Basic Studies and
New Technologies of
Architecture and
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Naqshejahan

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Evaluating The Effects of High rise building On Urban Heat Island by Sky View Factor: A case study of Narmak neighborhood, Tehran**

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Abstract

Urban heat island is a phenomenon caused by increased urban activities and transformations in the natural environment. Increased urban population and increase in the height of buildings, particularly in metropolitan areas, have led to vast changes in the urban geometry, amount of released heat, pollution rate, and meteorological parameters. All these factors contribute to the occurrence of heat island phenomenon in urban areas. Sky View Factor (SVF) is one of the main factors related to pollution, temperature variations, heat island, and other environmental parameters. Housing density policies stipulated in Tehran's detailed plan would possibly have several impacts on the sky view factor. The SVF axis of the Envi-met software uses various parameters such as topography, wind velocity, and urban morphology to simulate and measure sky view factor.

This study aims to evaluate impacts of the future high-rise developments, in the Narmak neighborhood of Tehran through modeling future changes in the sky view factor. For this purpose, data related to Haft Hoz square located in the Narmak neighborhood was collected, simulated and analyzed using SVF. Results indicate that in the business as usual scenario, the factor's value would be in a range between 0.19 and 0.77; whereas, by implementing the scenario proposed in the detailed plan the factor will decrease to fall in a range between 0.08 and 0.69. This reduction in the intensity will possibly increase heat island impacts in the study area. This study emphasizes the necessity of taking compensatory policy measures and incorporating environmental considerations in urban development plans.

Keywords: High-rise Building, Urban Heat Island, Sky View Factor, Meteorological Parameters, Narmak.

- * Corresponding author. Tel.: 09121860887; fax: 021-82883743.
- ** This paper is derived from the research project "The Modeling of Urban Development plans Impacts on Sustainable Urban Quality Improvement with special references to Urban Microclimate Changes" was supported by the Research and Technology Fund which performed between the years 2012-2013.
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doi:

[DOR: 20.1001.1.23224991.1394.5.4.6.3]

1. Main text

1.1. INTRODUCTION

Open spaces, streets and courtyards constitute about 60% of the total area of a typical city. This makes them important elements for any study focusing on urban climatology [1]. Due to variations in factors such as building geometry, urban morphology, vegetation canopy, material used for construction, and air movement between adjacent buildings; climatic conditions in different areas of a city may vary considerably [2]. Unprecedented rate of urbanization over the past century has led to various impacts on the environment, of which temperature increase and climate change are widely acknowledged. Increase in population, rapid rate of industrialization, increased levels of pollution in the lower layers of atmosphere, and Heat Island (HI) effects are among.

The main factors would lead to considerable changes in weather conditions and micro climate of large cities. Anthropogenic heat release, increased greenhouse gas emissions, and land use change are some of the main reasons for microclimatic changes in urban areas. Urban form can affect the microclimate of urban environment in various ways. As in illustration of this point, changes in building density may cause variations in air temperature and pollution [3]. Through obstructing air movement and slowing down the nocturnal release of heat stored in the daytime, increased urban density results in the occurrence of HI phenomenon.

Given this significant impact of density on the emergence of heat island, density related policies of urban development plans could have a direct and crucial impact on changes in urban microclimate. Formation and intensity of heat islands are obvious illustrations of these changes. Since Sky View Factor (SVF, often denoted by ψ_S) is related to vegetation canopy, height of buildings, and also UHI, the purpose of this study is to evaluate the density related policies of Tehran's detailed plan through analyzing SVF. Urban planners and decision makers are to make more informed decisions that could result in the improvement of urban climate; consequently, the results of this quantitative evaluation could be used efficiently.

1.2. LITERATURE REVIEW

UHI often occurs during calm and cloudless nights when more time is needed for the diurnal heat stored in materials such as asphalt and concrete to be released [4]. During daytime hours wind movement affects the urban heat through horizontally sweeping over the near surface layers [5]. When a city is characterized by significant variations in height, the released heat, as well as pollution, is more easily trapped between the buildings and this intensifies HI effects [6]. The intensity of Urban Heat Island (UHI) effect depends on parameters such as land use pattern, urban density, quality and quantity of open and green spaces, and SVF [7].

