COOL BUILDING ENVELOPE: AN URBAN HEAT ISLAND MITIGATION STRATEGY

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ABSTRACT

Protecting the environment and the urban climate seems never considered as a basis for building envelope design decisions. Instead of designing the envelope for architectural purposes only, the envelope design should be restricted to protect the urban climate as well as the indoor climate.

This study promotes an introduction of Cool Building Envelope, a step towards instituting an Urban Heat Island (UHI) mitigation scale. This is important not only to achieve UHI mitigation but also to maintain an energy balance within the building

غلاف المبنى كوسيلة للحد من ظاهرة الجزر الحرارية

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الملخص العربى

أن الحفاظ على البيئة الطبيعية المحيطة بالمبانى عادة ما يكون خارج رؤية المعمارى و المصمم للغلاف الخارجى للمبنى و لكن دائما يهدف الى جمال الشكل و التكوين المعمارى. أن الغلاف الخارجى للمبنى يجب أن يصمم ليس فقط ليحقق رؤية و أهداف المعمارى للكتلة المعمارية و لكن أيضا للحفاظ و ترشيد الطاقة داخل المبانى بالأضافة الى الحفاظ على البيئة الطبيعة المحيطة بالمبنى. و حيث أنة من الثابت علميا أن أرتفاع درجة الاسطح فى المواد المختلفة هى المحرك الرئيسى لرفع درجة حرارة الهواء فى المدن و هو ما سبب ما يعرف بظاهرة الجزر الحرارية أو أرتفاع درجة حرارة المدن.

لذا تهدف هذة الدراسة الى تحليل تأثير الغلاف الخارجى للمبنى على رفع درجة حرارة الهواء و دراسة معدلات خفض و أرتفاع درجة حرارة الأسطح من خلال تغيير قدرة السطح على أمتصاص مركبات الاشعاع الشمسى المباشرة و المنعكسة و أيضا التحكم فى معامل أنتقال الحرارة بالحمل و الأشعاع مع تغير سرعة الرياح. و قد خلصت الدراسة لعدد من النتائج من خلال حساب التغير فى درجات حرارة سطح الغلاف الخارجى للمبنى و التى تم عرضها فى صورة عدد من المنحنيات البيانية لتوضيح تأثير العوامل السابق ذكرها منفردة مع مقارنة النتائج النهائية للأسطح مجتمعة لتكون نواة لمعدلات و قوانين لتنظيم تصميم الغلاف الخارجى للمبنى كوسيلة للحد من ظاهرة الجزر الحرارية.

INTRODUCTION:

The objective of this paper is to investigate the possibility of developing a new concept of building envelopes that reduce the amount of heat released to the environment. This concept termed: Cool Building Envelopes, which defines a building envelope that can minimize the amount of stored radiant heat and consequently reduce the amount of released heat to the environment.

The concept of Cool Building Envelope not only conserves traditional energy use, but also helps in preserving the environment from pollutants and become an Urban Heat Island mitigation strategy. Individual building envelopes can be shaped and structured to reduce the effect of re-radiated long wave radiation to the urban environment. As the focus here is the building envelope and its behavior, the sharing point for generating the most appropriate building envelopes is its material properties selection.

SURFACE TEMPERATURE APPROACH

While the building envelope gets heated by solar irradiance during the day, most of this heat is stored in the building mass and released to the urban climate for sometime during the day and most of the times at night. Since the rate of heat transfer between surfaces depend on their temperature differences, surface temperature becomes a good indicator for quantifying the amount of the total radiant output emitted from a building envelope to the outdoor air. Consequently, the decision was made to evaluate the amount of heat transferred from building envelope due to its surface temperature in comparison with other ground surfaces near to the building such as sidewalks and roads.

The procedure selected for investigation in this paper is based on calculating outdoor surface temperature known as Sol-air temperature using equations provided by ASHRAE (2001). The calculation is made for horizontal surface as well as for the four main orientations of vertical walls. The calculation is done based on location specific data; the day of the year, latitude and longitude as well as clearness number “CN” for the city of phoenix, Arizona. The date selected for calculation was JUNE 26 to represent one of the hottest days in summer season.

