INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 3, No. 9, p. 42-50, 2013
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Surface temperature pattern of asphalt, soil and grass in different weather condition

A. A. Shamsipour, Gh. Azizi, M. Karimi Ahmadabad, M. Moghbel*

Department of Physical Geography, School of Geography, University of Tehran, Tehran, Iran

Article published on September 14, 2013

Key words: Urban heat island, surface temperature, land cover, Tehran.

Abstract

Urban Heat Island (UHI) is the result of accelerated urbanization and it is created when natural land covers replaced by heat-absorbing surfaces such as Asphalt, Cement and etc. Therefore, the main objective of this study is analysis of temperature pattern in three different surfaces such as asphalt, soil and grass in Tehran city during the April 2013 under sunny and cloudy weather conditions. To do so, two OPUS 200/300 Data Loggers with three PT100 sensors were installed over surfaces at Geophysics weather station in University of Tehran. Then, the mean daily surface temperature of land covers were simulated using air temperature by a regression model. According to the results, the highest temperature in both sunny and cloudy condition during the day is related to asphalt; soil and grass, respectively while the range of temperature (difference between maximum and minimum temperatures) in sunny condition is more than cloudy condition so that there is reverse relationship between cloudiness and surface temperature. Also, result of regression model illustrated that the model has proper accuracy to estimate surfaces temperature.

***Corresponding Author** M. Moghbel ✉ moghbel@ut.ac.ir

Introduction

Land covers and materials composition that make up urban regions are the key reason to why temperature in a city is much hotter compared to that in a rural area (Gui *et al.*, 2007). Scientists are conscious that human activities have triggered land use and land cover changes in the recent past to give high temperatures in urban areas that have modified the energy balance in cities. Density of buildings, high energy consumption, construction progress and transportation networking has made the potential for heat to be trapped even worse (Wijeyesekera *et al.*, 2012). In this regards, one of the primary causes is that in the process of urbanization, vegetated land surfaces are converted into concrete and asphalt surfaces (Yilmaz *et al.*, 2007).

These surfaces with relatively high volumetric heat capacity and reduced evapotranspiration due to their impermeability generate higher heat storage and temperatures. Such a phenomenon is widely known as the Urban Heat Island (UHI) effect (Stathopoulou *et al.*, 2009; Gui *et al.,* 2007; Oke, 1982; He *et al.*, 2007). Hence, urban land cover's thermo-physical properties are important parameters in temperature patterns of the land covers (Li *et al.,* 2012, Qin *et al.,* 2011).

As a result of these properties, solar energy is absorbed into roads and rooftops, causing the surface temperature of urban structures to become 50 - 70 °F higher than the ambient air temperatures (Gorsevski *et al.*, 1998) which the impact of the SR absorption on the pavement temperature distribution has been widely investigated (Harmansson, 2000; 2004; Qin *et al.*, 2011; Li, 2012). The hotter air contributes to the major health and environmental concerns such as thermal stress, air pollution and etc. Also, the resulting higher temperature caused by the urban heat island has the effect of increasing the demand for cooling energy in commercial and residential buildings (Li *et al.*, 2011).

According to these points of view, it is of great significance to determine surface temperature pattern of different materials which usually are used in urban areas. In other word, concentration of high thermal capacity buildings, low-albedo in urban surfaces and increased urban surface area are some of the factors that lead to an enhanced absorption of solar heat that causes the changes in the microclimate (Wijeyesekera *et al.*, 2012). Various researches have been conducted in this regard as follows:

Yilmaz *et al.* (2008), studied temperature differences between asphalt concrete, soil and grass surfaces of the city of Erzurum in Turkey and showed a mean temperature difference of 6.5°C between asphalt and soil, 5.3°C between soil and grass, and 11.79°C between asphalt and grass surfaces, respectively. According to Anonymous (2001) the temperature differences between air above concrete runways and adjacent grass can be as much as 4°C. Herb *et al.* (2008) simulated ground surface temperature for different land covers and presented that asphalt and concrete have the highest surface temperatures, while vegetated surfaces gave the lowest in urban areas. Li *et al.* (2012) simulated temperature of building materials and illustrated that thermal properties are fundamental parameters that influence the distribution and variation of pavement and other building material temperatures.

