A Study on the Effectiveness of Heat Mitigating Pavement Coatings in Singapore

Wong Chung Wan[1], Wong Nyuk Hien[2], Tan Phay Ping[1], Aw Zhi Wei Aloysius[1]
[1]Building System and Diagnostics Pte Ltd
[2]Department of Building, National University of Singapore, Singapore
[1]Email: tanpp@bsd.com.sg (Corresponding Author)

ABSTRACT

The primary root of Urban Heat Island (UHI) phenomena is urbanization, where natural softscapes are replaced with hard surfaces that absorb and re-radiate thermal energy back into the environment. Asphalt roads and pavements in particular were found to be able to heat up to as high as 60°C, and radiate the excess heat back into environment. This paper highlights the effectiveness and suitability of a dark coloured pavement coating with high albedo, named "*PerfectCool*", recently developed by NIPPO Corporation Co. Ltd, Japan

Laboratory tests reveal that *PerfectCool* was able to reflect up to 81% of near infrared red waves, had a low heat conductivity of 0.252 W/mK and had high emissivity value of 0.828. Throughout the duration of the controlled mock-up experiment, *PerfectCool* consistently recorded lower surface temperatures as compared to concrete slabs with and without conventional paving coating. *PerfectCool* was able to reduce peak surface temperatures by up to 5°C.

On-site measurements reveal that *PerfectCool* was able to reduce asphalt surface temperatures to about 38°C. This is a temperature reduction of up to 17°C as compared to a normal asphalt surface without *PerfectCool*. *PerfectCool* was able to prevent a built-up of heat within asphalt roads, preventing them from becoming a heat sink, which could prolong the service life of the asphalt surface. This is clearly supported by the low sub-surface temperatures of 34°C, 16°C lower than the asphalt roads.

Potential cost savings were also determined through energy simulation using IES(ve). With the application of *PefectCool* onto pavements surrounding a development, the potential electrical yearly savings of 3.46% can be derived, with a highest possible monthly savings of 4.88%. On a typical hot day, the possible reduction of chiller load can be up to 7.69%.

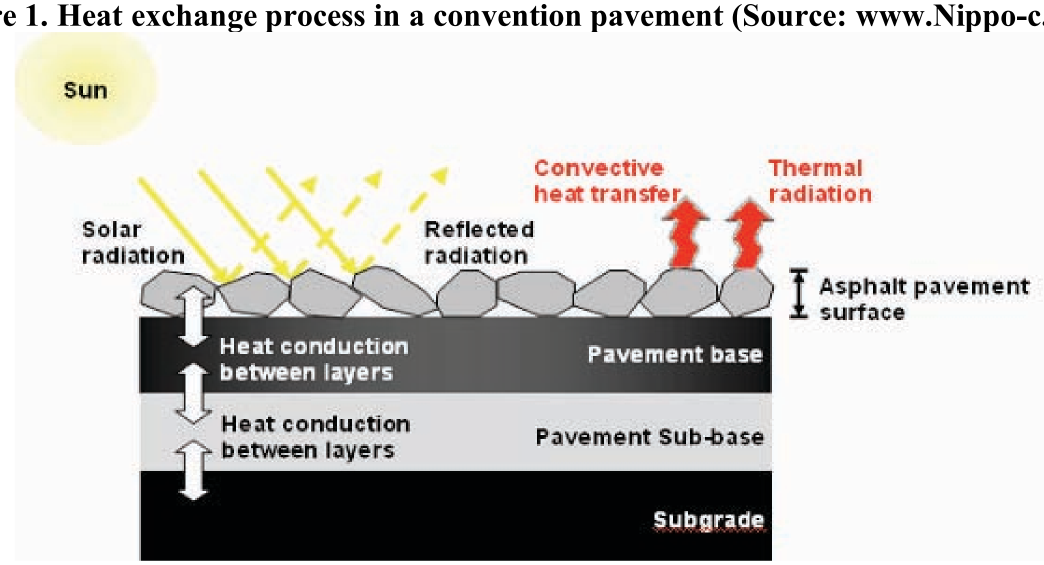
Introduction

The Urban Island Heat (UHI) effect is a phenomenon in which surface and air temperatures are elevated due to the retention and emittance of solar heat from hardscapes such as roads, buildings and other structures. Heat islands are typically formed when the city growth alters the urban fabric by replacing natural land cover with manmade asphalt pavements, buildings and other infrastructure resulting in such metropolitan area to become significantly warmer as compared to its rural areas (Source: http://eande.lbl.gov/heatisland/hightemps/).