The pattern of incoming short wave radiation is controlled by the azimuth and altitude. Based on that, values for solar position data A, B, C (extraterrestrial solar irradiance data) were used for solar data calculations as a function of the month of the year (ASHRAE 2001).

Sol-air temperature $\mathbf{T_{sa}}$ as defined by ASHRAE " is the temperature of the outdoor air that in the absence of all radiation changes gives the same rate of heat entry into the surface as would the combination of incident solar radiation, radiant energy exchange with sky and other outdoor surroundings and convective heat exchange of the outdoor air. The following is the sol-air temperature equation used for analysis in this paper.

Sol-Air Temperature $T_{sa} = t_o + ((\alpha/h_o) E_t) - ((\varepsilon / h_o) \Delta R)$

Where $\mathbf{t_o}$ is the outdoor ambient air temperature F^o , $\boldsymbol{\alpha}$ is the absorbance of surface for solar radiation, $\mathbf{h_o}$ is the coefficient of heat transfer by long wave radiation and convection at outer surface ($Btu/h.ft^2.F^o$), $\mathbf{E_t}$ is the total solar radiation incident on surface in $Btu/h.ft^2.F^o$, $\mathbf{\Delta R}$ is the difference between long-wave radiation incident on surface from sky and surroundings and radiation emitted by black body at outdoor air temperature ($Btu/h.ft^2$) and finally, $\boldsymbol{\varepsilon}$ is the hemispherical emittance of the surface. As indicated above on the Sol-air temperature equation, the overall value $\mathbf{(\varepsilon / h_o) \Delta R}$ is known as long-wave correction term which represents the amount of temperature drop due to long-wave radiation to the sky. An empirical value for temperature drop was suggested by Givoni (1997) for use based on climate condition. A value of 11 F^o was suggested for arid climates with clear skies, 7F^o for humid climates with clear skies and zero for cloudy sky conditions.(Givoni 1997).

Since vertical surfaces receive almost nothing from long wave radiation emitted from the sky, it is common practice to assume $\mathbf{\Delta R}$=0 for vertical surfaces. For ground horizontal surfaces, a value of 20 $Btu/h.ft^2$ was suggested as an average value for $\mathbf{\Delta R}$. (ASHRAE, 2001)

THE PARAMETERS

Ambient Air Temperature t_o

The ambient outdoor air temperature or Dry Bulb Temperature (DBT) represents the actual air temperature for a specific location. Hourly values for DBT were collected for the desired date through available weather stations on site and also compared with published weather data through Weather Underground Inc. (www.wunderground.com). The hourly profile values will be used later for temperature change analysis between sol-air temperature and air dry bulb temperature.

Total Solar Radiation

Since the position of the sun in the sky can be located by its altitude and azimuth angles, both are function of site latitude. The position of the sun determines the intensity of solar irradiance on various building surfaces such as walls and roofs. ASHARE (2001) provides all necessary equations for calculating solar irradiance. Values for total solar radiation were calculated for the city of Phoenix, Arizona for June 26 (day No. 176) on different wall orientations as well as for horizontal surface. The total solar radiation $\mathbf{E_t}$ is a function of not only direct solar irradiance but also diffuse and reflected short wave radiation. The sky condition and humidity rates affect the amount of diffused radiation. Also, reflected radiation from the surrounding ground surfaces and walls is affected by the properties of material and its surface color. The reflectivity of the bare ground depends on the type of soil ranging from 70% for sand to 20% of dark soil. Reflectivity of some materials such as concrete and asphalt surfaces differs with age of the surface as they become lighter in color with time.

