Jurnal
Teknologi

Full Paper

COMPARISON ON COLORED COATING FOR ASPHALT AND CONCRETE PAVEMENT BASED ON THERMAL PERFORMANCE AND COOLING EFFECT

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Article history
Received
16 July 2015
Received in revised form
12 October 2015
Accepted
2 November 2015

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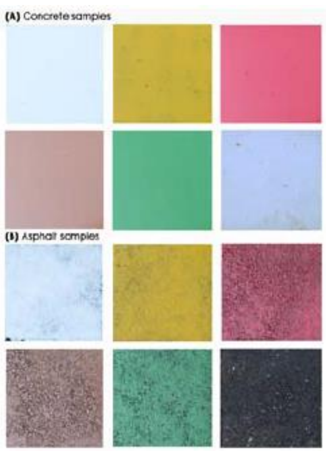
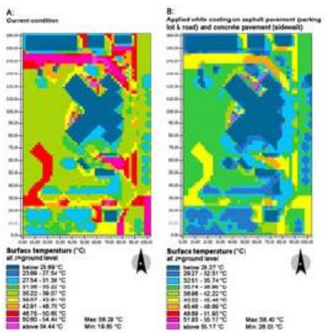
Graphical abstract





Abstract

In tropical climate, pavement surface temperature could reach up higher than the air temperature due to solar-energy absorption by pavement during the daytime. Colored ground surface such as in pedestrian walkway, parking lot, and bicycle track may be able to reduce the heat absorbed by the pavements. This paper reports the thermal performance of five different colors of coating applied at asphalt and concrete pavement surface. In order to investigate the thermal performance and solar reflectance of the colored coating pavement, infrared thermometer and solar power meter as well as thermal imager procedure were used. From the statistical analysis, it was found that all the colored coating on asphalt and concrete sample demonstrate lower surface temperature compared to conventional or uncoated asphalt and concrete. The highest surface temperature reduction and solar reflectance recorded was for the white coated asphalt sample was 17°C and 0.61, while for the white coated concrete sample was 10°C and 0.78. ENVI-met simulation is used for evaluating the thermal impact of applying the samples in site study. This study can assist in choosing more appropriate colored coatings for ground surface of the urban environment (pedestrian walkway, parking lot, plaza, etc.), and thus contribute to the reduction of the air temperature due to the heat-transfer phenomena as well as improve outdoor thermal comfort and cityscape appearance.

Keywords: Pavement, colored coating, surface temperature, solar reflectance

Abstrak

Dalam iklim tropika, suhu permukaan turapan boleh mencecah lebih tinggi daripada suhu udara disebabkan oleh penyerapan tenaga matahari pada turapan di siang hari. Permukaan tanah berwarna seperti di laluan pejalan kaki, tempat letak kereta, dan trek basikal berkemungkinan dapat mengurangkan haba diserap oleh turapan. Kertas kerja ini melaporkan prestasi terma terhadap lima warna salutan yang berbeza digunakan pada permukaan turapan asfalt dan konkrit. Bagi menyiasat prestasi terma dan pantulan matahari terhadap turapan salutan berwarna, termometer inframerah dan meter kuasa solar serta *'thermal imager'* digunakan. Daripada analisis statistik, didapati bahawa semua salutan berwarna pada sampel asfalt dan konkrit menunjukkan suhu permukaan lebih rendah berbanding dengan asfalt dan konkrit konvensional atau tidak bersalut. Penurunan suhu permukaan dan pantulan matahari yang tertinggi dicatatkan adalah bagi sampel asfalt bersalut putih iaitu 17 ° C dan 0.61, manakala bagi sampel konkrit bersalut putih ialah 10°C dan 0.78. Simulasi ENVI-met digunakan untuk menilai kesan terma terhadap penggunaan sampel dalam kajian tapak. Kajian ini dapat membantu dalam pemilihan salutan berwarna yang bersesuaian bagi permukaan tanah di persekitaran bandar (laluan pejalan kaki, tempat letak kereta, plaza, dan lain-lain), dan dengan itu dapat menyumbang kepada penurunan suhu udara yang disebabkan oleh fenomena pemindahan haba dan juga dapat meningkatkan keselesaan terma luaran dan penampilan skap bandar raya.

