Surface Albedo of Bangkok Roads

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Abstract: Albedo is the most significant thermophysical property of non-porous pavements which influences pavement surface temperatures. High albedo surfaces reflect more incident solar radiation back to the atmosphere. This allows lesser energy absorption and hence cooler pavements. Benefits expected from high albedo pavements include lower contribution to urban heat island formation, lower risk of thermal-related stress, lower temperature of surface water run-off, improved night time traffic safety, and reduced demand for lighting. This paper reports the measurement of albedo on selected sections of urban roads in several districts of Bangkok Metropolitan Area, comprising 106 samples of asphalt pavements and 43 of concrete pavements currently in use. It was found that the albedo of both asphalt and concrete pavements were quite low, i.e. less than 0.10. This result indicates an opportunity to increase pavement's albedo through various schemes of known as well as innovative surface treatment methods.

Key words: *road pavement, albedo, surface temperature, surface treatment*

1. INTRODUCTION

Albedo, or solar reflectance, is a radiative property of the surface. It represents the ability of a surface to reflect shortwave radiation covering the whole solar spectrum, including ultraviolet, visible lights and infrared waves, from about 300 to 3000 nm. Albedo value is determined by dividing the amount of reflected radiation by the total incoming radiation; making it a dimensionless property. A higher albedo value indicates a greater portion of short wave radiation would be reflected by the surface and thus it reduces the amount of absorbed solar radiation and keeps the pavement cooler.

Research conducted by US Lawrence Berkeley National Laboratory (Pomerantz et al., 2000) concluded that an increase of albedo value by 10% could reduce surface temperature of asphalt pavement by 4^{o}C. Currently, however, there has been no reference on how high this albedo value should be. Current road construction and engineering practices have not yet considered it as one of the criteria of design. However, the US Leadership in Energy and Environmental Design (LEED) program advocates for the use of surfaces having albedo higher than 0.3 for at least 30% of the non-roof paved surfaces (USGBC, 2009).

Research on high albedo pavements can be seen as the continuation of extensive studies on urban heat island (UHI) phenomena that seek to examine the influence of increasing a city's broadband albedo in mitigating the heat island effects (e.g Taha,1997; Konopacki and Akbari, 2001, 2002; NYSDERDA, 2006; Kolokotroni and Giridharan, 2008). Albedo improvement in this respect was aimed at impervious surfaces of the city, including roofs and pavements. It could be shown through simulation studies that increasing broadband albedo would reduce the average surface and air temperatures of the city.

At a smaller scale, increasing the albedo of surface pavements has been shown to reduce the surface temperature and heat retention more than other material properties (e.g. Gui et al., 2007). Reduced pavement surface temperature is also known to prevent reduction of pavement's useful life by preventing cracking caused by high temperature gradient within a pavement. Additional benefits of using high albedo pavements other than UHI mitigation have also been investigated. For example, it provides better luminance at night that would improve driver's visibility towards objects near the road and hence increasing road safety (Adrian and Jobanputra, 2005, Ziedman, 2005). With better luminance, lighter pavements would also help reduce the requirement of night lighting and thus reducing energy demand and installation costs (Pomertantz 2000; Adrian and Jobanputra 2005).

Increased albedo can be achieved through some ways. One way is to use lighter-colored aggregates and binders either in the mix designs or applied as a new surface through various surface treatment techniques. In this principle, higher albedo is correlated to lighter shades of colors, although by definition albedo covers the full spectrum of solar radiation, not just the visible range. In this way, one would expect that concrete pavements are normally lighter in color than asphalt pavements.

Another way is to coat the pavement surface with high albedo paints. Research in Japan, for example, (Kinouchi et al. 2004) has developed specially-designed paints that remain black in appearance but having high-albedo value. This type of paint specifically increases the surface reflectance across the infra-red range of the solar spectrum but absorbs the radiation within the visible range. By remaining black in appearance, high contrast between road marks and the pavement can be maintained and hence increasing road safety.

