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ORIGINAL RESEARCH PAPER

Evaluating the effects of increasing of building height on land surface temperature

H. Rezaei Rad[1,*], M. Rafieian[1], H. Sozer[2]

[1]*Department of Urban Planning and Design, Faculty of Art and Architecture, Tarbiat Modares University, Tehran, Iran*

[2]*Energy Institute, Istanbul Technical University, Maslak, Istanbul, Turkey*

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ABSTRACT: Global warming has obtained more and more attention because the global mean Land surface temperature has increased since the late 19th century. Land surface temperature is a significant parameter in urban environmental analysis. Production of anthropogenic heat for cooling systems, lighting and etc. led to have serious impacts on the thermal environmental quality such as quality of the air, increase in temperature, energy consumption and finally the formation of urban heat island. 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. his study combines the techniques of simulation and geographic information system to detect the spatial variation of Land surface temperature and determine its quantitative relationship with building height and density based on simulation modeling for the Narmak neighborhood of Tehran. For this purpose, data related to Haft Hoz Square located in the Narmak neighborhood were obtained, simulated and analyzed using Envi-met. Results indicate that comparison on the simulation between the existing conditions and proposed scenario area showed that the daily average air temperature differed by 1.38 °C. This increase in the building height will possibly increase land surface temperature and lead increase intensity of urban heat in the study area.

KEYWORDS: Building density; Energy consumption balance; Land surface temperature; Tehran; Urban heat

INTRODUCTION

Nowadays more than 50% of the world's population lives in cities. More than 20% of them live in megacities. This trend continues to grow in the developing countries, while, in the developed world, the growth of the cities remains more or less constant (Zhou, *et al*., 2011). Although urban areas occupy only about 3% of the Earth's surface impacts of urbanization on the environment are far reaching on the global level (Griffiths P., Hostert P., Gruebner O., van der Linden S, 2010). In addition to the scientific aspect, understanding the phenomenon of urban excess heating and the associated heat stress on city-dwellers, especially during hot spells (Mayer, 2006), is of considerable practical relevance for urban planning (Allen, 2012). 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. Being the basic variable in calculating UHI, the land surface temperature (LST) draws significant attention, as it modulates the air temperature of the lower layer of urban atmosphere, governs the energy balance and the surface radiation in urban area (Voogt and Oke, 1998). Population increase, rapid rate of industrialization, increased levels of pollution in the lower layers of atmosphere, and urban heat effects are among the main factors leading to considerable

*Corresponding Author Email: *H.Rezaei.Rad@Modares.ac.ir*
Tel. Tel. +98 912 186 08 87 Fax: +98 21 828 837 43

changes in weather conditions and microclimate of large cities. Urban form can affect the microclimate of urban environment in various ways. For instance, changes in building density may cause variations in air temperature and pollution (Rezaeirad and Rafeiyan, 2016). Through obstructing air movement and slowing down the nocturnal release of heat stored in the daytime, increased urban density results in the occurrence of UHI 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 Then, according to the Oke's energy balance concept that shows that all of the energy absorbed by the surface through radiation or from anthropogenic heat goes somewhere and warms the air above the surface, is evaporated away with moisture or is stored in the material as heat. For energy saving, therefore, this study aims to enhance the understanding of the role of height building on local microclimate. We continuously measured land surface temperature and combined it are with simulation modeling in a small urban area during summer. We determined the spatial variations in land surface temperature due to the distribution of building height and density in a local area.

This study was carried out at the Faculty of Art and Architecture, University of Tarbiat Modares from during 2016.