Compared with the roof levels, SVF and wind velocity are reduced in spaces between buildings. Therefore, SVF can be regarded as one of the main factors contributing to the formation of UHI phenomenon [8]. Due to its simplicity use, SVF has evolved to become one of the most applicable and important techniques for estimation and simulation of UHI [9].

Research on SVF and its association with UHI was pioneered by Oke in 1981 [10, 11]. Since then, many other studies have been conducted to improve the methodology used for estimation of SVF and further clarify the relationship between urban geometry and SVF [4, 8-10, 12].

SVF measures the degree of openness to sky. A dimensionless value lies between zero indicating complete obstruction and unity that means complete openness to sky. SVF is a measure that can be used to better understand the relationship between parameters such as HI, air pollution, heat release and energy exchange in urban environments [11, 13]. Increase in urban density and Floor Area Ratio (FAR) results in further obstruction of the open sky and consequently reduces the value of SVF [14].

In a study conducted in a high-rise, high-density area of Hong Kong; it was found that a 10% increase in SVF would result in 2.9% increase of diurnal UHI. Whereas, the same amount of increase in SVF would lead to a 0.3% reduction of the nocturnal UHI [15].

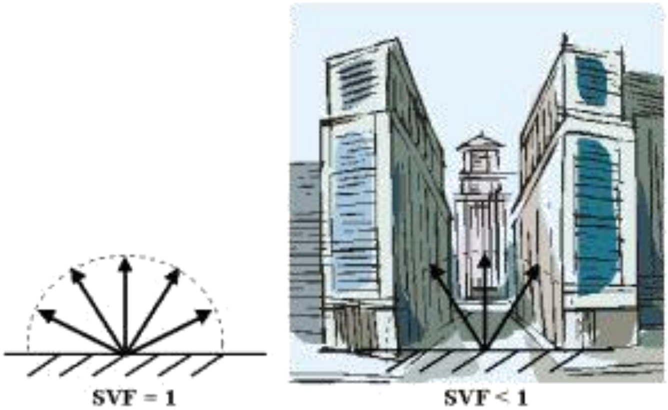

Fig. 1: Illustrative definition of the concept of SVF [16]

Three common techniques for measuring SVF in urban environments are analytical (sometimes referred to as geometrical), photographical and software-based [12]. In the following paragraphs, these three methods are briefly described.

A. *Analytical Methods*

In the analytical methods “geometrical characteristics and radiation exchange model of the urban canyons” are used to estimate SVF [10]. These geometrical characteristics are illustrated in Figure 2.

SVF is estimated by

$$\psi_{sky} = \frac{1}{\pi R^2} \int_{Sv} COS\phi dS \quad (1)$$

Sv denotes the section of the hemisphere representing the visible sky. “Is the angle from to the zenith, and R is the radius of the hemispheric radiating environment” [10]. A more simplified model for estimating SVF was introduced by Oke in 1981:

$$\psi_{sky} = COS\left[\tan^{-1}(H/D)\right] \quad (2)$$

$$\beta = \left[\tan^{-1}(H/D)\right] \quad (3)$$

H and D respectively represent height and the half-width of a symmetric and infinite urban canyon. Finding such an urban canyon would be difficult, if not impossible.

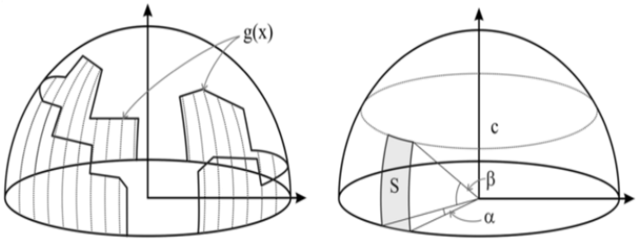

Fig. 2: Radiation exchange model between the sky and a surface element [17]

…etter represent conditions of the rea … asymmetric buildings [10]. This is g…

$$\psi_w = \frac{1}{2\pi}\left\{(\gamma_1 - \gamma_2) + \cos\beta\left[\tan^{-1}(\cos\beta\tan\gamma_1) - \tan^{-1}(\cos\beta\tan\gamma_2)\right]\right\} \quad (3)$$

$$\psi_w = \frac{1}{2\pi}\left\{(\gamma_1 - \gamma_2) + \cos\beta\left[\tan^{-1}(\cos\beta\tan\gamma_1) - \tan^{-1}(\cos\beta\tan\gamma_2)\right]\right\} \quad (3)$$

Represents wall view factor and, are the azimuth angles between the surface and the two ends of the wall [10]. Finally, SVF is calculated as

$$\psi_{sky} = 1 - \sum_{i=1}^{n} \psi_w(i) \quad (4)$$

n is the number of buildings surrounding the surface [10].