Surface Absorbance and Reflectivity

A materials reflectivity is a measure of visible light reflectance. **Albedo (â)** is the measure of incident light and solar reflectivity of a material or surface. Albedo is described as a ratio and is measured on a scale of 0.0 to 1.0. Materials or surfaces on the low end of the scale 0.0, absorb solar radiation. While those at the high end of the scale,1.0, reflect solar energy. *Akbari, Rosenfled and Taha (1990)* further describe albedo as the measurement of reflective amounts versus incident radiant energy. For opaque materials,

Perfect reflectors have â = 1,
perfect absorbers have â = 0.
absorbtivity is (1-â)

An Albedo ratio can be expressed as either a function or a percentage. Snow has a high albedo of 0.9 (90%) due its white color, while vegetation has a low albedo of 0.1 (10%). High albedo materials reflect more of the solar heat. Buildings treated with high albedo materials absorb much less heat to store and to transfer inward towards interior systems or to air near to the surface.

While it is general rule that surfaces that appear light-colored in the visible spectrum have high albedo and dark colored surfaces have a low albedo rating, color is not always a true indicator of albedo.

Surface	Albedo	Emissivity
Leaves	0.28-0.34	0.94-0.99
Forests, deciduous	0.15-0.20	0.97-0.98
Forests, coniferous	0.05-0.15	0.97-0.99
Grasses	0.16-0.26	0.90-0.95
Soils	0.05-0.40	0.90-0.98
Asphalt	0.05-0.20	0.95
Concrete	0.10-0.35	0.71-0.90
Brick	0.20-0.40	0.90-0.92
Paint, white	0.50-0.90	0.85-0.95
Paint, red, brown, green	0.20-0.35	0.85-0.95
Paint, black	0.02-0.15	0.90-0.98
Human skin, white	0.35	0.98
Human skin, black	0.18	0.98

Table (1): Typical albedos and long-wave emissivities of common surfaces (Oke 1978 and Monteith 1973).

The long wave radiation reflected from the surface depends on the amount of incident radiation and the surface albedo. For opaque surfaces, the portion of short-wave radiation not reflected is absorbed.

Due to the high reflectivity of light color walls, the effect of surface orientation will be minimized where a very small amount of long-wave radiation will be absorbed by the surface. Surface albedo for horizontal as well as for vertical surfaces was selected for analysis based on published data for common materials. The calculations were performed for every 0.05 albedo. Also, values for surface absorbance and reflectivity (albedo), were included for the calculation with reference to published albedo values from other studies. Table (1)

Surface Heat Transfer Coefficient (h_o)

One of the important parameters for calculating surface temperature is the outdoor surface heat transfer coefficient $\mathbf{h_o}$, where it represents the rate of surface heat loss by convection and radiation for outdoor surfaces. Surface heat transfer coefficient is usually determined at standard temperature and air velocity conditions. The surface heat transfer coefficient is estimated based on ASHRAE recommendation for winter condition as a maximum of 5.1 Btu/ft^2 for 15 mph wind speed and as low as 1.2 Btu/ft^2 for still air condition. A linear equation was performed to estimate $\mathbf{h_o}$ values due to local wind speed condition for Phoenix, Arizona. A value for surface heat coefficient transfer loss was concluded of 0.278 Btu/ft^2 for every increase of one mile per hour wind speed. In a study by Givoni (1997), a value of 6 Btu/h.ft^2.^{o}F or 20 w/m^2.^{o}C was suggested for use with wind speed of 7.8 mph or 3.5m/s. The values for $\mathbf{h_o}$ will be used based on values set forth by ASHRAE standards. A quick method of obtaining surface heat transfer coefficient $\mathbf{h_o}$ values relative to wind speed is used. The method utilized the minimum and maximum ASHARE values for $\mathbf{h_o}$ presented previously to interpolate other $\mathbf{h_o}$ values relative to wind speed. The following is the equation used for interpolation:

$$\mathbf{h_o = h_{o\ calm} + [\ V\ \ X\ \ ((h_{o\ winter} - h_{o\ calm}) / (\ V_{winter} - V_{calm}))]}$$