MATERIALS AND METHODS

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 building density and their possible contribution to the increase LST 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 Envi-met.ENVI-met allows to simulate the urban environment from a microclimate scale to the local climate scale with a resolution of 0.5 to 10 m in space and 10 s in time with 250 grids at maximum (Wang, *et al.,* 2015). In this study, the geometry, buildings, vegetation, and surface materials of the study area are defined on a 3D grid of 80×80×30 cells, with a 2 m grid cell size. This resolution allows to investigate local microclimate variations.LST 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 that is the closest to our study area. In addition, both models have simulated in summer and 16:00. We did this to make sure that the most appropriate meteorological data is used for analysis. Using the simulation model, the relationship between size and height building, and the LST distribution are explored. Further, the simulations allowed us to relate variations in microclimate due to height buildings with human comfort.

Urban Climate

Urban climate is defined by specific climate conditions which differ from surrounding rural areas (Eum, *et al.,* 2011). The amount of sunshine received by an urban area depends, not only on cloud cover, but also on air pollution, shades provided by buildings and even the orientation of the street network. Tall urban structures tend to influence radiation flows (Huang, *et al.,* 2011). The climatic impact of urbanization on a regional level is mainly described by urban heat island (UHI). UHI displays discrepancy in ambient temperature inside the city and its surrounding areas (Nonomura, *et al.,* 2009).

Urban land surface temperature

Land surface temperature (LST) is the main factor determining surface radiation and energy exchange (Weng, 2009) controlling the distribution of heat between the surface and atmosphere (Tan, *et al.,* 2010). Land Surface Temperature (LST) is a key variable that helps govern radioactive, latent and sensible heat fluxes at the interface (Guillevic P.C., Privette J. L., Coudert B., Palecki M. A., Demarty J., Ottlé C., 2012). Thereby, analysis and comprehension of LST dynamics and its relation to changes of anthropogenic origin is necessary for the modeling and forecasting of environmental changes (Mohan, *et al.,* 2011).

LST serves as an important indicator of chemical, physical and biological processes of the ecosystem. LST is influenced by such properties of urban surfaces as color, surface roughness, humidity, chemical composition etc. (Tan, *et al*., 2010).

Land surface temperature regulates lower layers of the atmosphere. Thus, it can be called weather variable and a critical factor for the urban environment because LST modulates the balance of energy (Retalis, *et al*., 2010).

Urban Excess Heating

Urban heat island (UHI) has long been a concern for more than 40 years. One of the earliest UHI studies was conducted in 1964 (Nieuwolt, 1966). Extensive urbanized surfaces modify the energy and water balance processes and influence the dynamics of air movement (Oke, 1987). When a city is characterized by significant variations in height, the released heat, as well as pollutants, is more easily trapped between the buildings and this intensifies HI effects (Smith, 1975). High daytime radiation, a negative radiation balance (Q*) in the evening and at night as well as a limited atmospheric exchange guarantee the development of a positive horizontal temperature difference between urban (tu) and rural, non-built-up surroundings (tr; $\Delta Tu–r > 0$ K). This phenomenon is called the urban heat island (UHI) (Kuttler, 2012). The intensity of Urban Heat Island (UHI) effect depends on parameters that show in Table1.

Table 1: A selection of meteorological and structural factors influencing the UHI (Kuttler, 2012)

Influencing factor (IF)	Sign of correlation coefficient between UHI and IF
Cloud cover	-
Wind speed	-
Anthropogenic heat emission	+
Bowen ratio, β^1	+
Population	+
Sky view factor, (SVF)	-
Ratio building height/street width (H/W)	+
Surface sealing	+
Green and water-surface area/total area	-
Latitude	+

β^1 = QH/QE;
(QH/QE = turbulent sensible/latent heat flux density)

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% (Rezairad, 2011). 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 2.