Pavements (includes roads, pedestrian walkways, etc) are one of the main hardscapes contributing to the heat island effect. They have high thermal mass capacity, allowing them to absorb and retain a huge amount of thermal energy from the sun during the day, causing surface temperatures to reach to as high as 60°C. When the pavements become considerably hotter than the ambient canopy temperature, the excess heat is radiated back into the atmosphere throughout the day and night, resulting in a higher ambient temperature as compared to rural areas. Although various studies have clearly linked human discomfort with the effects of the "hot pavements" (Iwama *et al*, 2006), slow progression of technologies in this area limits urban planners and building owners to plan ways to mitigate this problem.

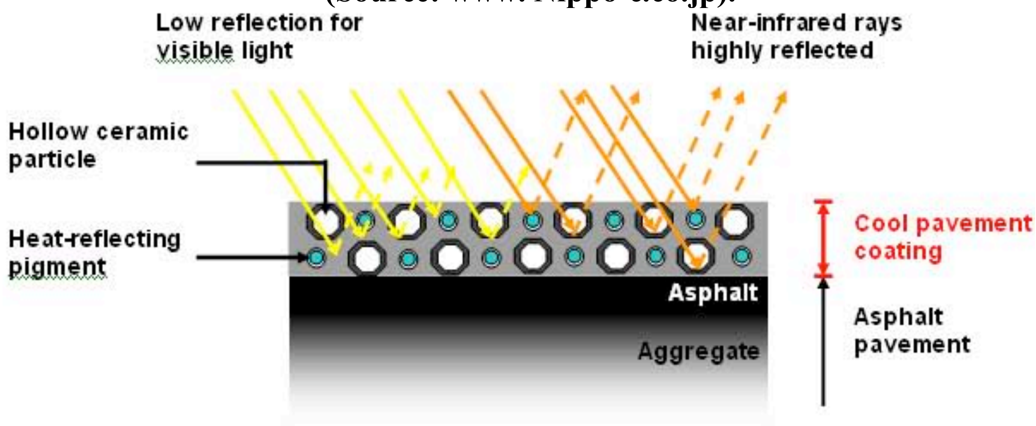
The *Public Works Research Institute, Nippo Corporation Co, Miracool Co. Ltd, Kanematsu* Corporation *Co.,* and *the Tokyo Institute of Technology* have worked together on a combined project to develop a dark pigmented coating with high albedo. The concept was to develop a surface coating to restrict the heat exchange process in a conventional pavement (see figure 1). Through numerous studies, the pavement coating (named "*PerfectCool*") was developed.

Figure 1. Heat exchange process in a convention pavement (Source: www.Nippo-c.co.jp).



PerfectCool is based on the principle that by increasing the reflectance of the pavement surface, less heat will be absorbed, thereby lowering the daytime temperature of the pavements. PerfectCool consist of dark, low reflective color pigments mixed with high infra-red heat reflective pigments and fine hollow ceramic particles to reduce thermal conduction and heating of the paints (see figure 2).

Figure 2. Close-up view of coating layer above the asphalt mixture (Source: www. Nippo-c.co.jp).



With the high reflectivity in the infrared-red region, PerfectCool is able to significantly reduce surface temperatures of pavements. This thus reduces the air temperature and long-wave radiation emitted from the pavement surface, while still maintaining low albedo in the visible region (Iwama *et al*, 2006). Other benefits of PerfectCool include good weatherability, good adhesion with a variety of pavement types, good torsional resistance and good resistance to rutting (Road Technology Research Group, 2003).