Kata kunci: Turapan, salutan berwarna, suhu permukaan, pantulan matahari

1.0 INTRODUCTION

The phenomenon of the heat island in urban areas are influencing to changing their microclimate. Open land covered with low natural vegetation are being replaced by buildings, roads and other infrastructures for improving our lives, comfort and needs. This development leads to the formation of called heat island effect, with temperatures in urban areas higher by several degrees compared to the surrounding rural areas, has been documented in many cities around the world [1, 2, 3]. Heat island effect particularly a problem during summer months when heat waves can negatively impact human health, human thermal comfort, increased anthropogenic heat, increased air pollution and increased energy demand [4, 5]. Five to ten percent of electricity demand is frequently used to cool these impacts from elevated temperature. Among the factors that contribute to the heat island effect, the thermal properties of the materials used in the urban fabric play a very important role. Pavements (roads, pedestrian walkway, parking area, bicycle path, squares, etc.) are one of the main hardscape contribute highly to development of heat island [6, 7]. Several studies have reported that pavements cover almost 29-45% of the urban fabric [8, 9, 10].

One of the heat island mitigation strategies can be achieved by the use of cool materials during the summer period [11-16]. Cool materials are characterized by high solar reflectance and high thermal emittance. The two properties could be reduce the temperature of the surface [17]. The term of solar reflectance is the ability of a material to reflect solar energy from its surface back into the atmosphere. Some previous studies related to cool materials [18, 19, 20]. Cool material for the urban environment could be for buildings and paving materials. Many studies report the combined effect of increasing solar reflectance of both roofs and pavements, which can reduce the summertime urban temperature and improve the urban air quality [21, 22].

This paper focus on exploring a cool pavement (reflective pavement) with increased surface reflectance, which reduces the solar radiation adsorbed by the pavement. The use of materials with increased solar reflectance on pavement in urban environment leads to direct and indirect benefits. The direct benefits are the reduction of the air temperature and surface temperature due to heat transfer phenomena, reduction electric demand for cooling and increased human thermal comfort [10, 23]. The indirect benefits from this ambient cooling of a city will turn decrease air conditioning needs, improve environmental comfort and retard smog formation [24]. In addition, reflective pavements can enhance visibility at night, potentially reducing lighting requirements and saving money and energy [25].

The performance of pavement materials with high solar reflectance and infrared emittance values, known as cool pavement, has been extensively studied [26, 27]. Several experimental studies have reported in the summer climate, the conventional pavements usually made of asphalt and concrete with solar reflectance values ranging between approximately 4% and 45 % [28, 29] and also can reach peak surface temperature of 48 to 67°C [30, 31]. The study report that increasing the pavement solar reflectance by 0.25 causes significant decrease of the pavement temperature by 10°C [10]. To avoid glare problem from raising the solar reflectance of pavement, [32]–[34] found that the new type of an innovative paint coating on conventional asphalt pavement that satisfies both high albedo and low brightness. The maximum surface temperature of the paint coated asphalt pavement is about 15°C lower than the conventional asphalt pavement. Demand for the colored pavement for improved street appearance as the development of the road system. Other reasons are as harmonize with the surroundings, expression of identity of place and to improve safety and comfort.

The study reports the measured thermal performance and optical properties of five colored coatings. All the coatings were used on asphalt and concrete samples of pavement, in order to reduce surface temperature and increase solar reflectance was investigated. The surface temperature and spectral reflectance of the samples under sunlight was measured, as well as the solar reflectance was calculated. The statistical analysis of the samples was carried out to further investigate the differences in the thermal performance observed among the coatings and pavement materials.

2.0 METHODOLOGY

In the framework of this study five (white, yellow, red, brown and green) colors of reflective coatings were selected from the international market. The coatings are used in external surfaces (building walls, floor, pavement, driveway, etc.). All the colored coatings were applied on asphalt and concrete sample. In addition, a sample of uncoated asphalt and concrete was also tested and used as reference. The sample had a size of 40cm x 40cm. the tested samples are shown in Figure 1.