Roth (2002) presented that the temperature is uniformly decreasing with distance away from the maximum (~14 ºC) observed around the commercial centers of Tokyo.

Solecki *et al.* (2004) demonstrated that High density residential land on average has the highest surface temperature (35° C) of any urban land use category.

Peterson (2003) studied urban surface temperature in the Contiguous United States and concluded that industrial sections of towns may well be significantly warmer than rural sites. Taha (1997) studied urban climates and heat islands and presented that increasing albedo and vegetation cover can be effective in reducing the surface and air temperatures near the ground.

This study is concerned with the surface temperature patterns of three different urban land cover in Tehran, Iran and is undertaken with two specific objectives. The first objective is to characterize the surface temperature pattern in different weather condition. The second objective is to develop a linear regression method between surface and air temperature.

Material and methods

Study area

Tehran is located between 35° 34′-35° 50′ N and 51 ° 8′-51° 37′ E. It has a semi-arid, continental climate. As it can be seen in Fig.1, summer is usually hot and dry with very little rain, but relative humidity is generally low and the nights are cool. Most of the annual precipitation occurs from late autumn to mid-spring. The hottest and coolest months are July (Mean Temperature 30°C) and January (Mean temperature 3°C), respectively.

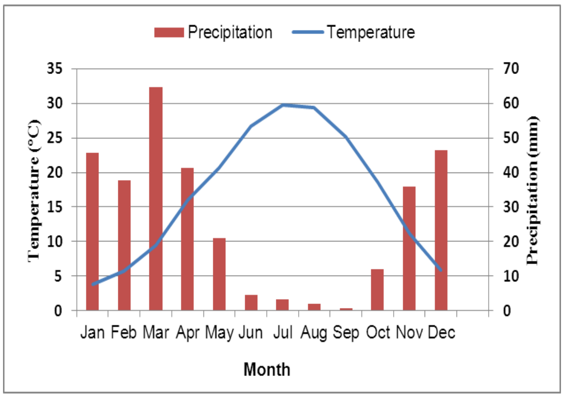

Fig. 1. Monthly mean temperature and precipitation in Tehran (1951-2005).

Tehran city as capital of Iran is center of economic, politic and social activities of the country. Therefore, in recent years, it experiences all unfavorable effects of urban environment because of distorted urbanization which cause some especial environmental problems such as air pollution, Urban Heat Island (UHI) which are due to high population, Transportation system, Factories and its geographical position which is surrounded by Alborz Mountains in the north. As the result of accelerated urbanization and industrialization, form and composition of its environment have significantly altered with engineered surfaces (e.g. asphalt, concrete, cement and etc.).

Research Methods

To analyze the urban surfaces temperature, two OPUS 200/300 Data Loggers with three PT100 (Platinum Resistance Thermometer) sensors were installed in Geophysic Weather Station in University of Tehran (Fig.2) and surface temperature of three different urban land covers such as Asphalt, Soil and Grass were measured in hourly time interval during the April 2013 (Fig.3). It is important to note that measurements were carried out under the direct effect of sun and there was no shadow on the surfaces during the measurement.

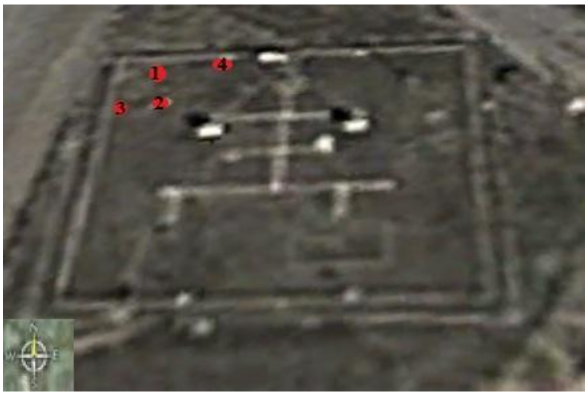

Fig. 2. Measurement points in Geophysic weather station at University of Tehran: 1) Soil 2) Asphalt 3) Grass 4) Data Loggers.

