, Dhaka has failed to create a comfortable dwellers' experience comparing to most other well-planned cities. For instance, 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 in new Dhaka (new part of the city) 12% of the land is green and open (Mowla, 2011). Another data says that 10.46% area of Dhaka city corporation is hard surface that consists of the roads and the highways. Use of excessive exposed hard surfaces like

brick and concrete pavements, and pitched roads is responsible for raising urban air temperature. This situation is alarming for a city such as Dhaka that aims towards ensuring a healthy living condition.

To alleviate the situation, the roads, paved ways and footpaths should be planned in a way that will invite more people for outdoor activities providing a comfortable environment for them. There are several criteria for a weather to be considered as comfortable such as air temperature, humidity, wind flow, wind velocity etc. Among these, air temperature is an essential criterion which can be moderated by roadside trees that provide shade on roads and surrounding surfaces. This study firstly focuses on the impact of roadside shade trees on roads, paved ways and built forms in terms of air temperature. The next phase of this study is to analyze tree properties that maximize the cooling effect and then to suggest some trees for roadside plantation in the context of Dhaka.

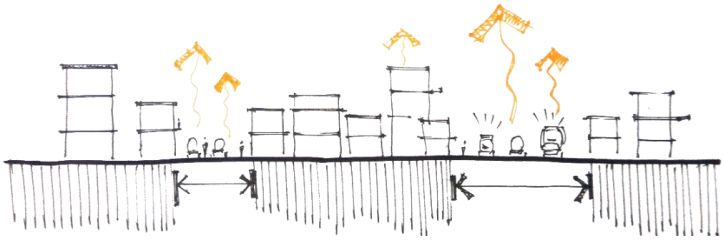

Figure 1. Hard saufaces and builtform are emitting heat which increases air temperature.

3. Objectives

In brief the objective of this paper can be summarized as follows:

- To analyze the influence of roadside shade trees on roads, pavements, footpaths and nearby hard surfaces in Dhaka city in terms of air temperature.
- To figure out the configuration of the trees required to improve the cooling effect on roads.
- To provide a suggestion of trees for roadside plantation according to their configuration.

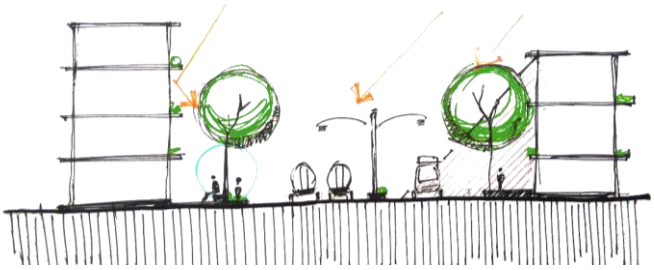

Figure 2. Roads with trees can create pedestrian level activity more comfortable by reducing air temperature.

4. Methodology

The methodology of this study can be described in three major steps.

4.1. STEP 01: LITERATURE REVIEW

In the literature review the morphological change of Dhaka city is studied. With time the conversion of land into built form and hard surfaces and simultaneously the drastic change in the amount of vegetation is discussed. Then the impact of vegetation and roadside trees in the comfort level is analyzed from different books, papers, articles, journals etc. The tree properties are taken into consideration and a list is made for roadside plantation in the context of Dhaka city prioritizing the quality of making the roads and surroundings cooler.

4.2. STEP 02: FIELD SURVEY

A short field survey in two major primary roads of the city is carried out in the present condition of the roads. Before selecting the two roads several major primary roads are practically overviewed to understand the layout, orientation and the number and species of trees planted in previous years alongside those roads. The first road taken into consideration for examination is the North South road

that connects the 'Noya bazar' bus stop and the 'CBS-2 bus terminal'. This is a mixed used development area and the road connects two node points. The second road is the Azimpur road that connects the Azimpur bus stop and the Nilkhet bus stop. Both the roads are laid in the north south direction and consist of both pitched surface and pavement. The only difference is that there are tall trees on both sides of the Azimpur road when the roadsides of the North South road is full of built forms. This survey will help us understand whether any variation of the air temperature takes place due to the presence of roadside trees.

The survey was conducted on June 2018 at noon. June was selected as the hottest month of the year when the shade is mostly needed. In order to measure the air temperature, 5 equidistant observation points on an imaginary line along the road in the north south orientation was taken for both roads. The distance between two successive observation points was taken as 100ft. Kestrel 3000 Pocket Weather Meter was used to measure the air temperature and all the measurements were taken 1m above the ground level.