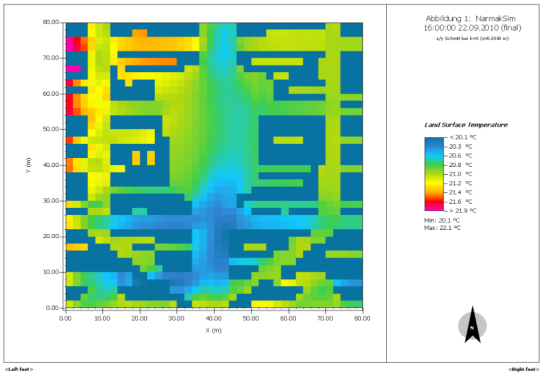
RESULTS AND DISCUSSION

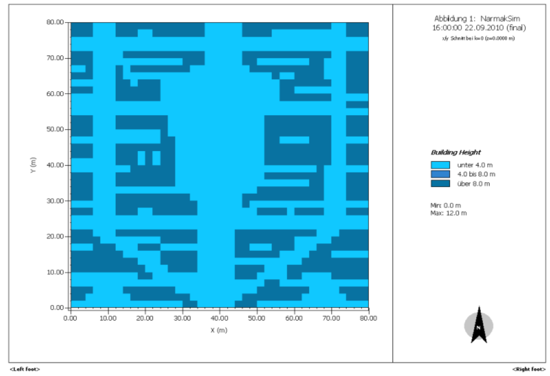
Simulations for the status quo and the proposed scenario were carried out using the Envi-met software. After running a 24 h simulation with a half hour interval the following features were extracted from the receptors on land surface. Physical and environmental attributes such as topography, urban morphology, wind speed, 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. Fig.1 and Fig.2 illustrates the height building and LST for the status quo.

Dark blue color in Figure 1 represents existing buildings with height average 9m in the study area. Number of floors in these buildings falls in arrange between 2 and 4. Figure 2, Our analysis showed that the existing LST is between 20.1 C and 22.1 C. Variations of LST are illustrated using a blue-to-red color spectrum. Blue color and red color respectively represent those surfaces with the lowest and highest LST. As well as our analysis showed that the existing average LST is 20.86 C. As well as, figure 3 shows the trend of land surface temperature changes in different parts of the study area that it shows in Fig. 3.

Table 2: General Characteristics of Dushan-tappe synoptic weather station

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





Figs. 1 and 2: Building height and land surface temperature in the existing conditions.

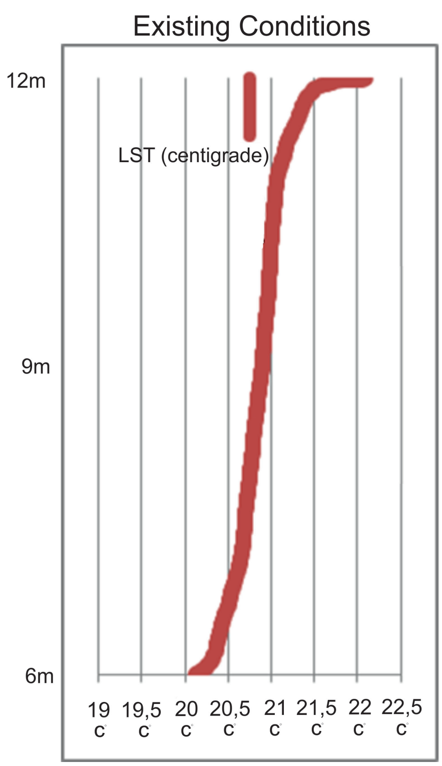


Fig. 3: Land surface temperature trends in the existing conditions.

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. Building height for the proposed scenario is depicted in Figs. 4 and 5.

As these simulations show, increase in building density and number of stories leads to increase in the LST. This result due to increase intensification of UH effects in the study area .Fig. 6.