The OPUS 200/300 is a universal 2 channel data logger which usually uses with 1, 2, 3 or 4 conductor techniques that resistance measurements with 4-conductor technique provide the best accuracy when measuring temperature and resistance, because the measurement takes place directly at the sensor. 4-conductor technique is applies chiefly in laboratories and in the field of meteorology and climatology with PT100 sensor. Also, meteorological data including air temperature (°C), relative humidity (%), precipitation (MM), cloudiness (Okta) were gathered from Geophysic Weather Station for determination of weather condition. To determine the effect of both surface thermal properties and weather condition on temperature, days with two weather condition (cloudy and sunny/calm condition) in April were selected and analyzed.

Regression Model

The relationship between surface and air temperature were studied using regression model. This model was extracted according to the SHRP (Strategic Highway Research Program) model which was presented by Mohseni (1998) and Hassan (2005) to simulate the asphalt surface temperature. To do so, air temperature was used as an independent variable and urban surfaces temperature as the dependant variable. The model for each surface is given by (Eq.1-4 and Fig.4). It is important to note that relationship between the air and soil temperature in dry and wet condition is different because of the effect of evaporation.

Fig. 3. Land covers (a) Asphalt b) soil c) Grass) and OPUS 200/ 300 Data Loggers (d).

T_Soil(dry) =0.92Tair+1.12 : Eq.1

T_Soil(saturated) =0.92Tair+2.2 : Eq.2

T_Asphalt=0.96Tair+1.4 : Eq.3

T_grass=0.85Tair+1.3 : Eq.4

Determination of regression model's accuracy

The accuracy of the model in predicting the each surface temperature using air temperature was determined by correlation and Nash-Sutcliffe efficiency coefficients. Nash-Sutcliffe efficiency coefficients can be calculated by Eq.5:

$$R_{NS}2 = 1 - \frac{\sum_{i=1}^{n}(o_i - p_i)^2}{\sum_{i=1}^{n}(o_i - o_{avg})^2} \quad : \text{Eq.5}$$

Where Oi, Pi and Oavg are observed temperature, estimated temperature and mean value of observed temperature, respectively.

Nash-Sutcliffe efficiency coefficient varies between -∞ and 1. When it is closer to 1, shows that the used model has proper efficiency for simulation.

Results and discussion

Surfaces temperature in sunny condition

To analysis of the surface temperature on three different urban surfaces (asphalt, soil and grass) a day with no cloud cover and windy condition was selected during the April. According to the table.1, the weather condition was reported calm and sunny with cloudless condition at Geophysic weather station on April 9th. As can be seen in table.1, there was no cloud cover in the sky during the day and maximum and minimum air temperature was 25 and 15 °C, respectively.

Table 1. Weather condition on April 9th in studied area.

Cloudiness (Okta)	Maximum wind speed (M/s)	Minimum air temperature (°C)	Maximum air temperature (°C)	Minimum relative humidity (%)	Maximum relative humidity (%)	Weather parameters day
0	3	15	25	30	48	April 9th