As a part of an initial study seeking to introduce the concept and application of cool pavements (i.e. high albedo pavements) for urban heat island mitigation in Bangkok, this paper reports the existing condition of road albedo in the urban area of Bangkok. Learning from the existing condition, further steps would then be considered, including identifying the best possible practices for increasing road albedo and cost benefit analysis for a series of implementation scenarios.

2. MEASUREMENT METHOD

Theoretically, albedo or solar reflectivity, a, of a surface is determined as follows:

$$a \equiv \frac{\int_{\varphi=0}^{2\pi}\int_{\psi=0}^{\pi/2}\int_{\lambda\approx 0.3}^{\pi\approx 3\mu m}\rho(\lambda,\psi,\varphi)\sin\psi\cos\psi\,R(\lambda,\psi,\varphi)\,d\lambda d\psi d\varphi}{\int_{\varphi=0}^{2\pi}\int_{\psi=0}^{\pi/2}\int_{\lambda\approx 0.3}^{\pi\approx 3\mu m}\sin\psi\cos\psi\,R(\lambda,\psi,\varphi)\,d\lambda d\psi d\varphi} \tag{1}$$

where φ and ψ are azimuth angle and elevation of the sun, respectively, both in radian; λ the wavelength, and R the spectral radiance. The lower part of Equation (1) describes the shortwave radiant flux density (in Wm^{-2}) received at the surface, which is integration of solar radiance (in $Wm^{-2}sr^{-1}$) over a solid angle 2π sr, and is referred to as global radiation. The upper part describes the portion that is reflected by the surface. Pavement is considered an opaque body: it does not transmit radiation (transmissivity = 0). Therefore, for a given wavelength it is assumed that the sum of absorptivity α and reflectivity ρ equals unity. As seen from Equation (1) reflectivity depends among others on the incoming radiation's wavelength. It is also dependent on the azimuth and elevation of the sun, and hence in reality it is not a perfect constant throughout the day.

In field measurement, albedo roughly corresponds to the reflected fraction of the shortwave radiation as measured with a double dome pyranometer. The equipment used consists of two coupled-pyranometers as the sensors (Figure 1), one faced upward to measure incoming solar radiation, and another faced downward to measure reflected radiation from the surface. Radiations captured by both sensors were read through a multi channel data logger.

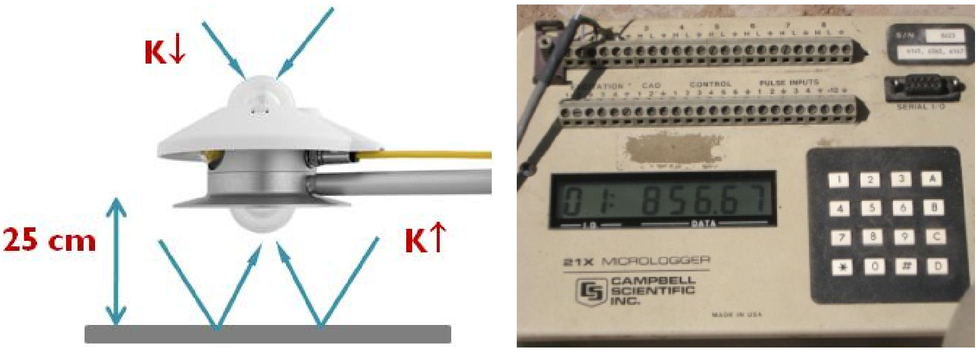

Figure 1 Albedometer (left) and a data logger (right)

The sensors used were LP PYRA 05 made by Hotek Technologies, while the data logger was a product of Campbell Scientific. Albedo of the surface is the ratio of reflected (K↑) and incident radiation (K↓). For a given point, measurements were carried out in clear days, repeated for different sun angles and averaged, following the ASTM-E 1918-97 standard. Observation points were selected on pavement surface which were exposed to direct sunlight and not protected from shadow of nearby objects. A single observation involved recording the radiation input in Wm^{-2} received by both sensors simultaneously on top of a pavement surface for a period of 60 to 120 seconds. For each day, measurements were conducted between 10.00 AM and 4.00 PM to include only high sun angles. Observation data which read global radiation less than 200 Wm^{-2} were discarded.

