A Study on the Effectiveness of Heat Mitigating Pavement Coating on Thermal Comfort and Development of a Prediction Model for Air Temperatures in the Tropics

Urban Island Heat (UHI) effect is a phenomenon in which surface and air temperatures are elevated due to the retention and emittance of mainly solar heat from roads, buildings and other structures. This heating effect contributes towards global climate change, causing overall temperatures to rise throughout the years. Heat islands are normally formed when city growth alters the urban fabric by replacing natural land cover with manmade asphalt pavements, buildings and other infrastructure. Pavements are one of the main hardscapes contributing to the heat island effect. Pavements 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℃ (figure 2). 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.

A high albedo pavement coating, named "*PerfectCool*"[1] has recently been developed to prevent pavements from excessive built up of heat. *PerfectCool* coatings consist of dark, low reflectivity color pigments mixed with high infra-red heat reflective fine hollow ceramic particles, allowing them to be highly reflectivity in the infrared red region, yet have low reflectivity in the visible light region. With most of the infrared red heat reflected away, less thermal energy is absorbed by the pavements, thus resulting in lesser heat radiated back into environment, thereby reducing the impact of UHI (figure 3). Its low reflectivity in the visible light ensures that the pavement do not cause discomfort glare for pavement users.

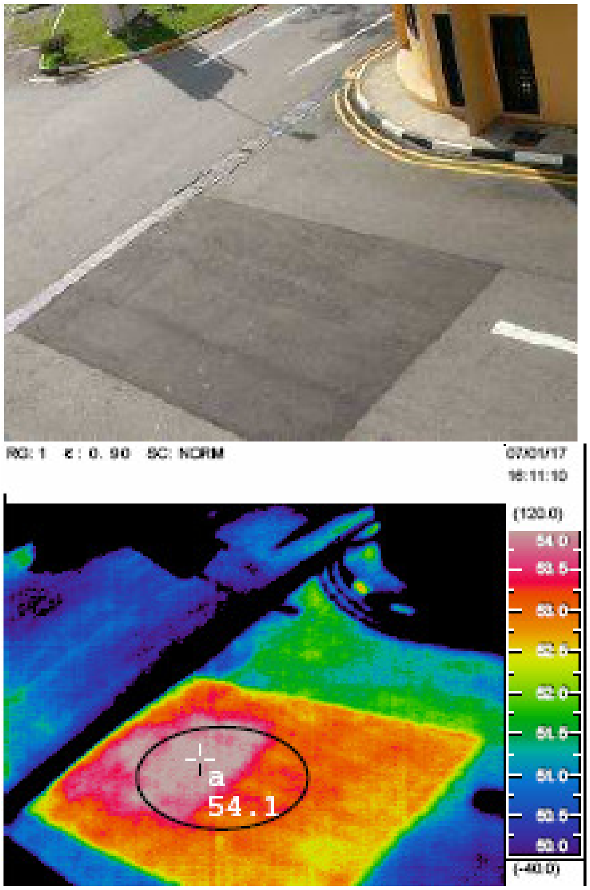


Figure 1. Thermal scan of an asphalt road showing high surface temperatures of 54.).

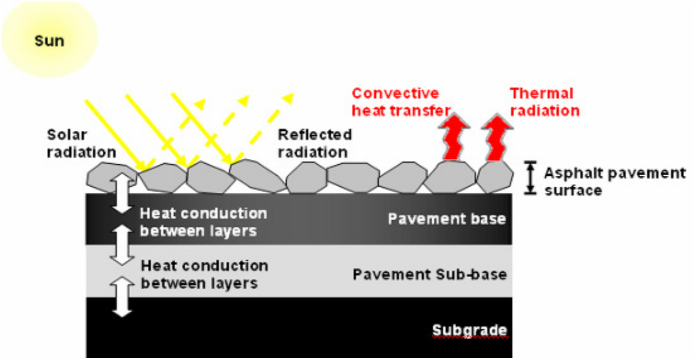


Figure 2. Heat exchange process in a convention pavement (Source: www.Nippo-c.co.jp).

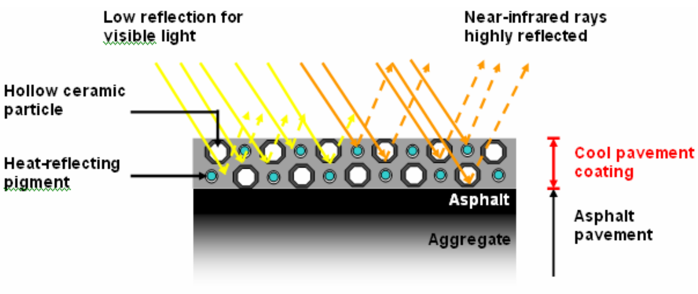


Figure 3. Close-up view of coating layer above the asphalt mixture (Source: www. Nippo-c.co.jp).