Although Iwama *et al* have recognized that the reflected infrared-red rays might increase the wall temperature of surrounding buildings they have shown through energy simulation that the increase in the wall temperature is slight. In addition the overall area-weighted temperature of walls and floors are significantly reduced with increased pavement albedo. Based on the sensory survey conducted by the same group, they have found that the majority of the respondents felt that coated surface was much "cooler" and more comfortable, despite the increase in reflected near-infrared rays. This is because near infrared ray is not likely to rise skin temperature for human body, as compared to ultra-violet and visible rays (Narita et al, 2001), resulting in a much cooler sensation.

This paper presents the findings of a study on the effectiveness of PerfectCool in improving the thermal comfort, reduction in urban island heat island and potential energy savings arising from its use in pavement in hot and humid Singapore.

Methodology

Two different color cool pavement coatings were supplemented for testing as follows:

Table 1: Cool pavement coatings and their respective sample reference and color codes

Coating	Colour code	Sample reference
PerfectCool (light gray)	N65	CP65
PerfectCool (dark gray)	N40	CP40
Control sample (light gray)	N65	NP65

Note: The color codes indicate the intensity of color; the lower the color code, the darker the color.

Investigation of the effect of cool pavement coating was conducted through a four pronged approach: laboratory testing, controlled measurements, on-site field measurements, and sensory surveys. Lastly, the potential cooling energy savings from large area hard surfaces such as car parking spaces, multi-purpose areas and pedestrian walkways (herewith collective termed as "Pavements") was performed via computer simulation.

The laboratory testing involved measurements of reflectivity, steady-state conductivity and emissivity and were conducted in accordance with the ASTM as recommended by Akabari *et al.*

The controlled experiment testing involved temperature measurements between CP65 and NP65 coated onto a concrete slab, measured at 5 minute intervals over a duration of 14 days.

The on-site experiment testing involved temperature measurements at various heights at two different locations: a concrete-based outdoor basketball court and an asphalt road. Matching color codes of *PerfectCool* coatings were selected to match the basketball court and asphalt road to reduce the discrepancy. The heights measured at these two locations are as follows:

Table 2: Heights of temperature measured for on-site experiment

Measurement Points Reference	Basketball Court	Asphalt Road
-50mm	50mm below surface	50mm below surface
-10mm	10mm below surface	10mm below surface
0mm	On surface	On surface
+10mm	10mm above surface	10mm above surface
+300mm	300mm above surface	300mm above surface
+600mm	600mm above surface	600mm above surface

A thermal sensory survey questionnaire was developed to gather response on the thermal sensations felt by participants at the two locations in the on-site experiments. A questionnaire was handed out to each participant at each location. Each questionnaire was divided into 2 categories: Pavement type 1 and Pavement type 2. No additional information was provided. The participants were asked to carry out a few tasks: To stand for a few minutes, to place their hands for a few minutes at approximately 10mm above the surfaces, and finally to touch the surfaces of each test site. The participants were than asked to rank on a scale of 1 to 7, where 1 is very cold, 4 is neutral and 7 is very hot, how their feet, body and hands feel when they are on each site. The participants were asked to compare between the Pavement type 1 and 2 at each location and gauge which is hotter.

Lastly, a 3-D massing model of a typical factory in Singapore was created for the energy simulation. Details of the factory model are given as follows:

Table 3: Details of factory model used for energy simulation

Size	45m by 30m by 8m
Layout	Two story office, 10m by 30m by 8m high, and a double volume working area, 35m by 30m by 8m high.
External wall	Standard wall construction
Internal wall	105mm thick brick wall with 13mm thick plaster on both sides
Fenestration	Low-e double glazing (6mm+6mm)
Roof	Pitch roof
External pavement	Asphalt road along the perimeter of the factory

Two typical scenarios were modeled: the typical factory surrounded with the asphalt pavement, and with the pavements coated with CP40. The following parameters were taken as the inputs for both scenarios:

Table 4: Input parameters for energy simulation

Asphalt	
Albedo	0.15 (Lovell et al, 2005)
Emissivity	0.93 (source: website "Cole-Parmer")
CP40	
albedo	0.46
Albedo	0.828

The albedo of CP40 is calculated by pro-rating the reflectivity results with the proportion of spectral energy distribution of solar radiated at ground level as simulated from IEC 60068-2-5:1975. The occupancy and lighting consumption were kept the same for both scenarios.