4.3. STEP 03: SIMULATION

ENVI-met software has been used to do the microclimatic simulation for a comparison with the survey data. The weather data of Dhaka is used for simulation with the survey data. Data input was provided separately for the two roads and separate model is made for each simulation.

5. Literature review

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 (Ahmed,2014). Figure 3 shows the physical development of Dhaka City at different stages of its growth.

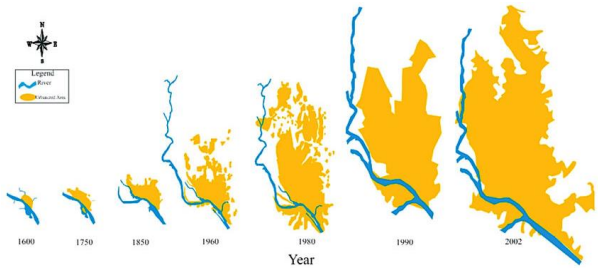

Figure 3. The historical growth of Dhaka City (not to scale). Source: Urban Planning Department, Dhaka City Corporation, 2007.

Urban population in Bangladesh is 52.56 million of which Dhaka city consists of 40% (Ahmed, 2018) making it one of the largest mega cities in the world. The necessity to meet the need of space for housing, business and industries for this large population has resulted in the rapid conversion of agricultural land to urban use. These kinds of meteoric urbanization trend results in tremendous scarcity of trees affecting the natural environment of urban areas. It has been reported that one of the major causes of the continuing environmental degradation in Dhaka city is deforestation (Islam, 2002).

There is a very close relationship between trees and improved urban environment since trees play a vital role in mitigating urban heat island (UHI) effect. While finding solution for maximizing the cooling effect of trees, in practice, designers and planners often have difficulty demonstrating their cooling properties. The most effective way to measure the cooling effect of roadside trees would be to compare the urban air temperature between two roads with and without mutual shading. For a credible comparison, we need to have a clear understanding of the physics of heat flows in our cities, and the scale of the measurements we are taking.

Theoretically, trees can help provide cooling in two ways: by providing shade, and through a process known as evapotranspiration. Locally, trees provide most of their cooling effect by shading. Like a Parasol, A tree's canopy can block out up to 90% of the sun's radiation and increase the amount of heat that we lose to our surroundings by cooling the ground beneath us. According to Wardoyo (2011), Individual leaves allow 20% radiation to be transmitted through them, absorb 55% and reflect the rest 25%. So, Trees can be used to tackle the problem of the urban heat island. During periods of calm, sunny weather, the air temperature of urban areas can be raised above that of the surrounding rural areas by up to 6°C, especially at summer seasons in Bangladesh (Mowla, 2005). In cities, the hard, dark asphalt and brick surfaces absorb almost all the incoming short-wave radiation from the sun, heating up to between 35°C and 40°C, and storing energy which is released into the air during night, when it can be trapped in the narrow street canyon.

Urban trees can impede this process by intercepting the radiation before it reaches the ground and using the energy for evapotranspiration. Evapotranspiration occurs when the sun's rays hit the trees' canopy, causing water to evaporate from the leaves. This cools them down – just as sweating cools our skin – thereby reducing the amount of energy left to warm the air. Evapotranspiration effects can be quantified in two ways. Firstly, one can measure the temperature of the tree canopy, which is typically much cooler than built surfaces – only 2°C to 3°C above air temperature. However, it cannot be claimed that this temperature difference is evidence of cooling capacity; leaves would be cooler than built surfaces even if they weren't losing water, because they are cooled more effectively by convection. A better method is to calculate the cooling effect of a tree directly on the air temperature change by comparing two different zones.

Simultaneously, the climatic data and environmental criteria of Dhaka city is also necessary to run this survey. Dhaka city is in warm humid tropical region. Considering the air temperature, humidity and the amount of rainfall, the climate of this area can be divided into four seasons. According to Hossain and Nooruddin meteorologically the climate of Bangladesh is categorized into four distinct seasons Winter (cool dry), Pre-Monsoon (hot dry), Monsoon (hot and wet), Post-Monsoon (hot and wet), where Winter months (December to February) temperature 21-26 C, Pre-Monsoon (March to May) temperature max 34 C, Monsoon (June to September) avg. 31 C, Post-Monsoon (October to November) temperature bellow 30 C (Ahmed, 1996). Average Relative Humidity is 60-80%. Radiation on a horizontal surface 5.00 kWh/ m2 and Air Flow 4.1 m/s (Ahmed, 1996).