B. *Photographical Methods*

Here fish-eye lenses are used to estimate SVF values. In these fish-eyed photos, the hemispheric environment is projected onto a circular plane. After processing the photos and identifying the skyline, SVF is estimated by calculating the share of the visible sky [10, 18]. An example of fish-eyed photos used for the purpose of this study is shown in Figure 3.

Advantage of using photographic methods is that it could be used when buildings with various configurations and also vegetation canopy exist in the study area. This enhances the precision of the estimation. However, these methods are time-consuming and therefore not suitable when the size of study area increases. Moreover, the favorable weather condition for these methods (cloudy sky) is not always easy to be met [10, 18].

Fig. 3. A fish-eyed photo used for the purpose of this study.

C. Software-based Methods

Commensurate with the rapid growth in the use of computer software and Geographic Information Systems (GIS), software methods are also increasingly used to estimate SVF [9, 10]. Software methods facilitate simulating and identifying relationship between UHI and SVF [19]. These methods have made it possible to deal with large quantities of data in a relatively shorter time period. Data such as building height and density, and digital elevation models (DEMs), are employed to simulate urban area in the computer environment [21].

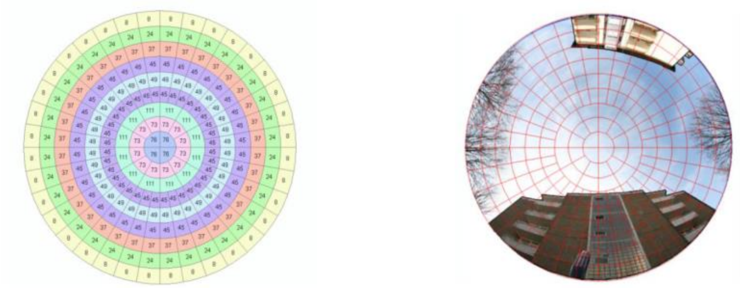

Fig. 4. An example of using software-based methods to estimate the value of SVF [19].

Software methods can be divided into two main types: vector-based and raster-based [10, 20]. While the former uses polygons to reconstruct the urban environment, in the latter one main focus is on using DEM databases [10, 19]. Figure 4 illustrates an example of using diagrams to estimate the value of SVF. These functions are embedded in both ArcGIS and also ENVI-met software

1.3. STUDY DESIGN

A combination of qualitative and quantitative methods has been used in this study. We first conducted an initial literature review to gain knowledge about the relationship between SVF and building density and their possible contribution to the formation of HI in urban areas. Following this, we reviewed the proposed detailed plan for district No. 8 of Tehran to understand density requirements stipulated for the study area (Haft Hoz square area of the Narmak Neighborhood). Data acquired from the review of the proposed detailed plan and also data available on the existing situation of the study area were used as input data for analysis in the GIS environment. SVF for both status quo and future scenario were calculated and used to further analyze and criticize the proposed detailed plan. Meteorological data required for this study were obtained from Dushantappe Synoptic Weather Station which is the closest to our study area. We did this to make sure that the most appropriate meteorological data is used for analysis.

1.4. STUDY AREA

Selected area for this study, which is known as Hafthoz, is located in the District No. 8 of Tehran at 1300 m above sea level on a plain with a mild slope towards the south. This area's climate is characterized by mild springs and autumns, hot, dry summers and cold, and dry winters. The average building density is 219%. In the recent years, building density has been constantly increasing. Between 1995 and 2010, it has increased by an average rate over 60%. Most of this increase occurred in the eastern part of the study area where density increased from 220% to over 300% [20]. According to the proposed detailed plan, developers are allowed to build up to 11 stories in the area. Data obtained from Dushatappe Synoptic Weather Station were used to simulate general climatic characteristics of the area. These characteristics are summarized in Table 1.