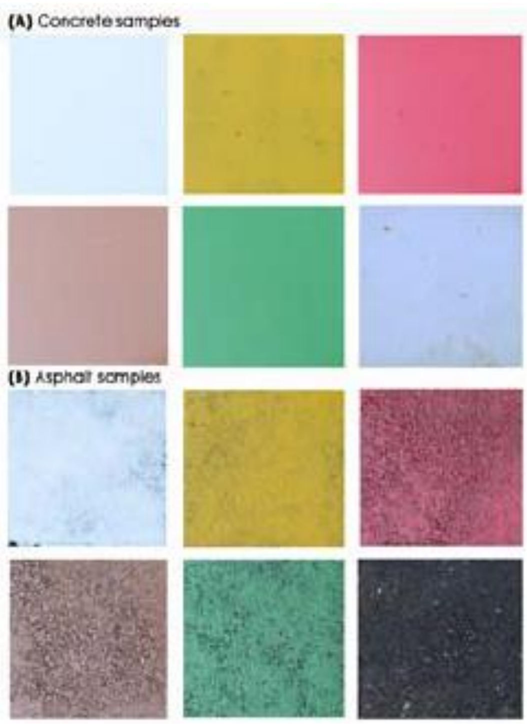


Figure 1 The color coated and uncoated concrete (above) and asphalt (below) samples

2.1 Measurement Procedure of Surface Temperature

The surface temperature of the samples. Measure and record the surface temperature of the concrete and asphalt samples by using the infrared thermometer (IRtek IR60) once every hour. To minimize the influence of ambient environment, temperature measuring points should be in the middle part of the coating area. Distance sensor from the surface sample is 5 cm. While that for the reference pavement sample should be near the corresponding coating in order to contrast the result. Thermal imager (Fluke Ti20) was also used to depict the temperature and thermal image between samples.

2.2 Measurement Procedure of Spectral Reflectance

The spectral reflectance of the samples. Measure and record the solar reflectance of sample by using solar power meter (TES-1333) once every hour. The measurement is carried out by pointing its sensor upward from the surface of sample to measure incident global solar irradiance (*Ii*), then directly toward the target surface to measure reflected solar irradiance (*Ir*) [35], [36]. Distance sensor from the surface sample is between 6 cm to 7 cm. Spectral reflectance measurements were performed according to ASTM E1918, E1918-06 and E1918A (Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field). Solar reflectance value can be obtained by calculation (Solar reflectance, *R*E1918=*Ir*/*Ii*) [35]. The solar reflectance value is from 0 to 1. A value of 0 indicates that the material absorbs energy and a value of 1 indicates total reflectance.

The platform of pavement sample was horizontal, unshaded and clear sky condition during the whole day. The experimental procedure took place during the month of June 2015. Measurements of the climatic condition (air temperature, relative humidity, wind speed and solar radiation) recorded from a meteorological station near the experimental site. All measurement was carried out for each sample from 10:00 to 16:00. Based on surface temperature and solar radiation measured, properties of various heat colored coatings can be evaluated by comparing with control sample.

3.0 RESULTS AND DISCUSSION

3.1 Analysis of the Thermal Performance of the Sample

Based on the surface temperature measurements, the mean surface temperature (10:00 – 16:00) were calculated for each sample are shown in Table 1. The temperature difference between the mean surface temperature of each coating and the uncoated asphalt and concrete samples that was observed during the experimental period for the daytime. The comparison of the thermal performance of the coated asphalt and concrete samples with the uncoated reference samples show that the use of suitable coating color can significantly reduce the surface temperature of the sample.

3.1.1 Asphalt

The mean temperature of the color coating samples ranges from 41.52 °C for white coated asphalt samples to 57.69 °C for the green coated sample. The corresponding temperature for the uncoated asphalt sample is 58.95 °C. It can be concluded that the green coated sample has a surface temperature that is by 1.95% lower compared to the surface temperature of the uncoated asphalt, the brown and red coated sample by 4.49% and 5.26% respectively, the yellow coated sample by 18.42%, and the greatest difference was recorded for the white coated sample that equals 29.57%. The cooling potential of the colored coatings is even greater regarding the peak surface temperatures. The surface temperature of asphalt sample coated with white coating was by 17.43 °C cooler than the uncoated sample. In contrast, the green colored coatings were found the less surface temperature decrease was by 1.26 °C cooler than the uncoated sample.

