3. OBJECTIVE OF STUDY

3.1 The main objectives of the study have been set to be:

a. To assess the improvement in thermal comfort, reduction in urban island heat island and potential energy savings properties of reflective cool pavement coatings through the study of their optical and thermal properties i.e. thermal conductivity, reflectivity (albedo) and emissivity.

b. To compare the thermal performance of reflective cool pavement coating with conventional pavements by on-site field measurements controlled experiments and sensory surveys.

c. To develop a cool pavement coating test protocol for use in tropical climates to evaluate the effectiveness of such coatings in improving thermal comfort, reducing urban island heat island effects and achieving potential energy savings by on-site field testing and laboratory experiments.

d. To develop a set of Performance Specifications for cool pavement coatings to evaluate the effectiveness of such coatings in improving thermal comfort, reducing urban island heat island effects and achieving potential energy savings. The standards and specifications may be forwarded to Spring Singapore for accreditation and adoption as Singapore Standards.

4. RESEARCH METHODOLOGY

4.1 Introduction

4.1.1 Investigation of the effect of cool pavement coating in reducing in Urban Heat, increase in thermal comfort and 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 conducted through a four pronged approach of laboratory testing, controlled measurements, on-site field measurements, and sensory surveys.

4.1.2 Two different color cool pavement coatings were supplemented for testing: *PerfectCool* coating with the color code N65 (hereinafter "CP65") and *PerfectCool* coating with the color code N40 (hereinafter "CP40"). The color codes indicate the intensity of color; the lower the color code, the darker the color. A normal pavement coating with the color code of N65 (hereinafter "NP65") was used as a control.

4.2 Laboratory Testing

4.2.1 Three properties of the coatings were tested: reflectivity, thermal conductivity and emissivity. Sample sizes of nos. five (5) were used for each testing. Further explanation can be found in the attached Annex A.

4.2.2 Reflectivity

4.2.2.1 The reflectivity of *PerfectCool* coatings was carried out with the use of a deskbound spectrophotometer SHIMADZU UV-VIS-NIR SCANNING (UV–3150), in accordance to the American Society for Testing and Materials (ASTM) E903, *Test Method for Solar Absorption, Reflectance and Transmittance of Materials Using Integrating Spheres* as a reference for the testing procedures.

4.2.2.2 The reflectivity of the three coatings were tested from the wavelength spectrum of 300nm to 2600nm, where 300-400nm are the wavelengths for ultraviolet A, 400-700nm are the wavelengths for visible light, and 700-2600nm are the wavelengths for near-infrared red. This was limited by the performance of the equipment.

4.2.2.3 Further details can be found in Annex A, section 1.1.

4.2.3 **Thermal Conductivity**

4.2.3.1 Laboratory measurements for thermal conductivity of the coatings were carried out using the QuickLineTM-10 Thermal Conductivity meter, and in accordance to ASTM E1530, *Standard Test Method for Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique*.

4.2.3.2 The rate which heat was transferred through each coating was measured under a state-state condition. The thermal conductivity of each coating was subsequently calculated.

4.2.3.3 Further details can be found in Annex A, section 1.2.

4.2.4 Emissivity

4.2.4.1 Emissivity laboratory testings were carried out using the Scaling Digital Voltmeter, Model AE RD1, in accordance to ASTM C1371-04a, *Standard Test Method for Determining of Emittance of Materials Near Room Temperature Using Portable Emissometers*.

4.2.4.2 The average emittance for each coating types (CP65, CP40 and NP65) was calculated.

4.2.4.3 Further details can be found in Annex A, section 1.3.

4.3 Controlled Experiment

4.3.1 The controlled experiment was carried out over the duration of 14 days. The coating types CP65 and NP65 were used because both had similar color types. Similar colored coating types allow us to isolate and identify the effects caused by *PerfectCool* coatings technologies. Both coating types were painted onto a 300mm by 300mm by 50mm cast concrete slab. A similar concrete slab was cast as a control.

4.3.2 The three concrete slabs (control, one coated with CP65, the other coated with NP65) were placed onto the roof for full exposure to the sun. To prevent any influence from the wind, the three concrete slabs were individually placed into a prefabricated clear acrylic box with an opening on the top. The clear acrylic boxes serves to block out the wind while still allowing sunlight to penetrate and heat up the slabs. The open top design was chosen to prevent a build-up of heat due to green house effect.