Results of Study

Laboratory tests revealed that the *pavement coating* was able to reflect up to 81% of near infrared red waves (figure 4 and table 1), had a low heat conductivity of 0.252 W/mK (table 2) and had high emissivity value of 0.828 (table 3), as compared to normal coatings with low reflectance of 25%, higher conductivity of 0.422 W/mK, and lower emissivity of 0.68. Controlled mock-up experiments conducted with light colored concrete slabs finished with the *pavement coating* consistently recorded lower surface temperatures as compared to samples without any coating. The *pavement coating* was able to reduce peak surface temperatures of the concrete slabs by up to 5℃.

On-site measurements revealed that the *pavement coating* was able to reduce asphalt surface temperatures to about 38℃. This corresponded to a surface temperature reduction of up to 17℃ as compared to an asphalt surface without the *pavement coating*. Sub-surface temperatures of 34℃ were recorded for the similar asphalt surface finished with *pavement coating,* representing as much as 16℃ reduction due to this *pavement coating*. Surfaces finished with the *pavement coating* were able to prevent a built-up of heat thus preventing the asphalt road from becoming a heat sink, thereby prolonging the service life of the asphalt surface.

Sensory surveys results of 30 participants showed that the majority were able to feel the difference in temperatures caused by the *PerfectCool* coatings.

Potential cooling cost savings as a result of ambient temperature reductions from the use of the *pavement coating* were determined through energy simulations. A hypothetical building development with surrounding hard surfaces applied with the *pavement coating* was simulated to achieve monthly cooling energy savings of 4.88%. On a typical hot day, reduction of chiller load was noted to be as high as 7.69%.

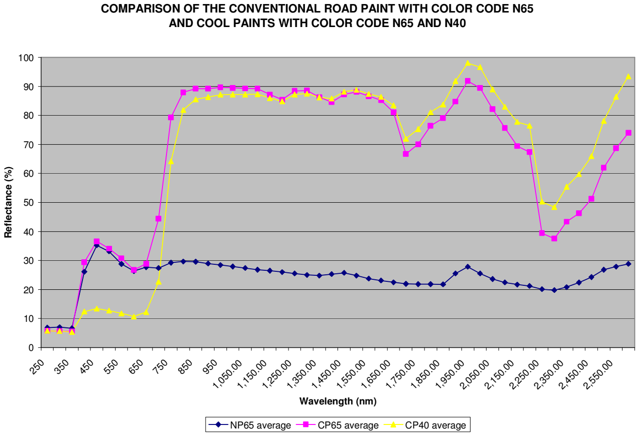


Figure 4. Graph comparing the percentage of reflectance between NP65, CP65 and CP40.

Table 1. Summary of reflectivity values at the ultraviolet, visible light and near infra-red region

	UV (300-400nm)	VIS (400-700nm)	NIR (700-2600nm)
Acrylic substrate with NP65	7%	30%	25%
Acrylic substrate with CP65	6%	31%	77%
Acrylic substrate with CP40	6%	12%	81%

Table 2. 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 3. Summary of results for Emissivity measurement of the different coatings

Coating Type	Emissivity
CP40	0.828
CP65	0.692
NP65	0.680

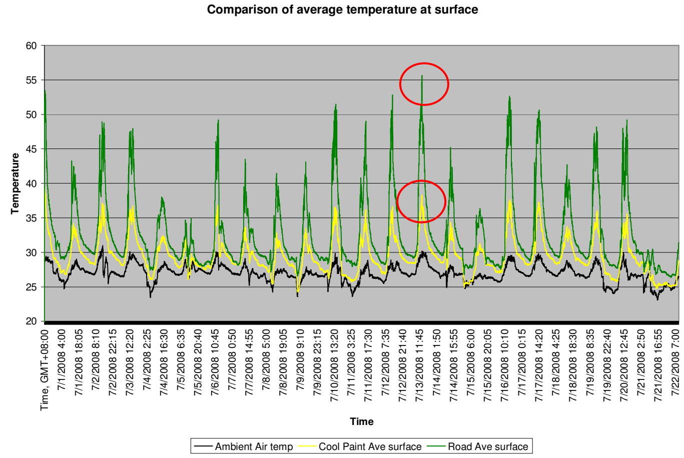


Figure 5. Comparison of average surface air temperatures between the Cool Paint and the asphalt Road on surface. Circled red from top to bottom are the peak temperatures of the Road surface, the cool paint surface and the ambient air respectively.