Where $\mathbf{h_o}$ is the interpolated surface heat transfer coefficient, $\mathbf{h_{o\ calm}}$ and $\mathbf{h_{o\ winter}}$ are surface heat transfer coefficient for calm and winter conditions, $\mathbf{V_{winter}}$ and $\mathbf{V_{calm}}$ are the wind speed for winter and calm conditions and $\mathbf{V}$ is the actual wind speed in mile per hour. Due to values published by ASHRAE, the final equation can be presented as follows:

$$\mathbf{h_o = 1.2 + [\ V\ \ X\ \ 0.278\ ]}$$

The above equations was used to calculate sol-air temperature for different orientations as well as for ground surfaces with the change of wind speed starting from 1 mph to 15 mph. Results were presented graphically for ground/horizontal surfaces as well as for west wall.

Hemispherical Emittance (ε)

Irradiance is the radiant flux density incident on a surface whereas emittance is the radiant flux density emitted by a surface. Any surface emits and absorbs long-wave radiant energy relative to its emissivity. The emissivity is independent of the color and for almost all nonmetallic surfaces the emissivity is about 0.9 regardless of its albedo. In any specific wave length such as long-wave radiation, the emissivity is equal to absorptivity. Metallic surfaces and specially polished metals have very low emissivity and consequently absorb and emit very little long-wave radiation. Since most building materials have emissivity values ranging from 0.85 to 0.95, an emissivity value of 0.9 was used for Sol-air temperature calculation for walls and ground surfaces.

A sensitivity analysis was performed to investigate the amount of change in surface temperature for vertical and horizontal surfaces due to the change in wind speed and surface heat transfer coefficient on the horizontal and vertical surfaces temperature. The surface heat transfer coefficient was correlated to local wind speed values based on ASHRAE (2001).

ANALYSIS AND RESULTS

Sensitivity of the Parameters

Surface Albedo

Given the fact that west wall is part of the building envelope that experiences large amounts of solar radiation, a selection was made to explore the sensitivity of parameters on its surface temperature. By applying the procedure discussed previously, the sol-air temperature on west wall was correlated linearly with the albedo change on its maximum value at 4 PM, where for every 0.05 rise in albedo, a surface temperature increase of 9^{o}F was observed (fig. 2). For example, a material having surface albedo of 0.2, such as common brick, will have higher surface temperature by about 54^{o}F than the same material with 0.5 surface albedo. Differently, for horizontal surfaces, the rate of temperature change due to surface albedo is lower (fig. 1). The amount of drop in horizontal surface temperature is only 5^{o}F for every 0.05 rise in surface albedo and the temperature drop, with the same albedo rise applied in the example discussed previously, will be 30^{o}F, a value of about half the amount observed for west wall. Therefore, surface albedo will be more effective as an urban heat island mitigation strategy for walls and building envelopes than for ground and horizontal surfaces such as roads and side walks.

