The seventh International Conference on Urban Climate,
29 June - 3 July 2009, Yokohama, Japan

THE SKY VIEW FACTOR EFFECT ON THE MICROCLIMATE OF A CITY ENVIRONMENT: A CASE STUDY OF DHAKA CITY

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Abstract

Urban geometry has an obvious, complex influence on the urban environment. The most important geometric effect is that of the sky view factor (SVF). The present study has investigated the effect of SVF on micro-climate, focusing on the solar radiation in the city center of Dhaka, Bangladesh. The relation between SVF and radiation has also investigated for different seasons. This study revealed that SVF was low in the city center, particularly along the narrow road between high-rise buildings. The average radiation assessed was also lower at the points on narrow roads irrespective of seasonal variation. Finally, a positive correlation between SVF and solar radiation was found in the study area.

Key words: sky view factor, solar radiation, microclimate

1. INTRODUCTION

Urban open spaces, streets, and courtyards typically cover about two-thirds of a city's total area and therefore their microclimate plays an important role in the city's overall climate [1]. Climatic conditions in urban canopy layer may differ significantly from each other even in the same overall climate context in a city. They can be affected by a variety of factors such as the geometry of adjoining buildings, the albedo of walls and roofs, vegetation anthropogenic heat release and so on. Several researchers have identified that urban geometry expressed as sky view factor (SVF) has a complex influence on urban climate [2-3]. The sky view factor (SVF) is a dimensionless parameter denoting the quantity of visible sky at a certain location.

The relation between SVF and air temperature has been studied for many years. Oke [4] identified parameters such as anthropogenic heat release and the thermal properties of materials as related to the intensity of heat islands. Giridharan et al. [5] identified the key urban design variables that influence the diurnal and nocturnal urban heat island (UHI), and developed corresponding models for coastal residential areas of Hong Kong. Daytime models indicated that a 10% increase in either solar radiation or SVF would increase UHI by 2.9% and 2.1%, respectively. However, the nocturnal model showed that increasing SVF by 10% would decrease UHI by 0.3%. The air temperature for a specific place is controlled by several factors such as radiation heat transfers, sensible heat transfer, location with respect to water bodies and air mass movement. Among them, the solar radiation is considered as the principal one. The seasonal change of temperature is mainly a function of solar radiation, and the amount of solar radiation entering a point in a space depends largely on SVF [5]. Until now, there has been no empirical research investigating the impact of SVF on the outdoor environment in the high-rise areas of Dhaka city, Bangladesh. Therefore the present study intends to investigate the effects of SVF on microclimate especially on solar radiation at different seasons in Dhaka.

2. STUDY AREA

The study area is the city center of Dhaka (23.24°N, 90.23°E), Bangladesh. This area is situated in the southern part of the city, which is characterized by relatively high built density and consequently a high population density of about 54470 people/km^2[6]. The location of this area is shown in Fig.1. In the study area, the outdoor spaces are mainly comprised of road areas; for this reason in this study all the measurements and simulations are made on the two main roads: Motijheel road and Dilkusha road (shown in fig.2).

3. METHODOLOGY

3.1. Field Survey and Measurement

A detailed field survey of the study area was conducted in April 2008 to investigate some building data: layout, height, materials, and so on. Again solar radiation and air temperature (T_a) were also measured by using Pyranometer and Thermo Recorder TR-72U, respectively in this area. These measurements were carried out only for the month of April due to lack of financial support for survey. The data was recorded from 7:00am to 18:00pm with an interval of 10min.

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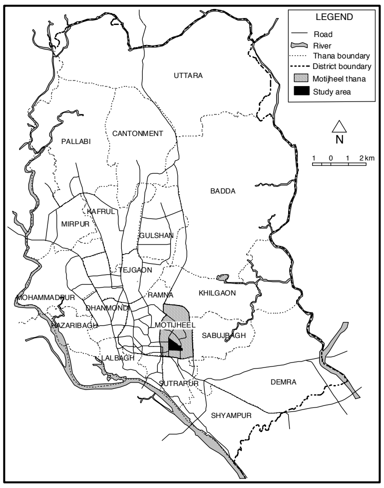