Table 1: GENERAL CHARACTERISTICS OF DUSHANTAPPE SYNOPTIC WEATHER STATION

Station	Type	Altitude	Latitude	Longitude	Statistical Period
Dushan-tappe	Synoptic	1209m	35° 42' N	51° 20'"E	1972-Present

1.5. FINDINGS

Simulations for the status quo and the proposed scenario were carried out using the SVF technique of the ArcGIS software. Various physical and environmental attributes such as topography, urban morphology, wind velocity, building height and density, and vegetation information are embedded as a default in the software. To reconstruct the status quo conditions, we obtained data related to building height and density through site visits and field studies. Figure 4 illustrates the estimated SVF for the status quo.

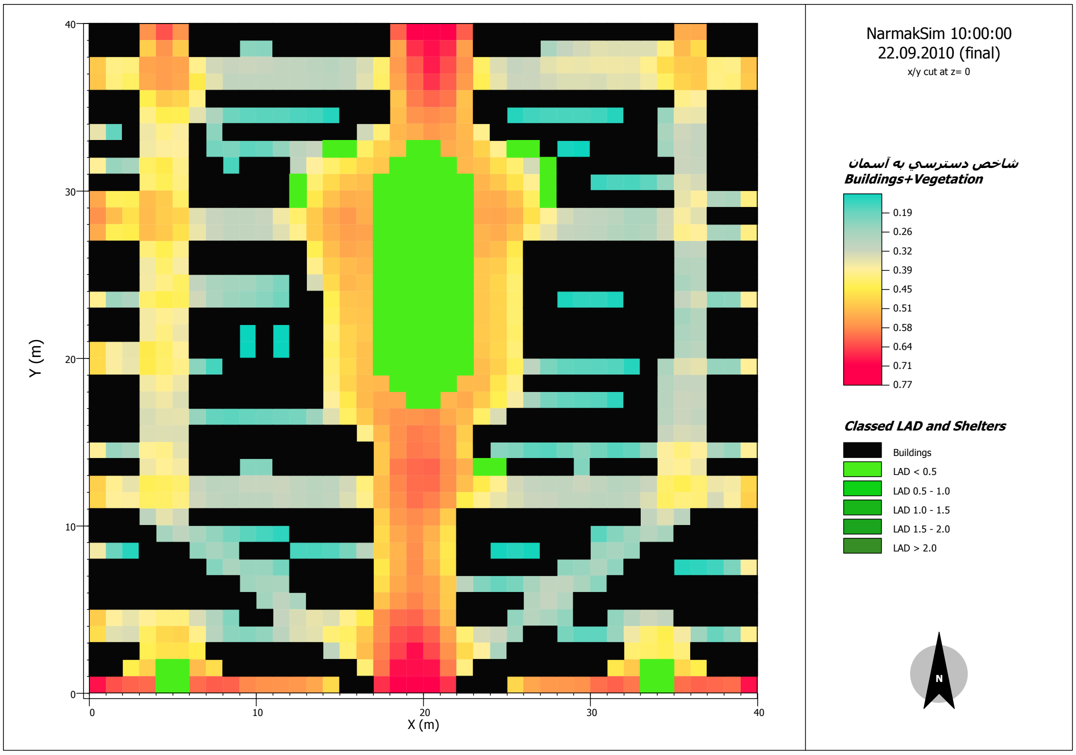

Fig. 5. SVF in the existing conditions.

Black color in Figure 5 represents existing buildings in the study area. Number of floors in these

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buildings falls in arrange between 2 and 4. The green color indicates available vegetation. Our analysis showed that the existing SVF value is between 0.19 and 0.77. Variations of SVF value are illustrated using a blue-to-red color spectrum. Blue color and red color respectively represent those surfaces with the lowest and highest SVF values

A similar simulation was carried out for the proposed scenario. All attributes except building height and density remained the same as the status quo. Data related to building height and density was extracted from the proposed detailed plan. SVF values for the proposed scenario are depicted in Figure 6. This value falls in range between 0.08 and 0.69 which shows a considerable decrease compared with the status quo scenario. This change is specifically evident along the main north-south axis crossing the main square.