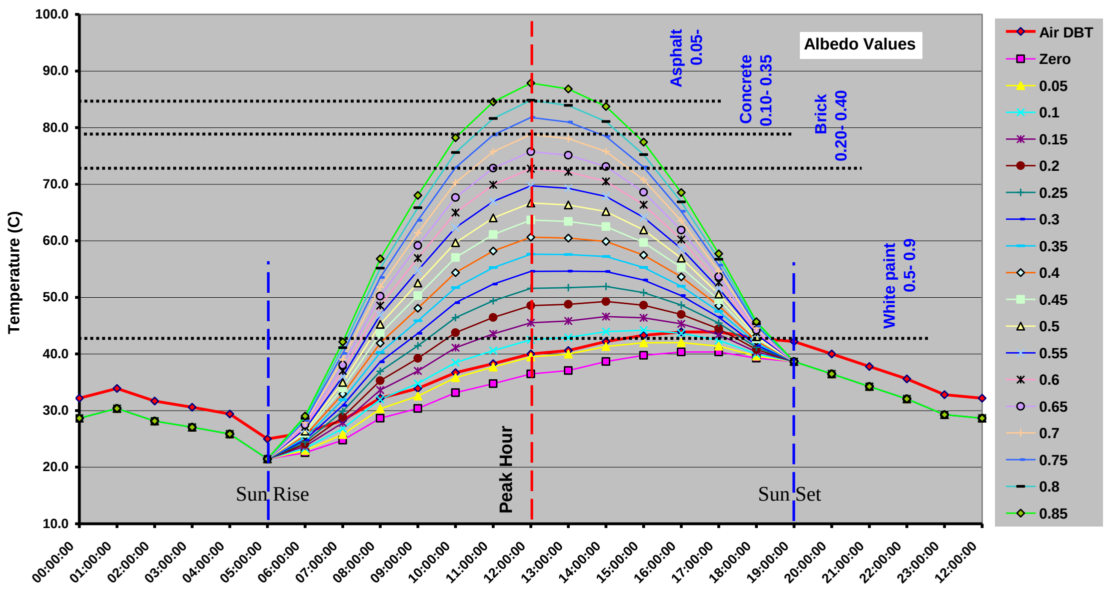

Figure 1 : Sensitivity of Absorbance on Surface Temperature for Horizontal Surfaces.

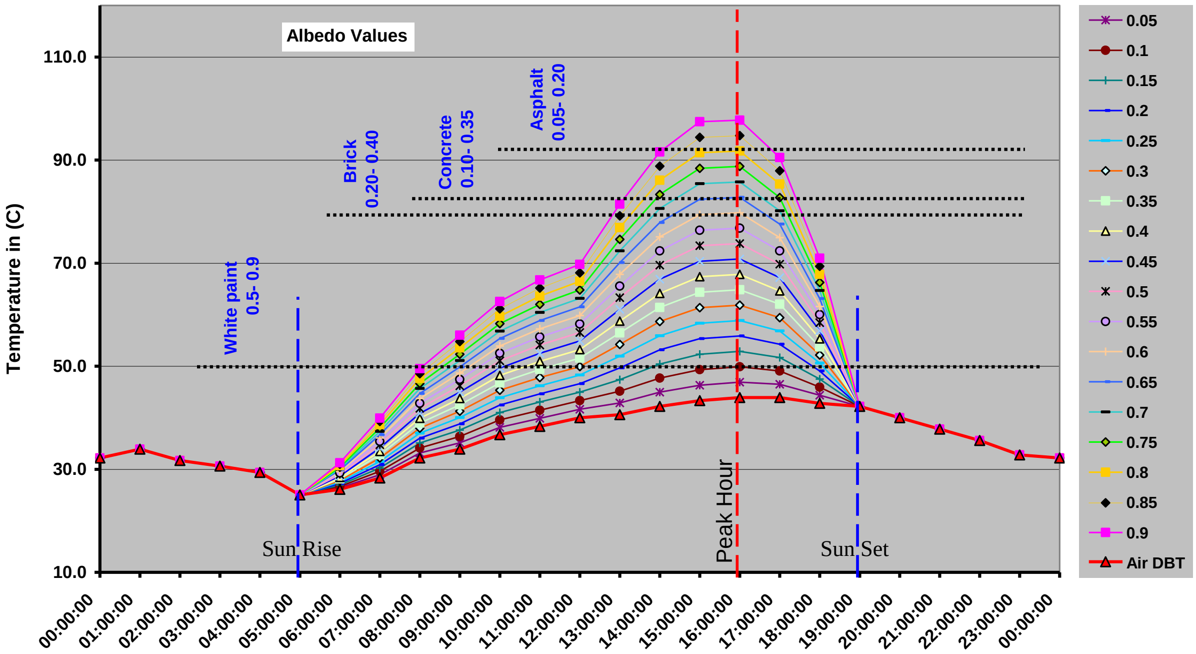

Figure 2 : Sensitivity of Absorbance on Surface Temperature For West Wall .