According to the surface temperature which measured on three different land covers, as can be seen in Fig.5, the trend of all surfaces temperature is sinusoidal and obeys the trend of solar radiation. It means the surface temperature of land covers start to increase after sunrise (around 6 a.m. in local time) and continue to rise until the noon when the solar radiation reaches to its maximum (peak). Then, temperature of all surfaces start to decrease and this trend will continue until the next day's sunrise time. It is important to note that, temperature rising trend before noon has sharper slope, while the slope of temperature decrease after noon is slow. In other word, surfaces lose their energy that gained during the day, slowly after noon. Also, according the Fig.5, Asphalt is the hottest surface with maximum value of 47.8 °C and then the soil surface is warmer with maximum value of 40°C than the grass with maximum value of 29.9°C. So, regarding to materials and surfaces thermal properties which is one of the great significance in their thermal behavior, one can conclude that surfaces which have low albedo and emissivity have higher temperature during the day (asphalt) while soil with higher albedo and emissivity in comparison with asphalt shows lower temperature. Also, the grass has higher albedo and emissivity than soil and asphalt, so its temperature during the day is lower than them. It should be mentioned that the evapotranspiration from the grass is another important factor which led to its lower temperature.

However, surfaces showed different trend during the night so that after sun set the highest temperature is related to soil, grass and asphalt, respectively. It represented that surfaces with high thermal conductivity like soil, has higher temperature during the night. To confirm this theory, the correlation between surfaces some thermal properties and maximum and minimum temperatures were analyzed in sunny weather condition. According to table.2, there is negative significant correlation between surfaces maximum temperature with albedo, emissivity, heat capacity and thermal inertia with amount of -0.72, -0.94, -0.81 and -0.85, respectively, which are significant at 0.01 and 0.05 levels. Moreover, there is direct correlation between surfaces minimum temperature with thermal conductivity and diffusivity. So, it can be concluded that in calm and sunny weather condition all thermal characteristics of materials and surfaces influence their temperature pattern.

Surfaces temperature in cloudy condition

According to the Geophysic weather station report which is illustrated in table.3, cloudiness varies between 5-7 okta during April 14th, minimum and maximum air temperature is 11 and 16.6 °C and average value of relative humidity is 55%. Therefore, temperature pattern of surfaces was analyzed during this day, as a cloudy condition.

Table.2. correlation between surfaces thermal properties and maximum/minimum temperature.

Pearson Correlation	Max Temperature	Min Temperature	Thermal Conductivity	Heat Capacity	Albedo	Emissivity	Diffusivity	Thermal Inertia
Max	1	.210	.139	.810*	-.724*	-.947**	.406	-.850*
Temperature		.690	.793	.051	.104	.004	.425	.032
Min	.210	1	.916*	-.431	.192	-.020	.882*	-.094
Temperature	.690		.010	.393	.715	.970	.020	.860
Thermal	.139	.916*	1	-.173	.293	.079	.904*	-.072
Conductivity	.793	.010		.743	.573	.881	.013	.892
Heat Capacity	-.810*	-.431	-.173	1	.655	.814*	-.373	.756
	.051	.393	.743		.158	.049	.467	.082
Albedo	-.724*	.192	.293	.655	1	.748	-.015	.815*
	.104	.715	.573	.158		.087	.978	.048
Emissivity	-.947**	-.020	.079	.814*	.748	1	-.131	.891*
	.004	.970	.881	.049	.087		.805	.017
Diffusivity	.406	.882*	.904*	-.373	-.015	-.131	1	-.216
	.425	.020	.013	.467	.978	.805		.681
Thermal Inertia	-.850*	-.094	-.072	.756	.815*	.891*	-.216	1
	.032	.860	.892	.082	.048	.017	.681	

**Correlation is significant at the 0.01 level (2-tailed).
*correlation is significant at the 0.05 level (2-tailed).

Table 3. Weather condition on April 14^{th} in studied area.