6. Considerations for roadside plantation

The following are the factors which should be considered for roadside tree plantation in urban area.

6.1. SPECIES SELECTION:

The climatic condition in the city streets is different from the residential areas. The species therefore selected for a given road must be adopted to it. Soil characteristics is an important factor for tree selection. Some trees grow in alluvial soil like Jarul, Kadam, Aam, Jam,Babla,Shishu, Shimul, raintree etc. Jam, Malina, Gulmohor, Shal, Aam, Kathal, Shimul, Hartaki, Karai grow in clay soil. Shisham, Shimul, Jhau, Babla grow in sandy soil while Jarul, Arjun, Hijal, Tarcharbi grow in water clogged soil (Mowla, 2005). Bueno-Bartholomei and Labaki found that, the structure of the crown, dimension, shape and colour of vegetation leaves influence reduction level of solar radiation (Bueno-Bartholomei and Labaki, 2005). Scudo (2002) establish that geometry, height, permeability and crown of the vegetation are the structural vegetal characteristic that influenced the controlling air movement and air temperature.

6.2. SPECIES COMPOSITION

Every attempt at plantation should aim at establishing polyculture forests consisting of the best kinds of trees. The highways can have 3-4 rows of trees whereas the primary roads can have single or double rows on either side. To contain more trees of the right kind, saplings should be planted following a good plan.

The lowest ebb of the roadside may have jarul saplings along with some babla and hijal. These plants can thrive in water. Aam, mahogoni, gorjan, debdaru, rendi koroi, jaam etc. may be planted in the middle. Kathal, shimul, segun, redwood etc. cannot withstand water, so they should be planted along the highest ebb.

6.3. SPACING OF TREES

Street trees are precise and require different type of planting as regards to availability of space, potential interference with curbs, side works, driveways, overhead wires, underground facilities, traffic signals, etc. Timber or flowering trees which are planted alongside primary roads require spacing from 10m to 20m according to species types. Spreading of roots, plant height, canopy shape and diameter are some parameters that determine tree spacing.

7. Field Survey

Road 01: The North South Road The North South road is one of the major primary roads in Dhaka city. There are several 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 where a few trees are planted. The trees do not provide any shade and the people on the pedestrian level are not benefited with the trees. As a result, temperature is higher in this road, roadside pavements and the nearby built forms.

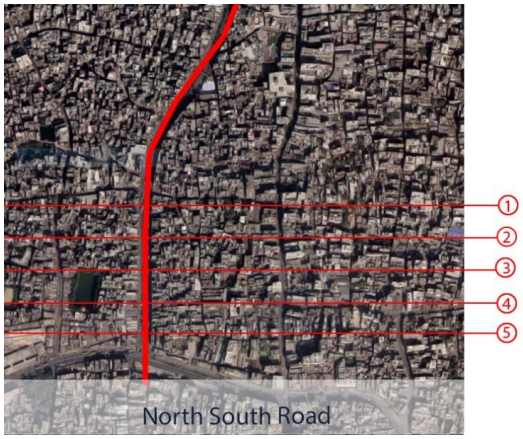

Figure 4: North South Road top view


Figure 5: Point 01


Figure 6: Point 02


Figure 7: Point 03


Figure 8: Point 04


Figure 9: Point 05

Road 02: The Azimpur Road The 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 lower. This makes the pedestrian level more comfortable there.

The average temperature of North South road without shade trees is 37c whereas the average temperature of Azimpur road of same width with roadside shade trees is 32c.

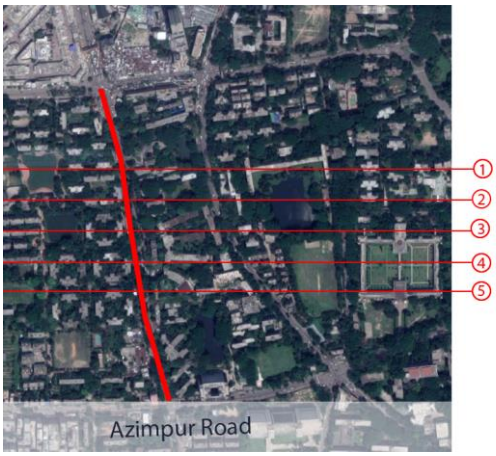

Figure 10: Azimpur Road top view


Figure 11: Point 01


Figure 12: Point 01


Figure 13: Point 03


Figure 14: Point 04


Figure 15: Point 05

8. ENVI-met simulation

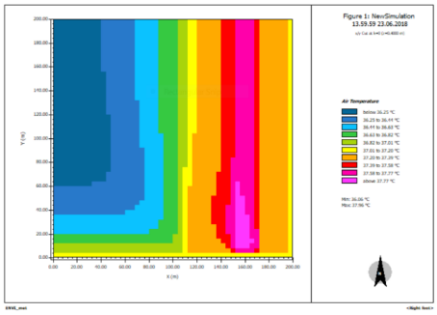
Figure 16. Thermal image of North South road