Surface Heat Transfer Coefficient (h_o)

The external surface coefficient ($\mathbf{h_o}$) represents the combined effect of the convective heat loss and long wave radiation from the surface to the urban environment. The magnitude of $\mathbf{h_o}$, depends on wind speed near surface. ASHRAE recommended values of $\mathbf{h_o}$ based on previous studies. It is expected that with a given wind speed the actual speed next to wall is affected significantly by the urban structure. Where in a dense built urban area would be about one half of the measured wind speed in weather stations (Givoni, 1998). Since the rate of change for surface heat transfer coefficient depends mainly on wind speed, a series of calculations were made to investigate the amount of change in $\mathbf{h_o}$ rate and consequently the surface temperature change due to change in wind speed. The calculation was made using wind speed values starting from 1 mile per hour, for calm conditions to 15 mile per hour representing the maximum winter condition, on one mile per hour increment.

Contrary to surface albedo, the surface heat transfer coefficient was interrelated with a non-linear relation to surface temperature. The amount of change in surface temperature can be estimated using a polynomial fit. As shown from (fig. 4), the surface temperature on west wall at 4 pm on 26 of June was reduced by 50 ^oF due to rise in wind speed from 1 mph to 4 mph where for wind speed rise from 4 mph to 7 mph only a drop of 23 ^oF was observed. Moreover, continuing to move up wind speed from 12 mph to 15 mph will reduce the surface temperature by only 7 ^oF. Horizontal surfaces followed the same behavior as for west wall but with higher rate.The amount of temperature drop for horizontal surfaces noon time at the same date was 70, 32, 9 ^{o}F respectively with same wind speed change mentioned previously.

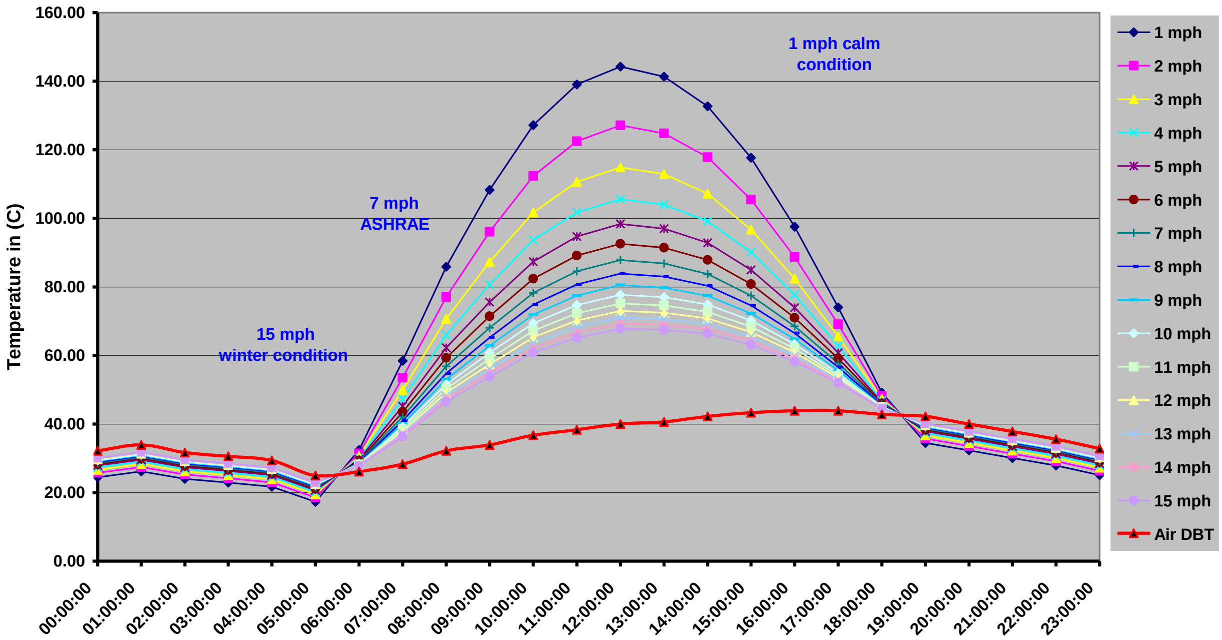

Figure 3: Sensitivity of Heat Transfer Coefficient on Surface Temperature For Horizontal Surfaces.