Results and Discussion

Laboratory Results

PerfectCool coatings mainly limit heat transfer through high reflective in the infrared-red region (wavelengths beyond 700nm). This high reflectivity property is able to directly reduce the amount of heat transferred to a medium through radiation. The hollow spheres integrated into *PerfectCool* coatings allow the coatings to remain highly reflective to heat, irregardless of color.

From figure 3 below, it was observed that both CP65 and NP65 (both light gray) have similar reflectivity profile in the visible light spectrum (400-700nm), indicating their similarity in color. CP40 (dark gray) on the other hand, has much lower reflectance.

From 700nm onwards (near infrared-red spectrum), the reflectance for NP65 remained consistently low, with a reflectance percentage of 25%. However, the reflectance of CP65 jumped from 31% (visible light spectrum) to 77% (infrared-red spectrum). A similar profile was also noted for CP40, with the reflectance percentage increasing from 12% to 81%.

Besides high reflectivity, it was also noted that *PerfectCool* coatings have lower thermal conductivity. From table 5 below, it can be observed the average conductivity results of the different coatings showed that the thermal conductivities for PerfectCool coatings (both CP 40 and CP65) were much lower than the NP65.

It is also worth noting the dark gray-colored CP40 is better at dissipating heat as compared to the light gray-colored CP65. From table 6 below, it can be observed that the emissivity of CP40 is 20% higher than CP65.

Figure 3. Reflectance of NP65, CP65 and CP40.