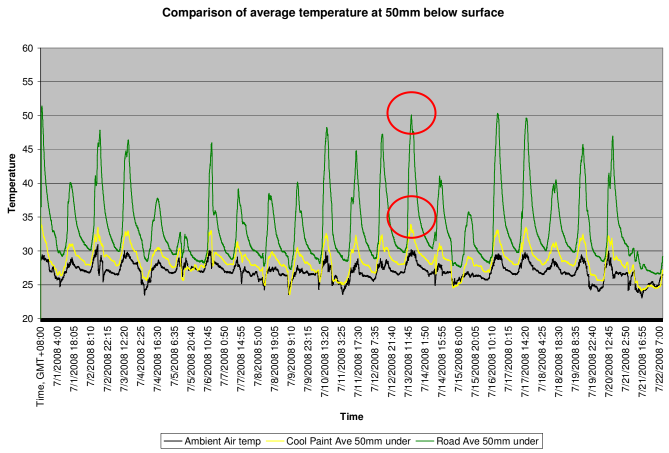


Figure 6. Comparison of average surface air temperatures between the Cool Paint and the asphalt Road at 50mm below surface. Circled red from top to bottom are the peak temperatures of the Road surface, the cool paint surface and the ambient air respectively.

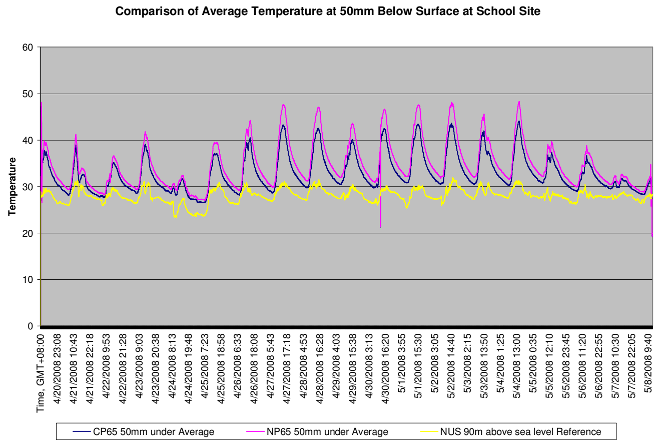


Figure 7. Average sub-surface measurements at Boon Lay Secondary School recorded at 50mm below surface.

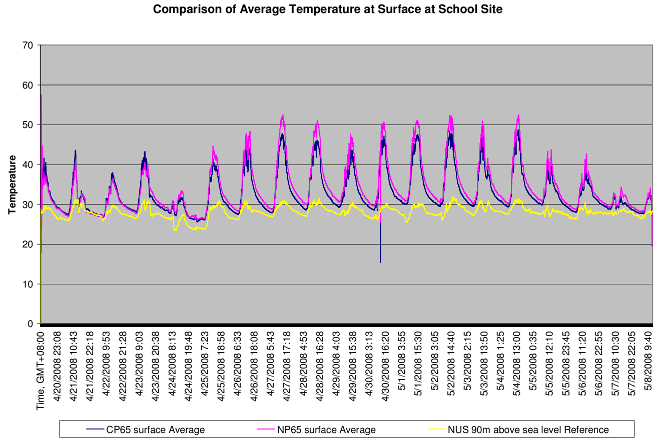


Figure 8. Average surface measurements at Boon Lay Secondary School recorded.

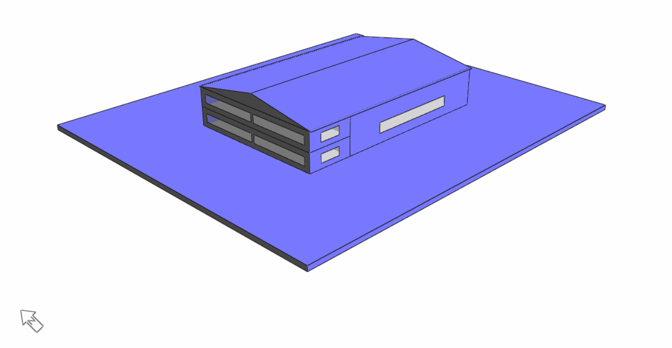


Figure 9. Overview of model of a typical factory simulated.