3.1.2 Concrete

The mean temperature of the color coating samples ranges from 38.15 °C for white coated concrete samples to 46.04 °C for the green coated sample. The corresponding temperature for the uncoated asphalt sample is 48.52 °C. It can be concluded that the green coated sample has a surface temperature that is by 5.15% lower compared to the surface temperature of the uncoated concrete, the brown and red coated sample by 8.75% and 9.86% respectively, the yellow coated sample by 17.59%, and the greatest difference was recorded for the white coated sample that equals 21.35%. The cooling potential of the colored coatings is even greater regarding the peak surface temperatures. The surface temperature of concrete sample coated with white coating was by 10.38 °C cooler than the uncoated sample. In contrast, the green colored coatings were found the less surface temperature decrease was by 2.49 °C cooler than the uncoated sample.

Table 1 Mean surface temperature of the tested samples

Sample	Asphalt		Concrete	
	Mean surface temp. (°C)	Mean surface temp. reduction (°C)	Mean surface temp. (°C)	Mean surface temp. reduction (°C)
White	41.52	17.43	38.15	10.38
Yellow	48.09	10.86	39.99	8.54
Red	55.85	3.10	43.72	4.81
Brown	56.45	2.50	44.26	4.26
Green	57.69	1.26	46.04	2.49
Uncoated	58.95	0.00	48.52	0.00

It is found, all the five color coating asphalt and concrete samples show lower surface temperatures compared to the uncoated asphalt and concrete samples. These temperature differences could be even higher if the coatings had been applied on dark colored surfaces (i.e. asphalt) rather than white ones (i.e. concrete).

3.2 Analysis of the Optical Properties of the Sample

During the day the optical properties of samples is mainly affected by their surface solar reflectance, because it represents the part of the incident total solar radiation that is reflected. The value of incident solar irradiance and reflected solar irradiance data were used to calculate the solar reflectance of each sample. The comparison of the optical properties of the coated asphalt and concrete samples with the uncoated reference samples show that the use of suitable color coating can significantly increase the solar reflectance of the sample are shown in Figure 2.

3.2.1 Asphalt

The mean solar reflectance of the color coating samples ranges from 0.61 for white coated asphalt samples to 0.14 for the green coated sample. The white coating asphalt sample with the highest solar reflectance by 0.61 appears to have the lowest temperature. As expected the uncoated asphalt sample that presents the lowest solar reflectance by 0.08 appears as the highest surface temperature. It can be concluded that the green coated sample has a solar reflectance that is by 0.06 higher compared to the solar reflectance of the uncoated asphalt, the brown coated sample by 0.11, the red and yellow coated sample by 0.16 and 0.29 respectively, and the greatest difference was recorded for the white sample that equals 0.53.

3.2.2 Concrete

The mean solar reflectance of the color coating samples ranges from 0.78 for white coated asphalt samples to 0.23 for the green coated sample. The white coating asphalt sample with the highest solar reflectance by 0.78 appears to have the lowest temperature. As expected the uncoated asphalt sample that presents the lowest solar reflectance by 0.21 appears as the highest surface temperature. It can be concluded that the green coated sample has a solar reflectance that is by 0.02 higher compared to the solar reflectance of the uncoated asphalt, the brown coated sample by 0.07, the red and yellow coated sample by 0.15 and 0.33 respectively, and the greatest difference was recorded for the white coated sample that equals 0.57.