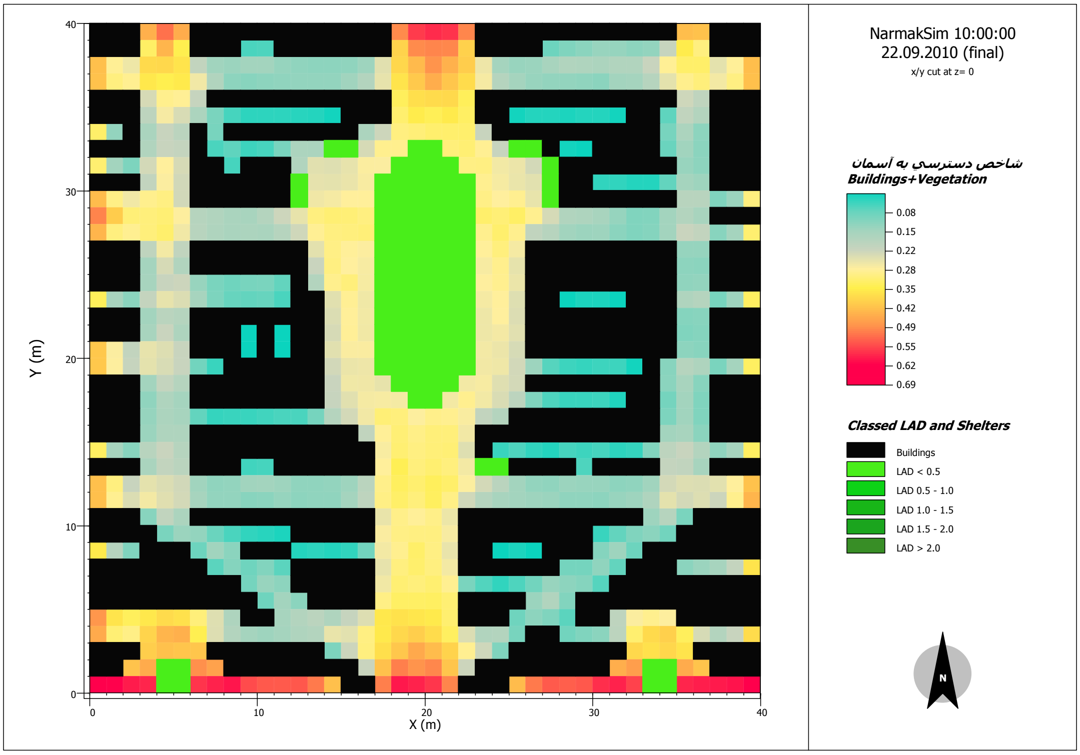

Fig. 6. SVF in the proposed scenario of the detailed plan.

As these simulations show, increase in density and number of stories lead to reduction in the SVF value. This reduction may result in the intensification of HI effects in the study area. Figure 7 shows the variations of SVF in status quo and proposed scenarios.

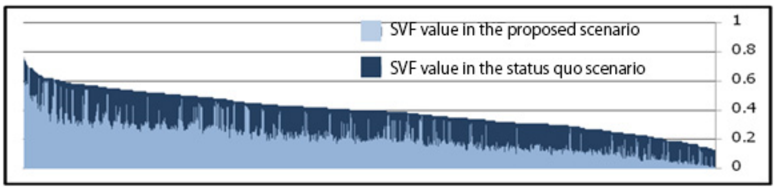

Fig. 7. Variations of SVF

Figures 5 through 7 clearly indicate that increasing building height in the proposed scenario would cause increase in the fluctuations of SVF values.

1.6. DISCUSSION AND CONCLUSION

This study showed that implementation of the proposed detailed plan would result in a 17% decrease in the SVF in the study area. This considerable decrease may have adverse impacts on the microclimatic conditions. Commensurate with urbanization trends in many parts of the world, in the past few decades high rates of urbanization in Tehran have caused significant changes in the climatic and meteorological characteristics of the city.

As explained in the literature review, changes in the SVF value may have considerable consequences for urban climate and lead to changes in various attributes such as temperature, levels of air pollution, and wind environment. Furthermore, it is proved that in many occasions a significant relationship exists between SVF and the intensity of HI. These all indicate that SVF is an important factor that needs to be well considered in urban planning and the decision making process. We suggest that this issue should be considered when revising and updating Tehran’s detailed plan.

[DOR: 20.1001.1.23224991.1394.5.4.6.3]

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