4.3.3 5 different heights were measured: 0mm (surface temperature), 10mm, 150mm, 300mm, and 600mm above the surfaces of the 3 concrete slabs. Dataloggers were used to data-log the temperature for each height, at an interval of 5 minutes for the entire duration of the experiment.

4.4 On-Site Measurement

4.4.1 Four determining criteria were used to gauge the suitability of the sites:

a. The site had to be surrounded by buildings. This was to study whether the reflective *PerfectCool* paints will result in any increase in surface and ambient temperatures to the surrounding facilities.

b. The surface had to be facing the east and west direction to receive full exposure of the solar radiation from the sun.

c. The site had to be cornered/barricaded to throughout the entire measurement period to ensure there were no disturbances.

d. Moderate flow of traffic with heavy vehicles (lorries and container trailers).

4.4.2 An initial site survey was conducted to identify suitable sites for the test. Based on the conditions mentioned above, three (3) sites were found suitable: the basketball courts located within Boon Lay Secondary School, the entrance within Tuas Road terrace factories and the vacant building located at Taman Jurong; (figures 11 to 13). The other sites surveyed are as attached in Annex B (figures 1 to 10).

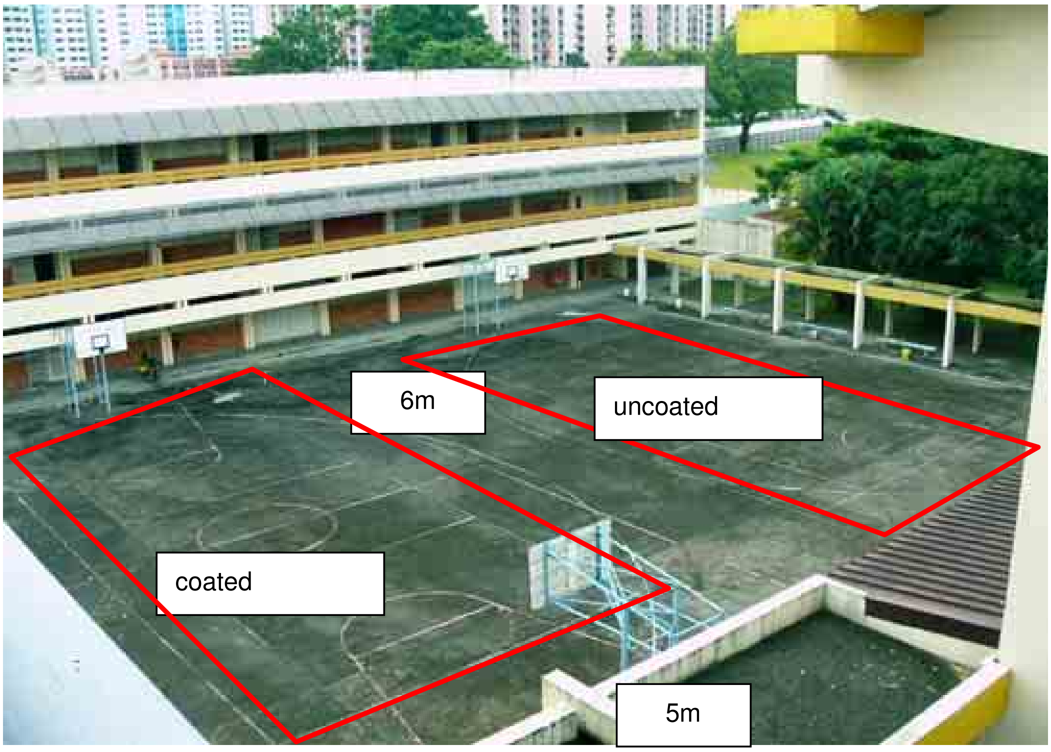

Figure 11. Boon Lay Secondary School basketball court

Figure 12. Driveway of Tuas road flatted factory.