Figure 1: Location of study area in Dhaka city

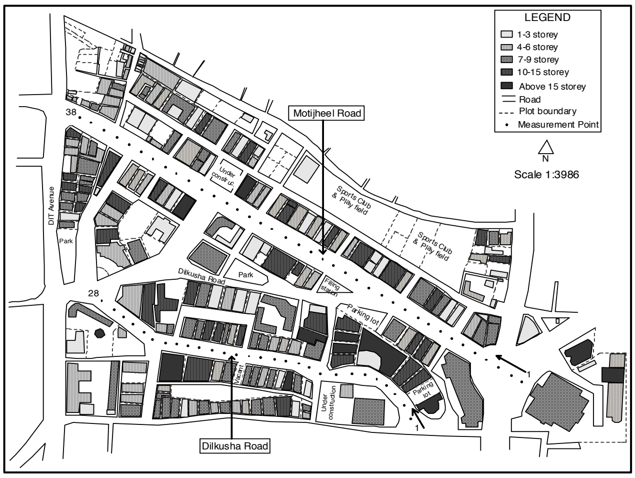

Figure 2: Study area with building heights and location of measurement points

3.2. Simulation

By using 3D model of the study area, the SVF and solar radiation were assessed with TownScope 3.1.1 [7]. Here SVF was calculated at 1.6 m (human mean height) above the ground. For solar access analysis, it is essential to fix some parameter, the date and some monthly data in the settings panel. The required geographical data are latitude and altitude. Meteorological data – the monthly average values for humidity, turbidity, edhcs/ethcs (ratio of diffused energy to total energy on horizontal surface in clear sky conditions), and clouding rate are essential for the analysis. The data on humidity and clouding rate were taken from the average monthly values of the last 5 years (2003 – 2007) [8]. The edhcs values were collected from NASA Surface Meteorology and Solar Energy Data Set. As the turbidity data for the study area was not available, the typical value for an urban area (0.10) was used here. For assessing SVF and solar radiation, a total of 38 points were defined along Motijheel road and 28 points along Dilkusha road. The points were located on the center of the road width and a distance half of road width was maintained between successive points as shown in Fig. 2. The direction of successive points is shown by arrows from point 1. Although there are six traditional seasons in Bangladesh, these can be categorized into three climate-types: hot-dry (pre-monsoon), hot-wet (monsoon and post-monsoon) and cool-dry (winter). From these three climate-types three months: April (hot-dry), September (hot-wet), and January (cool-dry) were selected to access solar radiation. The assessment was made on the 15th day of each month.

4. FINDINGS AND DISCUSSION

4.1 Survey Findings

Figure 2 shows the study area with plots and buildings with height. There are 219 plots and a total of 231 buildings in this area. The height of buildings varies from 1 to 30-storied. Among these, 130 buildings are above 5-storied and the average height of building is about 7-storied. In Bangladesh the standard height of a one-story building is 3.3 m. The widths of the Motijheel and Dilkusha roads are 38 m and 24 m, respectively. The measured solar radiation and air temperature (T_a) are presented in Fig. 3. It shows that solar radiation reaches at the maximum (about 850 W/m^2) at 12:00 in the noon when the sun is at the highest position. Comparing solar radiation on the two roads it is observed that in the wider road i.e. on Motijheel road radiation is higher than Dilkusha road during most of the hours of the day. The daytime (8:00am-18:00pm) averages of air temperature are found 36.8°C and 35.6°C on Motijheel road and Dilkusha road respectively. Similar to solar radiation, T_a is also higher on wider road during daytime. The maximum T_a is found in the afternoon hours at 13:00pm and 14:00pm for Motijheel (41.6°C) and Dilkusha road (39.68°C), respectively. It is important to notice that the effects of solar radiation on T_a acts in the succeeding hours. Converting these values it can be found that the total solar radiations in a day in April are 5337Wh/m^2 and 5238Wh/m^2 on Motijheel road and Dilkusha road, respectively.

4.2 Simulation Results

a. Assessment of SVF
SVF is represented by a value between 0 and 1. It approaches unity in perfectly flat and open land, while locations

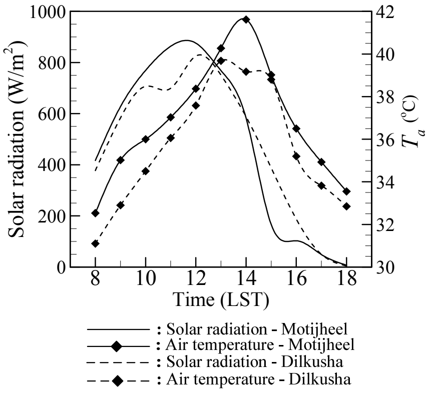

Figure 3: Measured values of solar radiation and air temperature on Motijheel road and Dilkusha Road