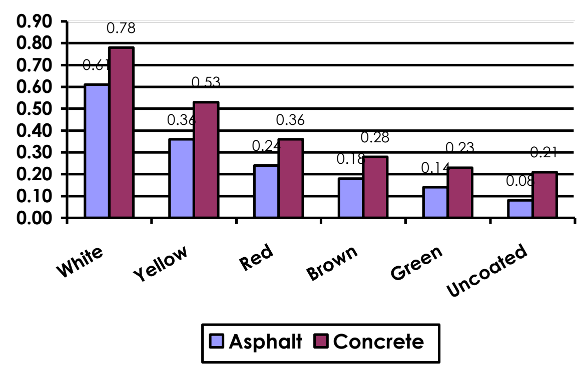


Figure 2 The solar reflectance of the tested color coated and uncoated for asphalt and concrete samples

It is found, all the five color coating asphalt and concrete samples show higher solar reflectance compared to the uncoated asphalt and concrete samples. The meaning is the higher the solar reflectance, the lower the surface temperature, as less solar radiation is absorbed by the sample. Emissivity has a lower impact compare to reflectance. This study looking for cool pavement with referring to ENERGY STAR [37] and Lawrence Berkeley National Laboratory research [38] found that, sample must have needed to achieve solar reflectance of 0.25 and 0.40.

3.3 Statistical Analysis of the Sample

3.3.1 Asphalt

The mean surface temperatures of asphalt samples were 53.09 °C (StD = 6.530). One-way ANOVA analysis showed that there were significant different between color coated and uncoated asphalt samples (F(5,6) = 222.585, P = 0.000). Post-hoc analysis showed that the uncoated, green, brown and red coated asphalt samples had significantly higher surface temperature than yellow and white coated asphalt samples.

The mean solar reflectance of asphalt samples were 0.27 (StD = 0.183). One-way ANOVA analysis showed that there were significant different between color coated and uncoated asphalt samples (F(5,6) = 466.032, P = 0.000). Post-hoc analysis showed that the white and yellow coated asphalt samples had significantly higher solar reflectance than red, brown, green and uncoated asphalt samples. The white and yellow coated asphalt samples had solar reflectance greater than to 0.25.

3.3.2 Concrete

The mean surface temperatures of concrete samples were 43.44 °C (StD = 3.796). One-way ANOVA analysis showed that there were significant different between color coated and uncoated asphalt samples (F(5,6) = 222.585, P = 0.000). Post-hoc analysis showed that the uncoated, green and brown coated concrete samples had significantly higher surface temperature than red, yellow and white coated concrete samples.

The mean solar reflectance of concrete samples were 0.39 (StD = 0.211). One-way ANOVA analysis showed that there were significant different between color coated and uncoated asphalt samples (F(5,6) = 403.234, P = 0.000). Post-hoc analysis showed that the white and yellow coated concrete samples had significantly higher solar reflectance than red, brown, green and uncoated asphalt samples. The red and brown coated concrete samples exhibited solar reflectance more than to 0.25. Meanwhile, white and yellow coated concrete samples had solar reflectance greater than to 0.40.

3.4 Relationship Between Solar Reflectance and Surface Temperature

3.4.1 Asphalt

The results show that surface temperature reduction (t = 17.774, P = 0.000) are significant factors for solar reflectance. The trends show in Figure 3 and 4 further demonstrate the surface temperature and surface temperature reduction influence on the solar reflectance value of asphalt sample. The asphalt samples of surface temperature reduction value showed an increase in solar reflectance value. The higher solar reflectance value corresponds to the higher surface temperature reduction values of the coated and uncoated asphalt samples. Therefore, the model predicts surface temperature reduction value with an R^2 value and standard error of estimate (SEE) of 0.969 and 0.034, respectively.

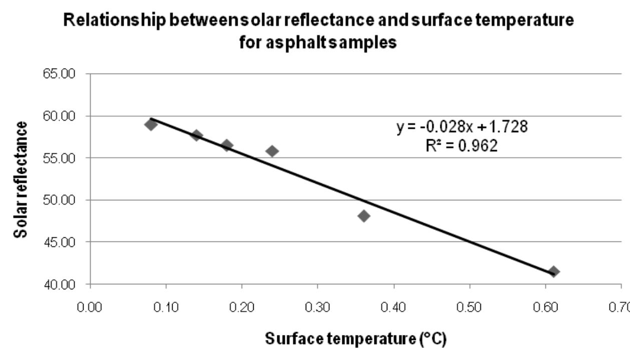


Figure 3 Regression of solar reflectance and surface temperature of asphalt sample