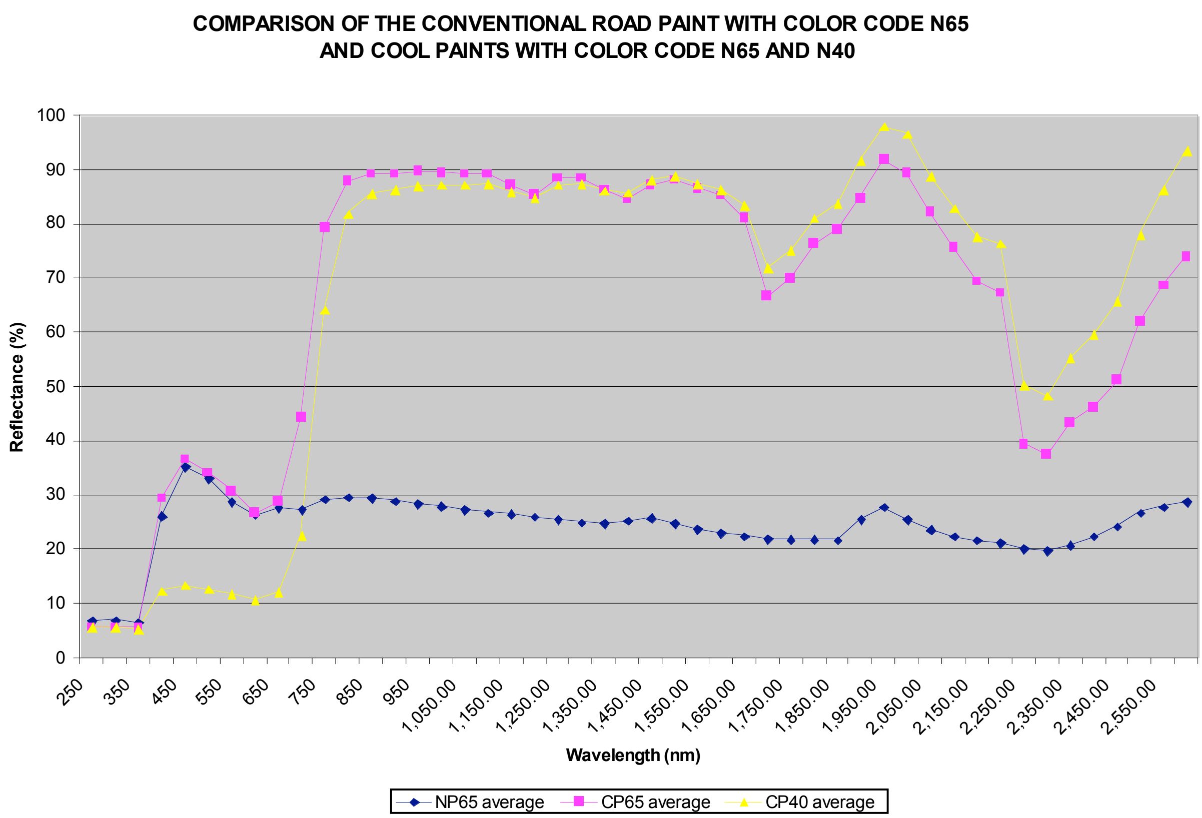


Table 5: Summary of results for conductivity measurement of the different coatings

Coating Type	Conductivity (W/mK)
CP40	0.264
CP65	0.252
NP65	0.422

Table 6: Summary of results for emissivity measurement of the different coatings

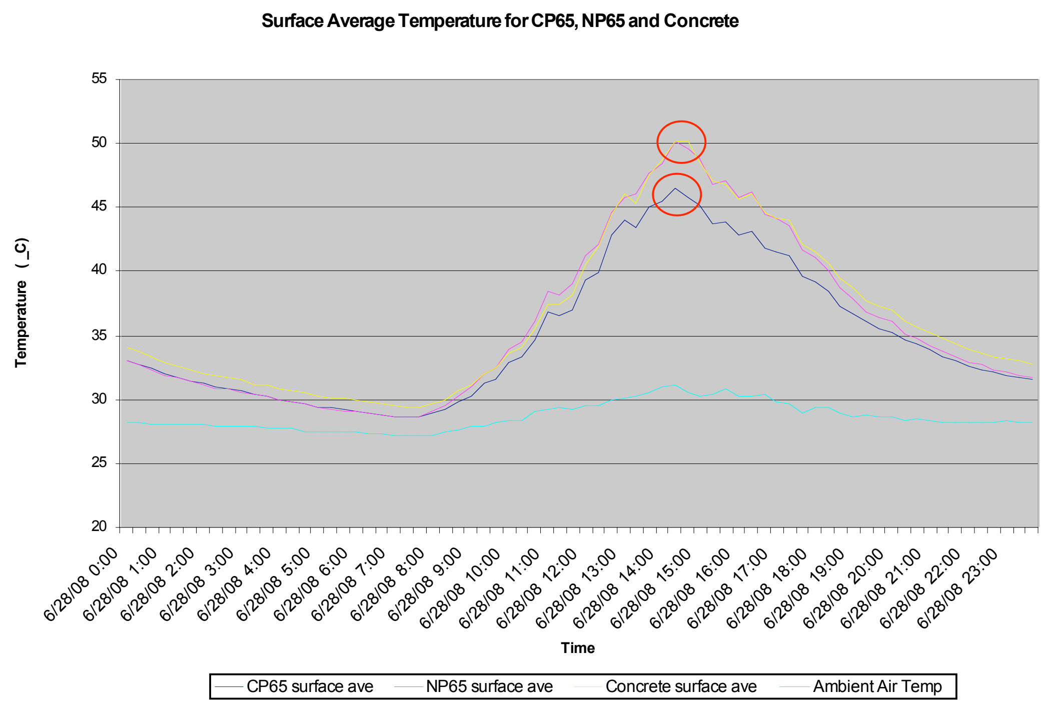
Coating Type	Emissivity
CP40	0.828
CP65	0.692
NP65	0.680

Controlled Experiment Results

The high reflectivity and emissivity properties of *PrefectCool* coatings are able to influence and reduce surface temperatures. This is clearly demonstrated from the results of the controlled experiment of coatings on concrete blocks. Figure 4 below clearly demonstrates that the average surface temperature of CP65 is 4°C cooler as compared to NP65.