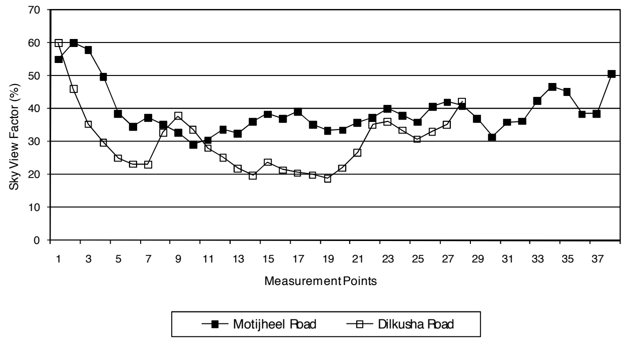

Figure 4: SVFs on the points along Motijheel Road and Dilkusha road

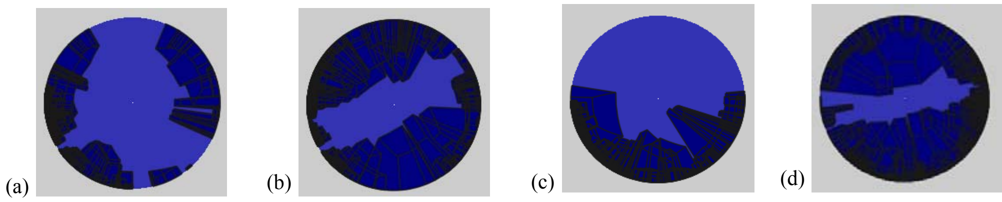

Figure 5: Fish eye lens showing the highest and lowest values for SVF in Motijheel road (a) 60.0% at point 2, (b) 29.1% at point 10 and Dilkusha road (c) 59.9% at point 1, (d) 18.8% at point 19

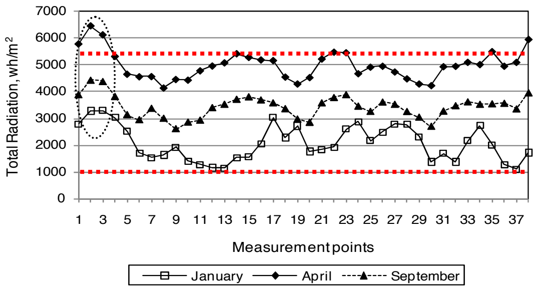

Figure 6: Seasonal variation of solar radiation on the points along Motijheel Road

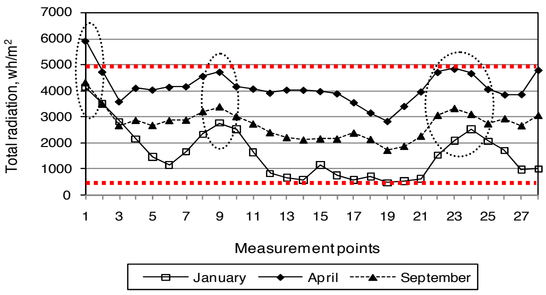

Figure 7: Seasonal variation of solar radiation on the points along Dilkusha Road

with obstructions such as buildings and trees cause SVF to be proportionally less. The SVF's along the measurement points are shown in Fig.4. It clearly shows that the SVF along Motijheel road was higher than in Dilkusha road. At wider spaces such as on the road intersections SVF increased (e.g. points 1 to 4 in Motijheel road and points 1, 2, 9, and 28 in Dilkusha road). SVF ranged from 29.1% to 60.0% and 18.8% to 59.9% for Motijheel road and Dilkusha road, respectively. The average SVF in Motijheel road and Dilkusha road is about 40% and 30%, respectively. The difference was due to the width of road. Figure 5 shows the fish eye lens view of the SVF with the highest and lowest values along Motijheel road and Dilkusha road.

b. Assessment of solar radiation

The seasonal variation of solar radiation is shown in Figs. 6 and 7. The solar radiation is the highest during the pre-monsoon season (hot-dry) in the month of April and lowest during winter season (cool-dry) in January. Comparing these two figures, it is revealed that along Dilkusha road the range of radiation was almost 500-5000 wh/m^2 whereas the range was about 1000-5500 wh/m^2 along Motijheel road (shown with the red dash lines).