Cloudiness (Okta)	Maximum wind speed (M/s)	Minimum air temperature (°C)	Maximum air temperature (°C)	Minimum relative humidity (%)	Maximum relative humidity (%)	Weather parameters day
5-7	4	11	16.6	45	65	April 14^{th}

As can be seen in Fig.6, the temperature of land covers was not completely sinusoidal pattern because of the effect of cloud cover so that there are some fluctuations on surface temperature trend during the day. To understand the impact of cloud cover on temperature changes, variation of cloud cover during the day was displayed in Fig.7. As can be seen, the time of fluctuation in temperature patterns is exactly according to the cloudiness variations. For instance, temperature peak value was occurred at 11 a.m. when the cloud cover has descending trend. Then, temperature of all surfaces show descending trend around 12-13 p.m. when cloudiness shows ascending trend. Also, investigation of temperature range (difference between maximum and minimum temperatures) in this day illustrated that temperature has lower range in comparison with sunny condition so that it range for asphalt, soil and grass is 30.5, 19.9 and 13.4 °C, respectively. While the temperature range in sunny condition for asphalt, soil and grass was 40.5, 28 and 21.7 °C. Therefore, it is obvious that cloudy condition not only changes the temperature pattern but also affects surface temperature values. It is appropriately corresponded to this theory that UHI intensity usually occurs in calm and sunny weather condition.

Modeling surface temperature using air temperature

As air gains its energy from the land surfaces, there is a significant correlation between air temperature and surface temperature so that one can calculate surface temperature using air temperature. In this section, we calculate three different lands covers mean temperature using mean air temperature during April 2013 based on regression model which was explained in methodology. Then, the accuracy of the model will be determined by correlation and Nash-Sutcliffe efficiency coefficients. According to the results of model which were displayed in Fig.8-10, estimated temperature by regression model overestimated the surface temperature but according to the correlation and Nash-Sutcliffe efficiency coefficients this amount of error is acceptable.

According to the Fig.11 there is significant correlation between observed and estimated mean surface temperature for all land covers. Correlation coefficients for asphalt, soil and grass are 0.90, 0.88 and 0.84, respectively which are significant at 95% level. Moreover, the results of Nash-Sutcliffe efficiency coefficients illustrated that the used regression model has proper efficiency for simulation of mean surface temperature (table.4). Also, analysis of cloudiness impact on surface temperature demonstrated that there is direct relationship between cloud cover variations in the sky and surface temperature changes so that when cloudiness increase, surfaces temperature show descending trend and vice versa.

Table 4. Nash-Sutcliffe efficiency coefficient for different surfaces.

Surface	Asphalt	Soil	Grass
R_{NS}^2	0.88	0.93	0.80

Conclusion

Determining of temperature pattern on different urban land covers illustrated that there is significant difference between them which obeys their thermo-physical properties so that asphalt with the lowest albedo and emissivity showed the highest temperature during the day while it displayed the lowest temperature at night because of low thermal conductivity. Therefore, it can be concluded that for determining of the temperature behavior on land covers all of their properties must be considered simultaneously. Also, comparison of temperature pattern in clear sky and sunny condition with cloudy condition, illustrated that cloudiness have significant direct effect on temperature changes over surfaces so that increasing cloudiness is associated with temperature descending trend over surfaces. On the other hand, in cloudy condition, the range of temperature decreases, too. It means the potential of UHI formation or expanding in clear sky is more than cloudy condition. This is confirmed the result of Qin *et al.* (2011) that showed the surface maximum temperature and thermal stresses shift by up to 5°C in urban areas, when the local weather shifts from sunny day to cloudy day or vice versa. As mentioned before, Tehran has hot and dry weather condition in 6 months of the year so that the result demonstrated that some surfaces maximum temperature such as asphalt in warm period of the year reached to 50°C. it is obvious that regarding to the urbanization and population growth in the city, using this type of surface covering is the main factor which contribute to the development of Tehran's Urban Heat Island (UHI). While the maximum surface temperature of grass surface in warm period of the year is 30 °C. From this point of view, the grass surface is most advantageous one for temperature lowering because of the effect of evapotranspiration. Therefore, development of grass surfaces in open spaces between roads and construction of more green spaces in urban areas can reduce the effect of UHI. Finally, results of used regression model to predict surface temperature by air temperature, illustrated that the model has proper accuracy in estimating the surface temperature so that correlation and Nash-Sutcliffe efficiency coefficients confirmed the accuracy of the model.