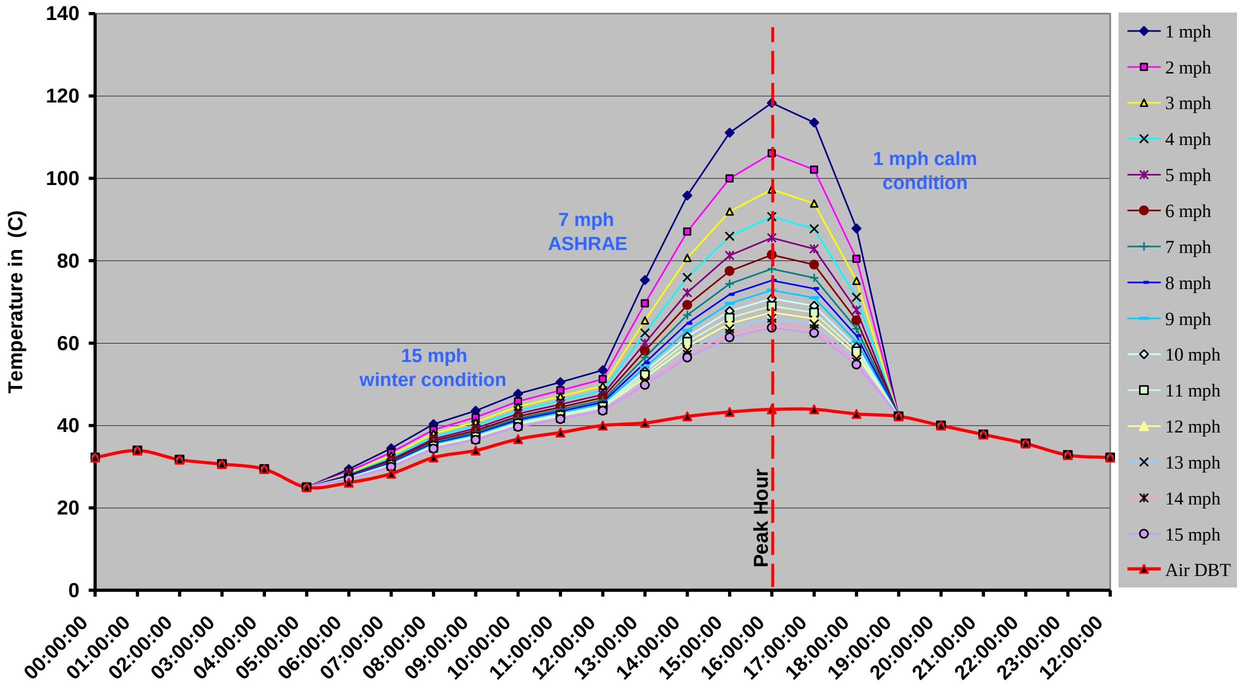

Figure 4: Sensitivity of Heat Transfer Coefficient on Surface Temperature For West Wall

Method Limitation:

The ASHRAE Sol-Air temperature method represents the temperature of sunlit surfaces where it accounts for: 1) Direct and diffuse solar radiation, 2) Surface heat loss by radiation, 3) Surface heat loss by convection as a function of local current wind. And finally 4) Air ambient temperature.

At the same time, the method is limited by its day time calculation only where it does not take into effect surface heat losses by night cooling to the sky. Also, the effect of material thermal mass and its capability to store heat was not included where material behavior through the night differs than its actual behavior. In addition to that, the cooling effect through earth contact process known as earth coupling and heat released from surfaces to the soil in contact where not accounted for. Large amount of heat stored within ground surfaces usually lost by conduction to deep soil.