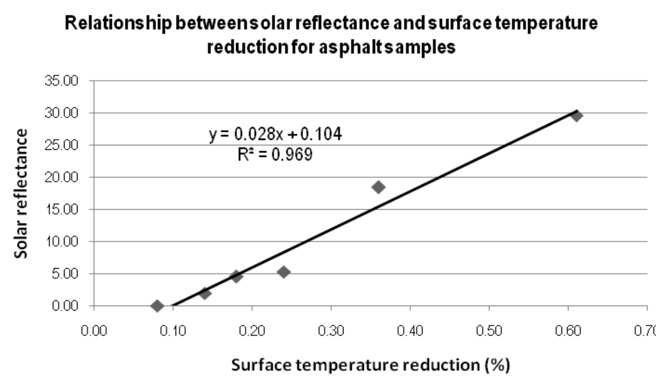


Figure 4 Regression of solar reflectance and surface temperature reduction of asphalt sample

3.4.2 Concrete

The results show that surface temperature reduction (t = 8.171, P = 0.000) are significant factors for solar reflectance. The trends show in Figure 5 and 6 further demonstrate the surface temperature and surface temperature reduction influence on the solar reflectance value of concrete sample. The concrete samples of surface temperature reduction value showed an increase in solar reflectance value. The higher solar reflectance value corresponds to the higher surface temperature reduction values of the coated and uncoated concrete samples. Therefore, the model predicts surface temperature reduction value with an R^2 value and standard error of estimate (SEE) of 0.870 and 0.080, respectively.

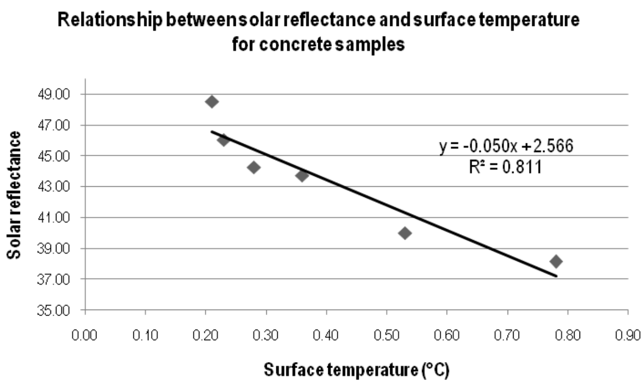


Figure 5 Regression of solar reflectance and surface temperature of concrete sample

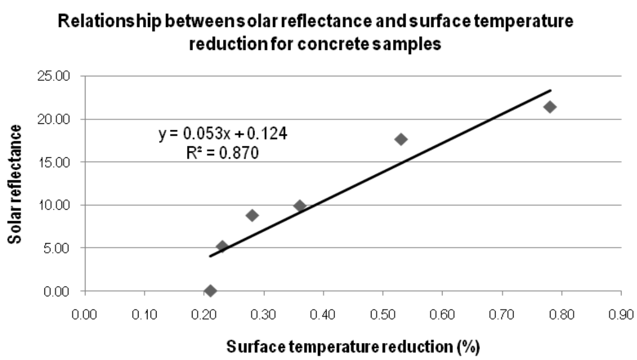


Figure 6 Regression of solar reflectance and surface temperature reduction of concrete sample

3.5 Evaluation of the Impact of Applying the Samples in Outdoor Space

The evaluation of the current as well as the proposed situation after the application of the pavement coating for microclimate modification was achieved with the use of ENVI-met model. ENVI-met was used to simulate the interaction of surface-air-plants in three dimensional model. The expected impact of cool asphalt and concrete pavement on surface temperature at local scale between a current condition where uncoated asphalt and concrete pavement was used and another modification were developed to compare and evaluate the cooling potential of using the white coated asphalt and concrete pavement. The findings were discussed based on two conditions and were coded as: (A) current condition, and (B) applied white coated asphalt (parking lot and road) and white coated concrete pavement (sidewalk). Simulations were performed at Tekun hostel of University Sains Malaysia in the sunny day. The maximum building height in the study area was 30 m (10 stories). A main model domain area was built within 52 x 81 x 20 grids with input dimensions of *dx, dy* and *dz* = 2 m. Basic data settings in this simulation for air temperature is 29.85 °C, wind speed is 1.5m/s at 10 m height, relative humidity is 78% and roughness length in 10 m is 0.1.