During the 14 days experiment from 28th June to 11th July, 2008, the day with the highest solar radiation and ambient air temperature was selected as a typical hot day. CP65 was noted to be 4.4°C cooler than the control and 3.8°C cooler than NP65.

Figure 4. Comparison of average surface temperature of control slab, CP65 and NP65. Note peak temperature of CP65 is about 4°C lower than NP65 and control.

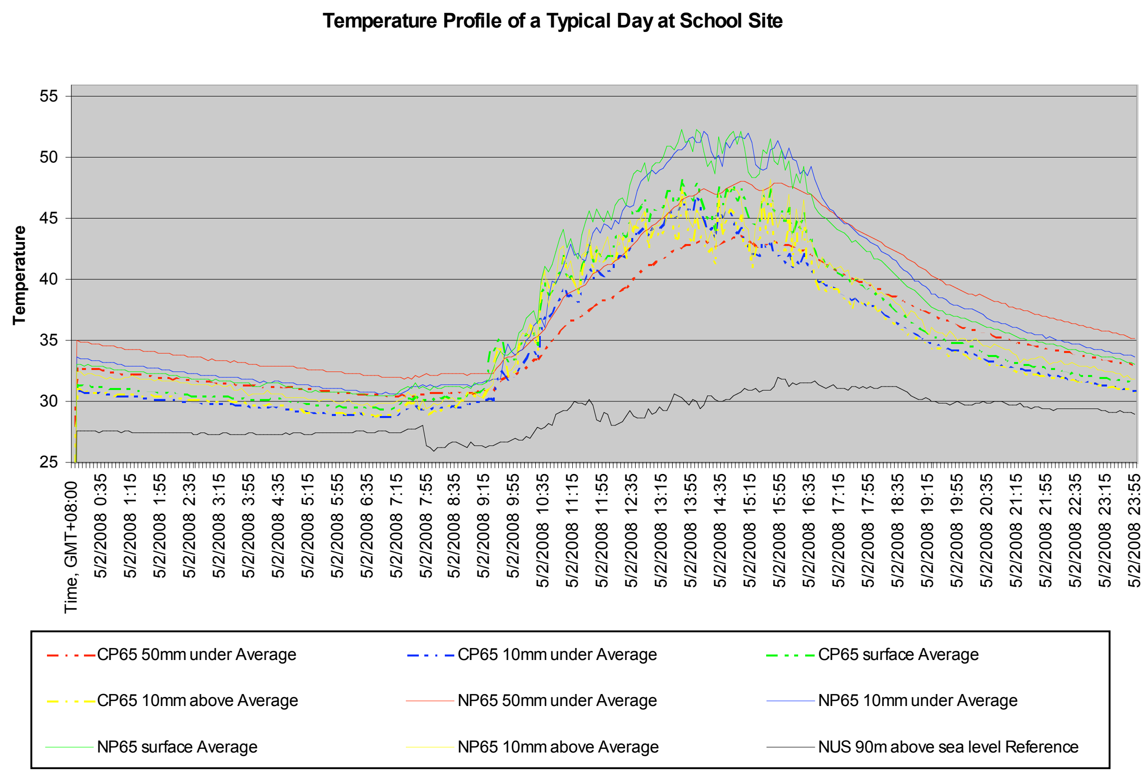


On-site Results

Similar to the controlled experiments, the on-site experiments clearly show that *PerfectCool* coatings have significantly cooler surface temperatures. Sub-surface measurements reveal a huge reduction in heat that is transferred into the substrate (concrete and asphalt from both sites) after the application of *PerfectCool* coatings.