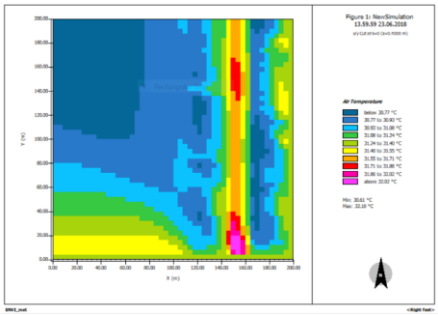
Figure 17. Thermal image of Azimpur road

Here the two thermal images of the two roads show the difference of temperature in the stated roads. The maximum and minimum temperatures in the North South road are 37.96 C and 36.06 C respectively while the maximum and minimum temperatures in the Azimpur road are 32.18 C and 30.61 C respectively. The difference of temperature is almost 5-6C which is determined from the simulation.

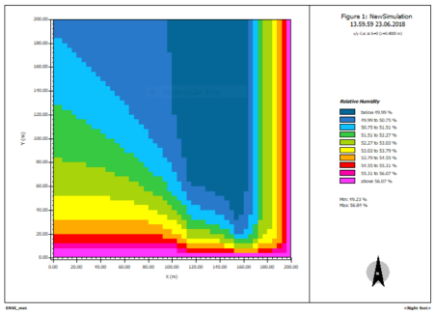
Figure 18. Relative humidity image of Azimpur road

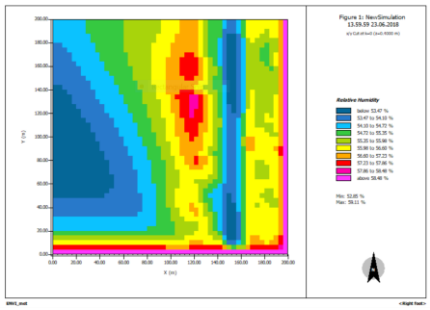
Figure 19. Relative humidity image North South road

Both roads have a relative humidity within comfortable range (25 - 60%) though the humidity in the North South road is lower by around 3%. Hot air has the capacity to hold more water than cooler air. Therefore, as the temperature rises with no extra moisture added to the air, the relative humidity decreases.

9. Impact of tree configurations

From the two case studies it is found that shade trees contribute in reducing the air temperature. Temperature at roads with trees is much lower than the roads without shading. Here are some configuration which help in maximizing the cooling effect provided by the shade trees.

9.1. MATURE HEIGHT

Tree height is a factor that is directly connected with shading properties. In case study 02 Weeping Debdaru, Babul, Mahogany, Bakul, Neem etc. are planted along the Azimpur road. Most of them are timber producing tree with a mature height of 7m to 30m. A few of them are not very high shade trees but can afford pedestrian thermal comfort.

9.2. SHAPE OF TREE

During daytime shade trees provide reduced temperature by blocking sunlight, increasing air humidity and by providing shade. The shade offered largely depends upon the shape of the crown of the tree. Crown shape varies from tree to tree such as round shape, oval shape, pyramid shape, weeping, spreading, free form etc. Round, oval or spreading shaped crown provide better shade though shade also depend on foliage density. In case study 02, the Azimpur road has Debdaru trees in the median which has a columnar crown shape and do not produce much shade. At the same time sidewalks have Mahogany, Bakul trees having round crown providing better shade.

9.3. CANOPY DIAMETER

Tree crown size is a key variable in this context as it correlates with the space a tree occupies. Canopy with large diameter can provide shade and block sunlight from reaching the ground to a great extent. Average crown diameter of timber type trees covers a wide range from 10m to 60m according to the tree types. For the studied roads, the Azimpur road has both small crown trees such as Debdaru (3m) and large crown trees such as Mahogany (15m).