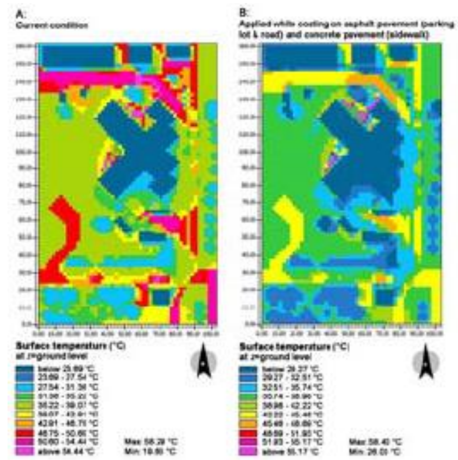


Figure 7 Surface temperature at two different conditions: current condition (A) and modified conditions (B) compared at 15:00 in ground level

Figure 7 shows surface temperature at two different conditions at 15:00 hours. In condition A, where the uncoated asphalt is applied on the road and parking lot, the surface temperature at ground level, ranged between 46.75 °C – 54.44 °C (average 50.60 °C) and for concrete pavement is applied on the sidewalk, ranged between 39.07 °C – 46.75 °C (average 42.91°C). Thus, in condition B, where the white coated asphalt was applied on the parking lot and road, the surface temperature at ground level, ranged between 42.22 °C – 48.69 °C (average 45.46 °C) and for white coated concrete pavement is applied on the sidewalk, ranged between 35.74 °C – 42.22 °C (average 38.98°C).

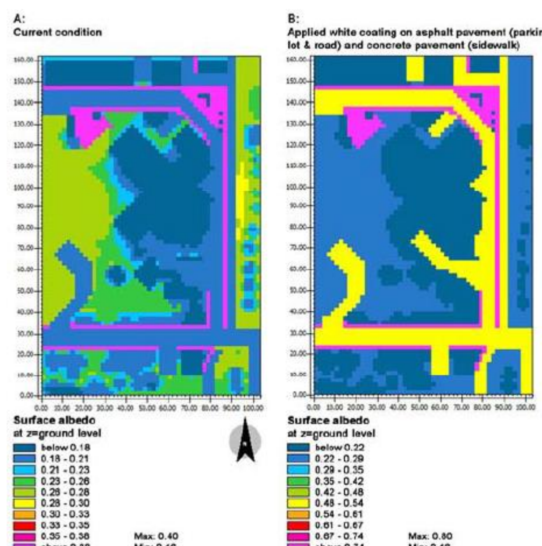


Figure 8 Surface albedo at two different conditions: current condition (A) and modified conditions (B) compared at 15:00 in ground level

Thus, Figure 8 shows surface albedo at two different conditions at 15:00 hours. In condition A, where the uncoated asphalt is applied on the road and parking lot, the surface albedo at ground level, ranged between 0.18 – 0.21 (average 0.20) and for concrete pavement is applied on the sidewalk, ranged between 0.35 – 0.38 (average 0.37). For condition B, where the white coated asphalt was applied on the parking lot and road, the surface albedo at ground level, ranged between 0.48 - 0.54 (average 0.51) and for white coated concrete pavement is applied on the sidewalk, ranged between 0.67 – 0.74 °C (average 0.71).

Meanwhile in Figure 9 shows air temperature at two different conditions at 15:00 hours. In condition A, where the uncoated asphalt is applied on the road and parking lot, the air temperature at pedestrian level, ranged between 36.50 °C – 38.12 °C (average 37.31 °C) and for concrete pavement is applied on the sidewalk, ranged between 34.88 °C – 36.50 °C (average 35.70 °C). For condition B, where the white coated asphalt was applied on the parking lot and road, the air temperature at pedestrian level, ranged between 35.75 °C – 37.27 °C (average 36.51 °C) and for white coated concrete pavement is applied on the sidewalk, ranged between 34.23 °C – 35.75 °C (average 35.00 °C).