3. RESULTS AND ANALYSIS

Field survey program was conducted during October to November 2010. Decision was made to include road sections in selected districts within and adjacent to the city center. These are zones where pavements cover relatively larger surface area and where the heat island phenomena are more likely to take place. To identify these zones, a freely available Landsat 7 ETM+ satellite image was analyzed according to the method proposed by Aniello *et al.* (1995) to reveal the temperature distribution across Bangkok (Figure 2). The following districts were then selected for field survey: Chatucak, Phayathai, Din Daeng, Ratchathewi, Patumwan, Pomprab, Huay Kwang, and Watthana.

Survey program managed to collect albedo data from altogether 149 measurement points on road sections in the selected Bangkok Metropolitan's districts, comprising 106 samples taken from asphalt pavement surfaces and 43 samples from concrete pavements. Geographical distributions of the sampling points are shown in Figure 3. Information about when exactly the measured surfaces were constructed was still to be compiled. However, there was no case of newly laid pavement (i.e. less than 3 months) found in the survey.

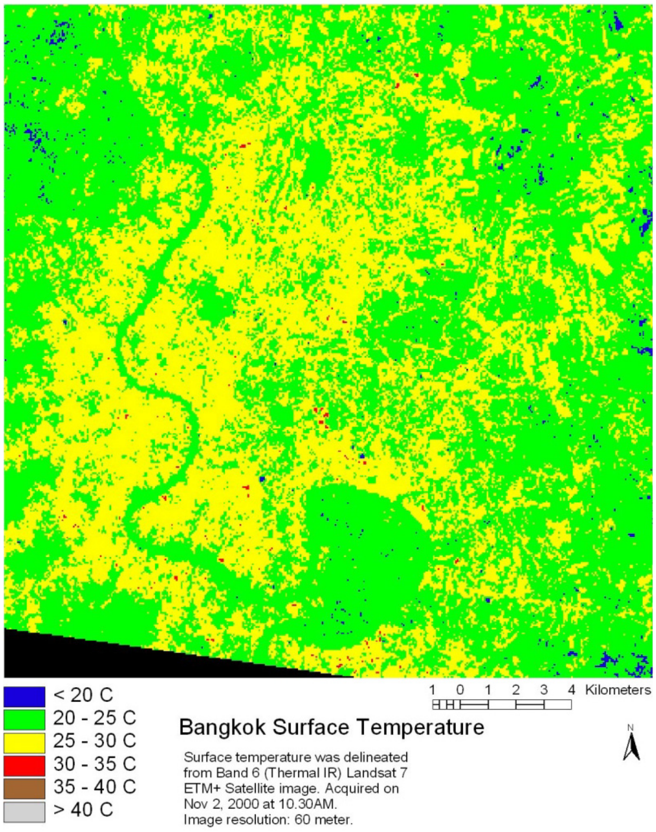

Figure 2 Thermal IR Landsat 7 ETM+ image of Bangkok analyzed to show surface temperature distribution