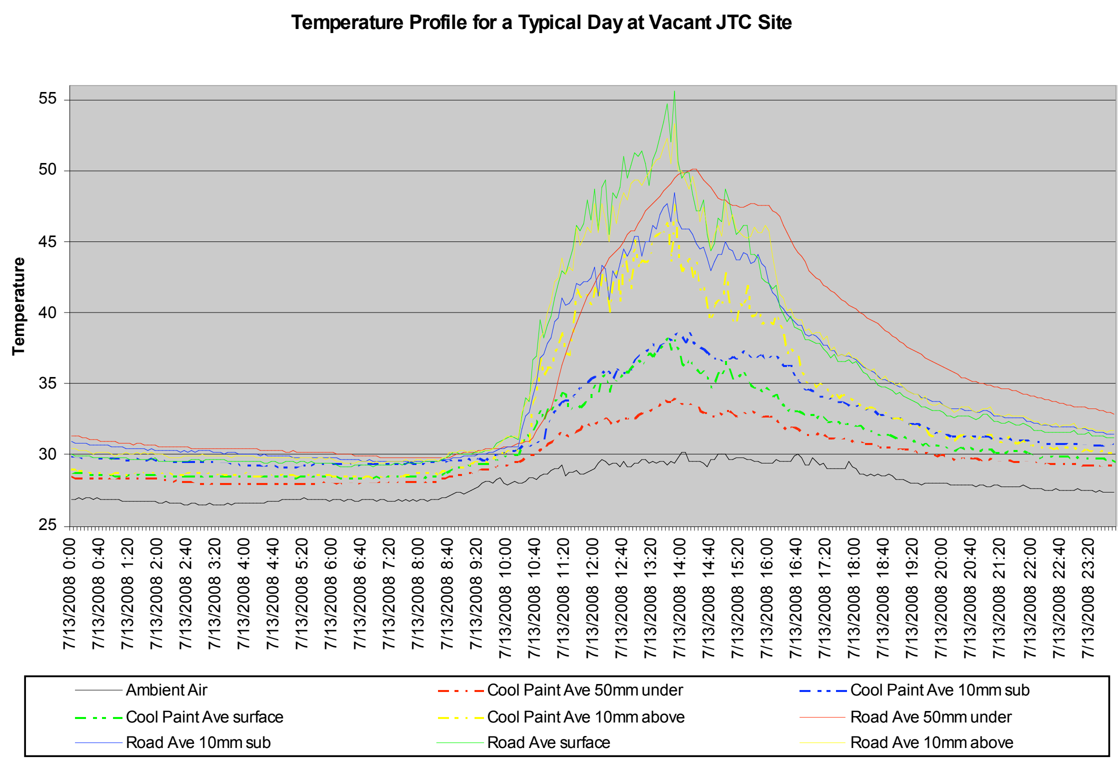
The school site experiment ran for 18 days (20th April to 8th May, 2008). Figure 5 below shows the temperature recorded plotted against time for a typical day. From the figure below, a 5°C difference in peak temperatures were consistently observed for all 4 heights. It is also noted that the temperatures of *PerfectCool* coatings were cooler by 1°C. Minimal difference in temperatures were noted for the ambient air temperature profiles recorded at +300mm and +600mm. This was probably due to external influences such as wind.

Figure 5. A 24-hour temperature profile of a typical day at the school site



The JTC site experiment ran for 23 days (from 30th June to 22nd July, 2008). Figure 6 below shows the temperature recorded plotted against time for a typical day. From the figure below, a minimum difference of 16°C in peak temperatures was noted for all 4 heights. Similarly, the night temperatures of *PerfectCool* coatings were also lower than control, by an average of 1.6°C. Minimal differences were noted between temperatures recorded for *PerfectCool* coatings and the control at +300mm and +600mm. Again, it is deduced that external influences such as wind reduce the impact of the coatings.

Figure 6. A 24-hour temperature profile of a typical day at the JTC site.



Survey Questionnaire

Although the ambient air temperature results were inconclusive, the temperature reduction caused by the cool paint can still be felt by its users. This is because humans are more sensitive to sensible heat. The cool paint is able to give a cooler sensation as compared to the asphalt roads through the mitigated heat conduction through the feet and the upward long wave radiation (Kinouchi, 2004). Results to the survey questionnaire clearly demonstrate this. The majority of the participants were able to feel the "cooling" effect of the *PerfectCool* coatings; the participants rated that they felt cooler when they were on the *PerfectCool* coatings, as compared to the control.