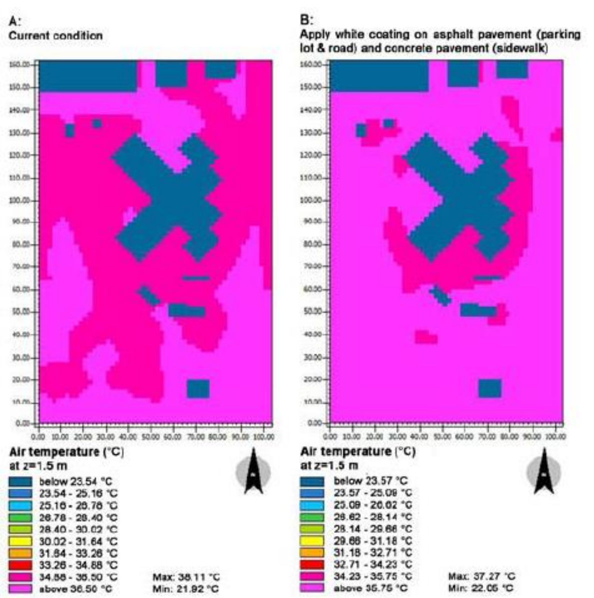


Figure 9 Air temperature at two different conditions: current condition (A) and modified conditions (B) compared at 15:00 in pedestrian level (1.5 m)

Comparing the results of the A and B condition it can be concluded that the application of the white coated asphalt on the road and parking lot, resulted in a significant surface temperature reduction, increases surface albedo and air temperature reduction in the simulated area equal to 5.14 °C, 0.31 and 0.8 °C, respectively. Meanwhile, the application of the white coated concrete pavement on the sidewalk resulted in a significant surface temperature reduction, increases surface albedo and air temperature reduction in the simulated area equal to 3.93 °C, 0.34 and 0.7 °C, respectively. This study show by the fact that a pavement surface with higher solar reflectance (white coated asphalt and concrete pavement) will stay cooler under the sun compared to the ground surface covered with uncoated asphalt and concrete pavement, as it was verified experimentally. To mitigate of heat island effect by considering that pavements cover with a large percentage of the surface in urban areas, application of this cool coating on pavement surface could have significantly impact in reducing surface and air temperature through convection and radiation.

4.0 CONCLUSION

This paper set out to illustrate the five colored coating that applied on asphalt and concrete sample pavements have been developed and tested in order to evaluate their thermal performance and optical properties. Study find that all the coated samples demonstrated higher solar reflectance values and lower surface temperature compared to uncoated asphalt and concrete samples. White and yellow coated asphalt samples showed best cooling effects were 17.43 °C and 10.86 °C respectively. While, that best cooling effect of white and yellow coated concrete samples were 10.38 °C and 8.54 °C respectively. The white and yellow coated asphalt samples with red and brown coated concrete sample had solar reflectance greater than to 0.25. Meanwhile, white and yellow coated concrete samples had solar reflectance greater than to 0.40. This study is a part of passive solution to mitigate the negative effects of the heat island phenomenon. However before applying these coatings at a specific area, a thorough study should be implemented in order to estimate or predict the impact of reflective surfaces on the surrounding microclimate. It is because to avoid occurrence increased glare and ensure optimum application of such materials. ENVI-met simulations showed that applying colored coating on uncoated asphalt and concrete pavement in a road, parking lot, sidewalk and open space could lead to an average surface temperature decrease of 5.14 °C and 3.93 °C respectively, under low wind speed conditions. Therefore, the implementation of cool pavement technologies at local government level especially in urban planning and design process to create a strategic plan following with evaluation procedures, policies for application and financial incentive. The effect at city scale, it could contribute to the reduction of the air temperature due to heat transfer phenomena, as well as can improve outdoor thermal comfort, reduce the heat island effect and also enhance the urban landscape aesthetic appearance.

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