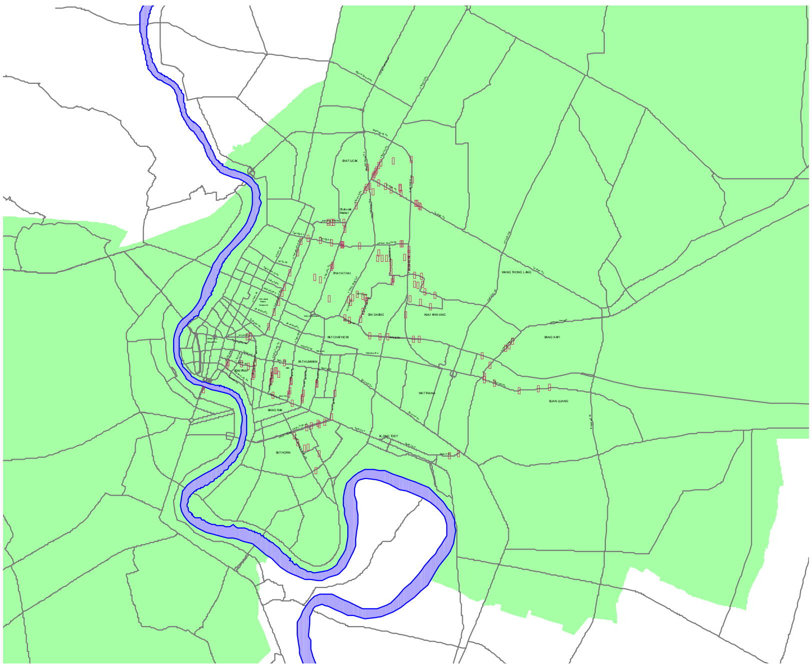

Figure 3 Geographical distributions of sampling points across Bangkok

Figure 4 shows the distributions of pavement albedo for asphalt and concrete pavements collected during the survey. Descriptive statistics of asphalt pavement data showed the mean and standard deviation values of 0.045 and 0.002, respectively. The maximum albedo value was found to be 0.106 and there were 11 observations which had albedo value less than 0.02. These indicate that the observed asphalt pavements reflect on average only about 5% of the incoming solar radiation flux while the rest 95% was absorbed, stored, before released back to the lower atmosphere as heat.

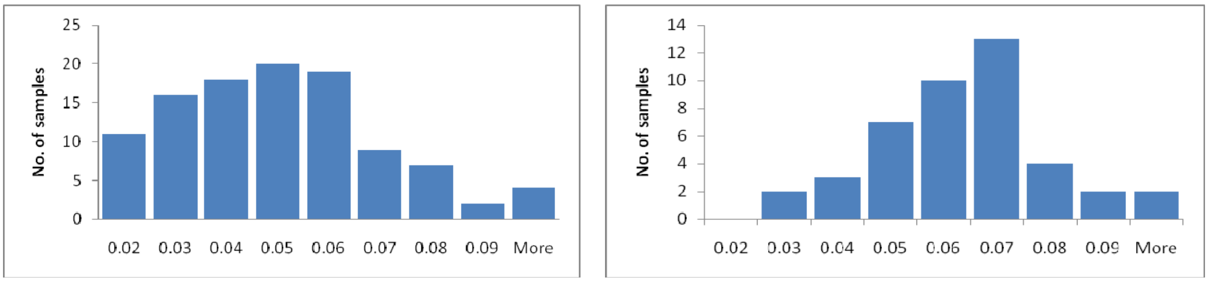

Figure 4 Albedo distributions for asphalt pavements (left) and concrete pavements (right)

The mean and standard deviation of concrete pavement samples were higher than those of the asphalt, i.e. 0.061 and 0.004, respectively. According to t-test results both samples have significantly different means at significance level α of 0.05. The albedo difference between the two pavement types is, however, quite small in practical sense. This small difference means that the existing concrete pavements could reflect short wave radiation only for 2% more on average than the asphalt pavements would do. One may expect that concrete pavements should have higher albedo value due to the fact that they are generally lighter in color when compared to asphalt pavements. However, albedo of lighter surfaces could also be lower than that of the darker ones if the darker surfaces absorb solar radiation more in the infrared range. In fact, visible lights to which colors relate only constitute about 43% of the total energy in the whole solar spectrum, while more than 50% energy radiation lies in the infrared range (ASTM, 1998).

4. CONCLUDING REMARKS

Results of this survey suggest that albedo of both asphalt and concrete pavements in Bangkok are rather low. They would therefore absorb most part of solar radiation flux throughout the day and store the energy with respect to their heat capacity and release it back to the lower atmosphere in contribution to the formation of urban heat islands.

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