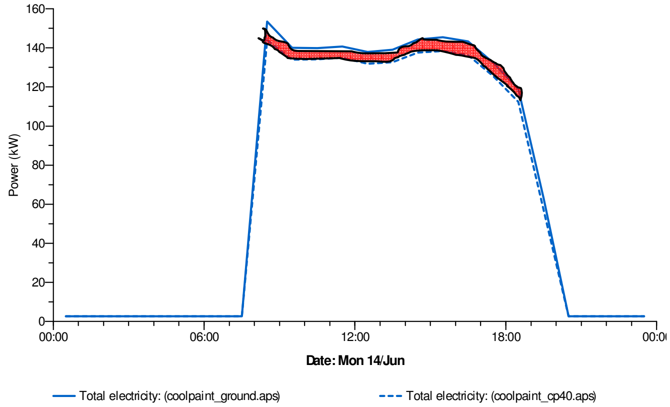


Figure 10. Peak electrical consumption was found to be on 14 June. Graph above shows the peak electricity consumption comparing for with and without cool paint. Dotted line represents electrical consumption of factory with pavement coated with *PerfectCool* coating CP40. Highlighted area represents savings by with *PerfectCool* coating CP40.

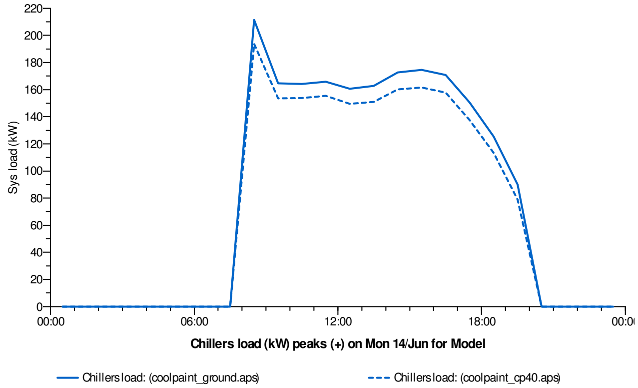
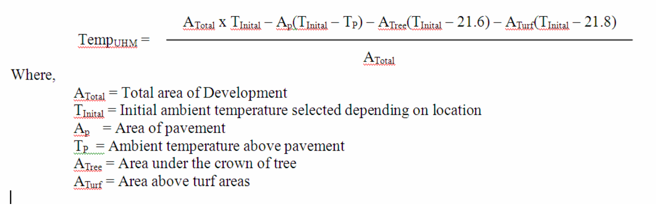


Figure 11. Chiller load of factory of peak electrical consumption which falls on 14th June. The dotted line represents the chiller load for factory with pavement coated with *PerfectCool* coating CP40.

A prediction matrix was also developed as a design tool to provide an indication of the effect that the surface treatment to hard surfaces (such as pavement coatings, turf, trees, etc) have on ambient air temperatures. This will allow various heat-mitigating strategies to be compared. The prediction matrix makes use of the results from this *study* as well as various established publications on greenery to determine the overall ambient air temperature of the development [2,3,4] and is given as:



$$\text{Temp}_{UHM} = \frac{A_{Total} \times T_{Inital} - A_p(T_{Inital} - T_P) - A_{Tree}(T_{Inital} - 21.6) - A_{Turf}(T_{Inital} - 21.8)}{A_{Total}}$$

Where,

A_{Total} = Total area of Development
T_{Inital} = Initial ambient temperature selected depending on location
A_p = Area of pavement
T_P = Ambient temperature above pavement
A_{Tree} = Area under the crown of tree
A_{Turf} = Area above turf areas

Reference:

[1] Co-developed by *Nippo Corporation Co,, Miracool Co. Ltd, Kanematsu Corporation Co., Public Works Research Institute* and the *Tokyo Institute of Technology*, Japan

[2] Wong N.H., Jusuf S.K., Aung Aung L.W., Htun K.T., To S.N., Wu X. (2007) Environmental Study of the Impact of Greenery in an Institutional Campus in the Tropics. *Building and Environment*, 41, 2949-2970

[3] Wong N.H., Tan P., Chen Y. (2007) Study of Thermal Performance of Extensive Rooftop Greenery Systems in the Tropical Climate. *Building and Environment*, 41, 25-54

[4] Chen, Y. and Wong, N.H. (2006). “Thermal Benefits of City Parks”. *Energy and Building*, 38, pp 105-120

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