In Motijheel road, the maximum radiation values for January, April and September are found to be 3288 wh/m^2 at point 3, 6429 wh/m^2 at point 2, and 4433 wh/m^2 at point 2, respectively. The minimum values are 1090 wh/m^2 at point 37, 4127 wh/m^2 at point 8, and 2600 wh/m^2 at point 9 in January, April, and September respectively. The average radiation values in Motijheel road are 2065, 4972 and 3436 wh/m^2 in January, April and September respectively. In this road the radiation at points 2 and 3 are greater (shown by dashed ellipses) as these points are located at a wider distance from the buildings than the others. In Dilkusha road, the maximum radiation in January, April and September are found to be 4119, 5917 and 4314 wh/m^2 respectively and the minimum values are 511, 2840 and 1739 wh/m^2. The

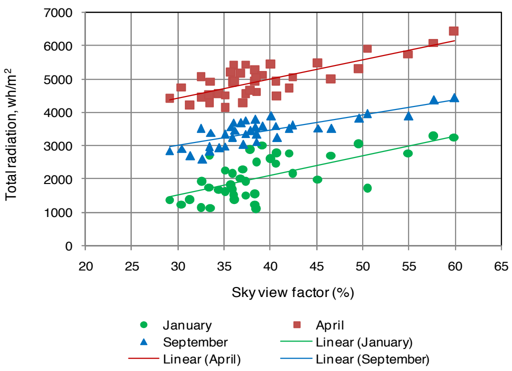

Figure 8: Relation between sky view factor and solar radiation in Motijheel Road

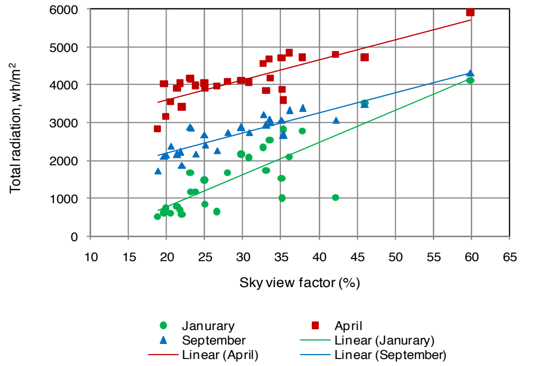

Figure 9: Relation between sky view factor and solar radiation in Dilkusha Road

maximum radiation is found at point 1 and the minimum at point 19 irrespective of seasonal variation. The average radiation is 1626, 4140 and 2738 wh/m^2 for January, April and September respectively. In this case the radiation is maximum at point 1 as this point is located in a wider space than the other points. Again, points 8 and 9 are located at road intersection so the radiation is also raised here. Furthermore, the space is wider at points 22, 23, 24 and 25, resulting in higher solar radiation at those points. These are shown in the figure by dashed ellipses. Moreover the total solar radiations measured in a day in April are 5337Wh/m^2 and 5238Wh/m^2 on Motijheel road and Dilkusha road respectively. These values are very near to the simulated values at the points 21 and 2 on Motijheel road and Dilkusha road, respectively near the set-up of instruments.

4.3 Relation between SVF and Solar radiation

The relationship between SVF and solar radiation is illustrated in Figs. 8 and 9. A positive correlation is found between SVF and solar radiation. In fact, an increase in SVF increases solar radiation. In September, the relation is stronger compared to other months with correlation coefficients of 0.79 and 0.89 for Motijheel and Dilkusha road, respectively. In April the correlation coefficients are 0.78 and 0.81 in Motijheel and Dilkusha road, respectively. Again in January the correlation coefficient is found 0.82 in the narrower road (Dilkusha road) whereas it is 0.65 for wider road (Motijheel road). Among the reasons for seasonal variation in solar radiation, clouding rate is an important one. In clear sky condition, the proportion of diffuse radiation to the total solar radiation received is about 10 to 14% at the earth's surface [8]. Only this diffuse radiation may reach the earth's surface during extremely cloudy days. In January, there is very little diffuse radiation in Bangladesh as the average clouding rate is very low: about 18% over the last 5 years. In contrast, the clouding rate in April and September was high at about 55% and 75%, respectively.

5. CONCLUSIONS

This study evaluated the urban canyon geometry of the Dhaka city center area with respect to sky view factor. It has identified a positive relation between sky view factor and solar radiation irrespective of seasonal variation. This relation should be considered in case of climate sensitive urban planning and design.

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