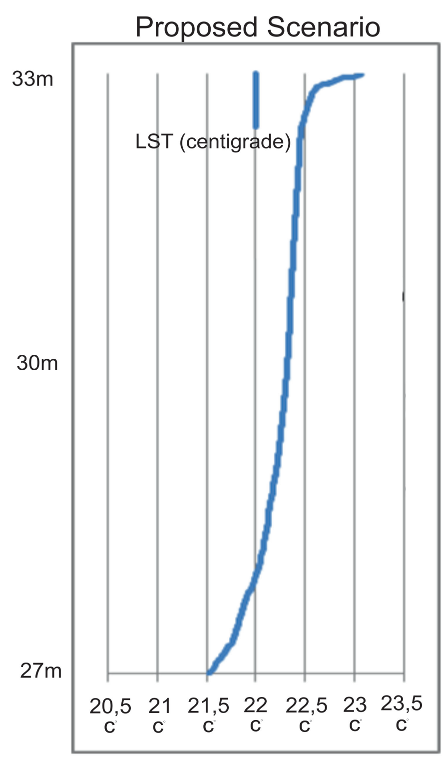
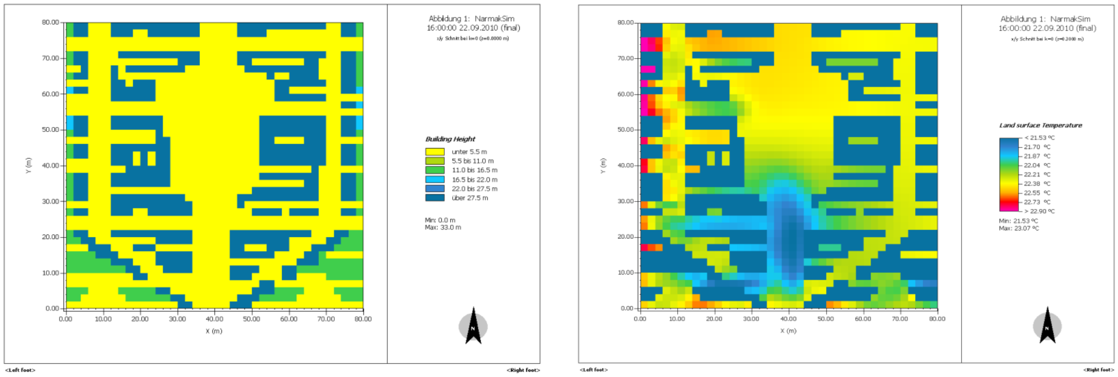


Fig. 6: Land surface temperature trends in the proposed scenario.



Figs. 4 and 5: Building height and land surface temperature in the proposed scenario

Dark blue color in Fig. 4 represents proposed scenario with height over 27m in the study area. Number of floors in these buildings falls in arrange between 9 and 11. As well as, figure 5 is showed LST in range between 21.53 °C and 23.07 °C that shows a considerable increase compared with the status quo scenario. This change is specifically evident along the main north-south axis crossing the main square. In addition, average land surface temperature is 22.24 °C.

Fig. 6, clearly indicate that increasing building height in the proposed scenario would cause increase in the trend of land surface temperature.

RESULTS AND DISCUSSION

This study provides new insight into the role of building height and density on microclimate and LST in a local urban area through field measurements and numerical modeling. Although this study showed that implementation of the proposed detailed plan with taller building would result in increase in the land surface temperature in the study area. This considerable increase may have adverse impacts on the microclimatic conditions and urban energy consumption balance. 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. The results from the simulations showed that building height altered the surrounding summer microclimate. The comparison on the simulation between the existing conditions and proposed scenario area showed that the daily average air temperature differed by 1.38 °C. Significant spatial LST variations were caused by the increase building height. As explained in the literature review, changes in the building height and density may have considerable consequences for urban climate and lead to changes in various attributes such as land surface temperature, levels of air pollution, and wind environment. Furthermore, it is proved that in many occasions a significant relationship exists between building height and the intensity of HI and LST. Also the simulations with ENVI-met showed strongly varying land surface temperature conditions spatially. Hence, when studying the influence of building height on the microclimate, weather conditions must be considered, especially in the summer. We suggest that building height should be considered when planning and the decision making process Tehran's plan.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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