9.4. GROWTH RATE

In terms of growth rate of a tree, the designation slow means the plant grows 12” or less per year; medium refers to 13 to 24” of growth per year; and fast to 25” or greater (Manual of Woody Landscape Plants, by Michael Dirr). Most of the trees planted by roadside are fast growing. Within three of four years they become suitable for providing shade at pedestrian level.

9.5. SHADE PROVIDED

The results of our field survey and simulations proves that the strategic selection of tree can play a vital role to ensure human comfort. It is assumed that tall trees with dense foliage will provide dense shade but there is a possibility for hazards when they are placed too close to a structure. The structural damage by this kind of phenomenon disqualify the benefits by those trees (McPherson et al. 2005). Therefore, a balance between the size and the shade provided by the trees is needed. The Azimpur road trees are neither very tall nor do they have very dense foliage. Still they manage to produce a desired thermal condition. Here is a list of trees and their configuration which are planted by the roadsides of Dhaka city.

Scientific name	Common name	Shape	Mature Height	Canopy Diameter	Growth Rate	Shade Provided
Saraca asoca	Ashok	Rounded	7–10 m	15-20 m	fast growing	Medium shade
Acacia auriculiformis	Akashmoni	rounded	15–30 m		fast growing	dense shade
Albizia richardiana	Albizzia	rounded	10-15 m	5-10 m	fast growing	dense shade
Mimusops elengi	Bakul	rounded	16 m/ 15 - 30 m	10 m	medium rate	Dense shade
Michelia champaca Linn.	Champa	conical to cylindrical	up to 50 m	6-10m	fast growing	light shade
Peltophorum	Goldmohur	umbrella-like	15–25 m	15-20 m	fast growing	Dense shade

Pterocarpum						
Polyalthia longifolia	Debdaru	narrow columnar	10- 18 m	15-20 m	slow growing	light shade
Lagerstroemia speciosa	Jarul	round, vase, upright	to 20 m	15-20 m	fast growing	Medium
Albizia Procera	Korai	irregular ovoid	10 to 20 m	5-10 m	fast-growing	light shade
Delonix regia	Krishnachura	umbrella shaped	10 - 18 m		fast-growing	moderate shades
Swietenia mahagoni Linn	Mahagoni	rounded	30–35 m	13-20 m	fast growing	dense shade
Mesua ferrea	Nageshwar	pyramidal-shaped	10-20 m		slow growing	moderate
Azadirachta indica	Neem	roundish	15–20 m	20–25 m	fast-growing	dense
Butea monosperma	Polash	irregularly shaped	5-20m	15-20 m	slow growing	light shade
Enterolobium saman Prain	Rain tree	umbrella-shaped	15–25 m	30-60 m	Moderately fast	dense shade
Dalbergia sissoo Roxb	Sishu	Oval	up to. 30 m		fast growing	Dense shade
Cassia fistula	Sonalu	irregular, vase- or oval-shaped	10 – 15 m	15-20 m	fast growing	light shade
Madhuca longifolia	Mohua	rounded,	16-20 m	15-18m	fast-growing	dense
Eucalyptus camaldulensis	Eucalyptus	irregular	20 -45 m	Upto 20m	fast growing	light shade

Source: Field survey and reference 8,9,10 and 11

Historically, planting different invasive alien species like Eucalyptus, Sissoo and Akashmoni throughout the peripheral areas of Bangladesh did not have a good impact. These trees were planted as fast-growing, shady trees with commercial value. However, the thirst of their roots and how the trees would cause a fall in the underground water level had not been properly anticipated. Even when it comes to planting trees in avenues, we should have a strong precedence of native trees, as pointed out by the eminent botanist Dwijen Sharma (2015).

10. Conclusion

This study focuses on the impact of roadside shade trees on roads, paved ways and built forms in terms of air temperature, analyzes tree properties that maximize the cooling effect and then suggests some native trees for roadside plantation in the context of Dhaka city. It has been found by means of field survey and simulation that roadside trees reduce direct solar radiation, provide shade and by this way contribute producing a lower temperature (5C-6C lower). We note that most of the primary roads are in the north south direction and wind flows from south east direction in our country. As a result, trees alongside these roads invite air flow and block the sunlight. One of the drawbacks of this study is, the result of this study implies on north south oriented roads, but result may vary where it is otherwise. Impacts of buildings alongside these roads can also be considered for further studies for shading purpose in urban context. This work maybe beneficial and approaches can be taken in future in landscape and urban planning with a preference of pedestrian level comfort.

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