References

Anonymous. 2001. Joint aviation authorities' airline transport pilot's license. Theoretical knowledge manual. 050 Meteorology. Oxford Aviation Service Limited. Published by Jeppesen GmbH, Frankfurt, Germany.

Gorsevski V, Taha H, Quattrochi D, Luvall J. 1998. Air pollution prevention through urban heat island mitigation: An update on the Urban Heat Island Pilot Project. Proceedings of the ACEEE Summer Study, Asilomar, CA, **9**, 23-32.

Gui J, Phelan P E, Kaloush K E, Golden J S. 2007. Impact of pavement thermophysical properties on surface temperatures. Journal of Materials in Civil Engineering **19(8)**, 683-690.

Hassan HF, Al-Nuaimi AS, Taha R, Jafar TMA. 2005. Development of asphalt pavement temperature models for Oman. Journal of Engineering Research **2**, 106-116.

He JF, Liu JY, Zhuang DF, Zhang W, Liu ML. 2007.Assessing the effect of land use/land cover change on the change of urban heat island intensity. Theoretical and Applied Climatology **90**, 217-226.

Herb WR, Janke B, Mohseni O, Stefan HG. 2008. Ground surface temperature simulation for different land covers. Journal of Hydrology **365**, 327-343.

Hermansson A. 2000. Simulation model for calculating pavement temperatures including maximum temperature. Transportation Research Record, Journal of the Transportation Research Board **1699**, 134-141.

Hermansson A. 2004. Mathematical model for paved surface summer and winter temperature: comparison of calculated and measured temperatures. Cold regions science and technology **40**, 1-17.

Li J, Song C, Cao L, Zhu F, Meng X, Wu J. 2011. Impacts of landscape structure on surface urban heat islands: a case study of Shanghai, China. Remote Sensing of Environment **115(12)**, 3249-3263.

Li H, Harvey J, Jones D. 2012. Multi-dimensional transient temperature simulation and back-calculation for thermal properties of building materials. Building and Environment,1-16.

Mohseni A. 1998. LTPP seasonal asphalt concrete (AC) pavement temperature models. No. FHWA-RD-97-103.

Oke TR. 1982. The energetic basis of the urban heat island. Quarterly Journal of the Royal Meteorological Society **108(455)**, 1-24.

Peterson TC. 2003. Assessment of urban versus rural in situ surface temperatures in the contiguous United States: No difference found. Journal of Climate **16(18)**, 2941-2959.

Qin Y, Hiller JE. 2011. Modeling the temperature and stress distributions in rigid pavements: Impact of Solar Radiation absorption and heat history development. KSCE Journal of Civil Engineering **15(8)**, 1361-1371.

Roth M. 2002. Effects of cities on local climates. In Proceedings of Workshop of IGES/APN Mega-City Project (pp. 23-25). Kitakyushu, Japan.

Stathopoulou M, Cartalis C. 2009. Downscaling AVHRR land surface temperatures for improved surface urban heat island intensity estimation. Remote Sensing of Environment **113(12),** 2592-2605.

Taha H, Sailor D, Akbari H. 1992. High-albedo materials for reducing building cooling energy use (No. LBL--31721). Lawrence Berkeley Library, CA, United States.

Wijeyesekera D, Nazari M, Affida N, Lim S, Masirin M, Zainorabidin A, Walsh J. 2012. Investigation into the Urban Heat Island Effects from Asphalt Pavements. OIDA International Journal of Sustainable Development **5(06**), 97-118.

Yilmaz H, Toy S, Irmak M A, Yilmaz S, Bulut Y. 2008. Determination of temperature differences between asphalt concrete, soil and grass surfaces of the City of Erzurum, Turkey. Atmósfera **21(2)**, 135-146.

Yilmaz S, Toy S, Irmak M A, Yilmaz H. 2007. Determination of climatic differences in three different land uses in the city of Erzurum, Turkey. Building and environment **42(4)**, 1604-1612.