CONCLUSION

In attempt to have more accurate and realistic results, it is intended to perform additional studies to investigate the night cooling rate and thermal mass using other computer modeling techniques such as Rad-Therm tool where all data for building and local climate can be easily introduced.

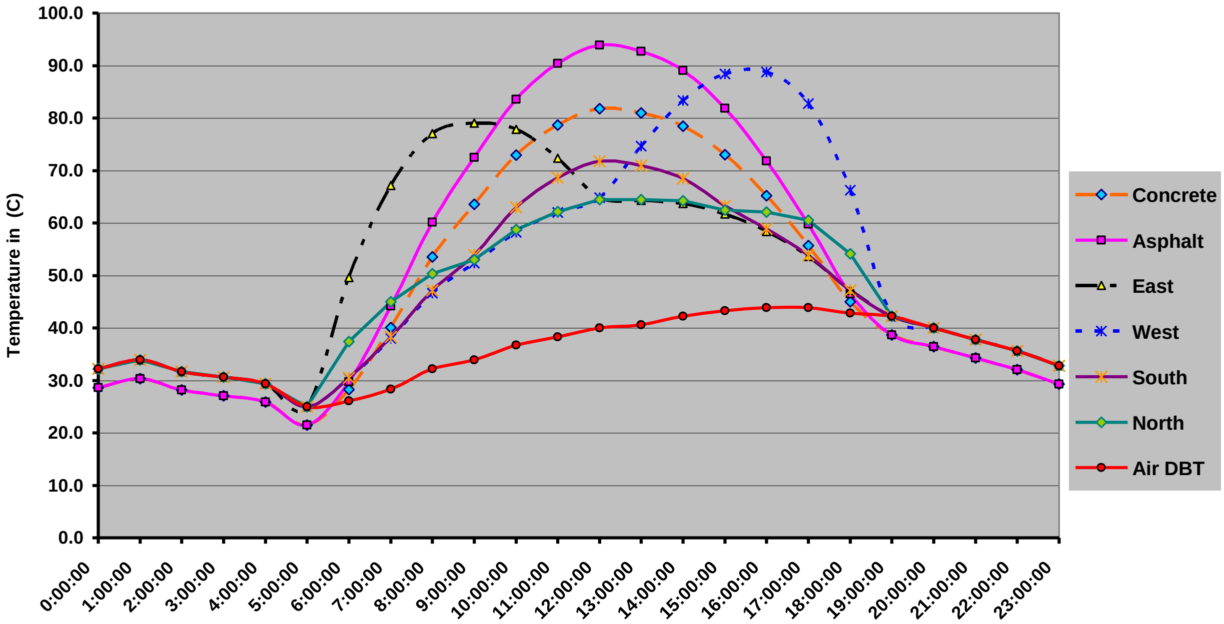

Figure 5: Surface Temperature For Different Wall Orientations and Different Paving Surfaces, June 26, 04
Where: albedo =0.25, wind speed =7mph, h_o=3.14 Btu/ft^2

Since adopting urban wind speed and wind pattern is considered one of the most difficult correction parameters to edit, it is recommended to utilize surface albedo concept as a UHI mitigation strategy. In conclusion, the impact of direct solar radiation on outdoor surface temperature can be minimized through the use of high albedo materials for walls and also for ground surfaces. Light color surfaces can consider one of the handiest ways to use for heat reduction mitigation. Further, using shade trees can also offer shading to building surfaces.

REFERANCES:

ASHRAE (1997). *Handbook of Fundamentals*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, GA.

Stein, B. and Reynolds, J. S. (1992). *Mechanical and Electrical Equipment for Buildings*. New York: John Wiley & Sons, Inc.

Givoni, Baruch (1997). *Climate Considerations in Buildings and Urban Design*. New York: Van Nostrand Reinhold.