The survey results gathered from the basketball court showed that 90% of the participants felt that the control was hotter. The remaining 10% were indifferent. At the asphalt road, all the participants felt that the control was hotter.

Energy Simulation

With the application of *PerfectCool* coatings, the amount of heat which pavements throw back into the environment is significantly reduced. This results in a reduction of ambient air temperatures, which in turn, will reduce the total energy consumption of neighboring low-rise buildings. Through the energy simulation, the yearly electrical consumption for the factory surrounded with pavement made with asphalt and coated with CP40 were 354.82 MWh and 342.54MWh. This computes to a monetary savings of 3.46% for the factory with its pavements coated with CP40.

The energy simulation has also identified that the peak electrical consumption to fall in the month of June. The total electrical consumption and chiller load consumption were tabulated and the percentage savings possibly achieved through the application of CP40 were 4.88% and 7.69% respectively.

The external wall surface temperatures of the factory for both scenarios, during the period of when the peak electrical consumption was identified, were tabulated into a graph for comparison. It was observed that the external wall surface temperatures of the factory surrounded with CP40 was consistently lower as compared to the factory surrounded with asphalt pavements.

Conclusion

PerfectCool coatings have a direct influence on the transfer of heat from the sun to the medium (asphalt roads, basketball courts, etc.), and back into the environment. The transfer of thermal energy (heat) from one medium to another only occurs via three methods: conduction, convection and radiation. Conventional media such as roads, basketball courts, etc., have high thermal mass, absorbing a huge amount of solar radiation from the sun and build up its internal heat. This built up thermal energy is thrown back into the environment, thus raising the overall temperature. PerfectCool coatings serves as a barrier, not only protecting the media from direct sunlight, it also limits the transfer of thermal energy from the sun to the media and back into the environment.

Laboratory tests reveal that *PerfectCool* was able to reflect up to 81% of near infrared red waves, had a low heat conductivity of 0.252 W/mK and had high emissivity value of 0.828. Throughout the duration of the controlled mock-up experiment, *PerfectCool* consistently recorded lower surface temperatures as compared to a concrete slabs with and without conventional paving coating. *PerfectCool* was able to reduce peak surface temperatures by up to 5°C.

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Potential cost savings were also determined through energy simulation using IES(ve). With the application of *PefectCool* onto pavements surrounding a development, the potential electrical yearly savings of 3.46% can be derived, with a highest possible monthly savings of 4.88%. On a typical hot day, the possible reduction of chiller load can be up to 7.69%.

With the reduced surface temperatures of the roads, it is expected that the life span of the roads can be extended due to increase in durability. High temperatures soften the surfaces of the roads, which increases the rate of rutting and shoving of surfaces, eventually leading to the unevenness of pavement surfaces. High temperatures also accelerate fatigue damages, such as gradual cracking of surfaces, bleeding of asphalts, etc. Cool paint is able to reduce significantly the surface temperatures of the roads and the asphalts becomes less soft (Loustalot et al, 1995). It was identified, in a rutting experiment conducted by Pomerantz et al, that when the surface temperatures of roads were reduced by 10°C to 42°C, the lifespan of the pavements increased by more than 10 fold. With reduced surface temperatures, rutting, shoving and other fatigue damages are less likely to occur, thus increasing the lifespan of the roads, reducing the cost of repaving.

The lifespan of the roads can also be increased with the reduction of the internal temperatures. Analysis also shows that cooler asphalt road slows down the chemical reactions which make them brittle, thereby maintaining their flexibility for a longer period (Monismith et al, 1994). As the internal temperature of the pavement builds up, the pavement loses its flexibility and becomes brittle. Cool paint is able to prevent this internal built up of heat, slowing down the chemical reactions, thus increasing the overall lifespan of the roads.

With the increase lifespan of the roads, the cyclical maintenance of the roads can be extended. Rosenfeld et al estimated that a resulting potential saving of $1.08/ m2 can be achieved.

Acknowledgements

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