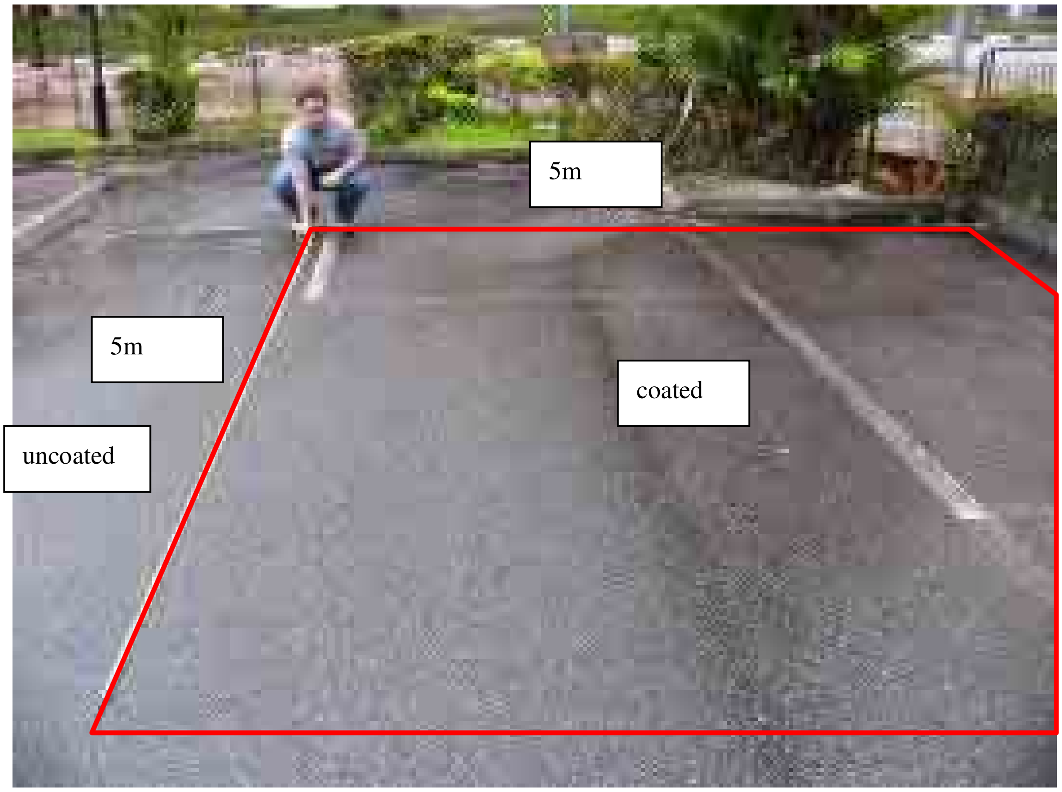

Figure 13. Building located at Taman Jurong.

4.4.3 The basketball court in the vacant school was coated with CP65, with the other basketball court coated with NP65 to act as control. For the vacant building, *PerfectCool* coating with the color code of 40 (CP40) was found to have the closest matching color with the asphalt (see figure 14). The temperatures of CP40 and the asphalt were measured.

4.4.4 The entrance of the terrace factory was found ideal for the visual assessment because there is a constant flow of heavy vehicles driving through the entrance. Both the vacant building and school were ideal because they have minimum risk of vandalism which will affect the readings.

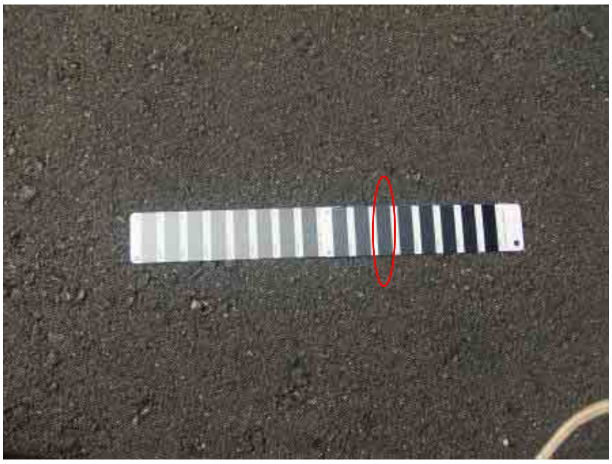

Figure 14. Road condition of the terrace factories located at the Tuas Road. The color code N40 will be used.

4.4.5 A shading profile was conducted for vacant sites to identify possible locations for measurements. Figure 15 shows the shading profile and locations for measurements for the vacant building. The locations for measurements at the vacant school site were located at the centre of the courts as it was observed to be unshaded from 0800-1730hrs.

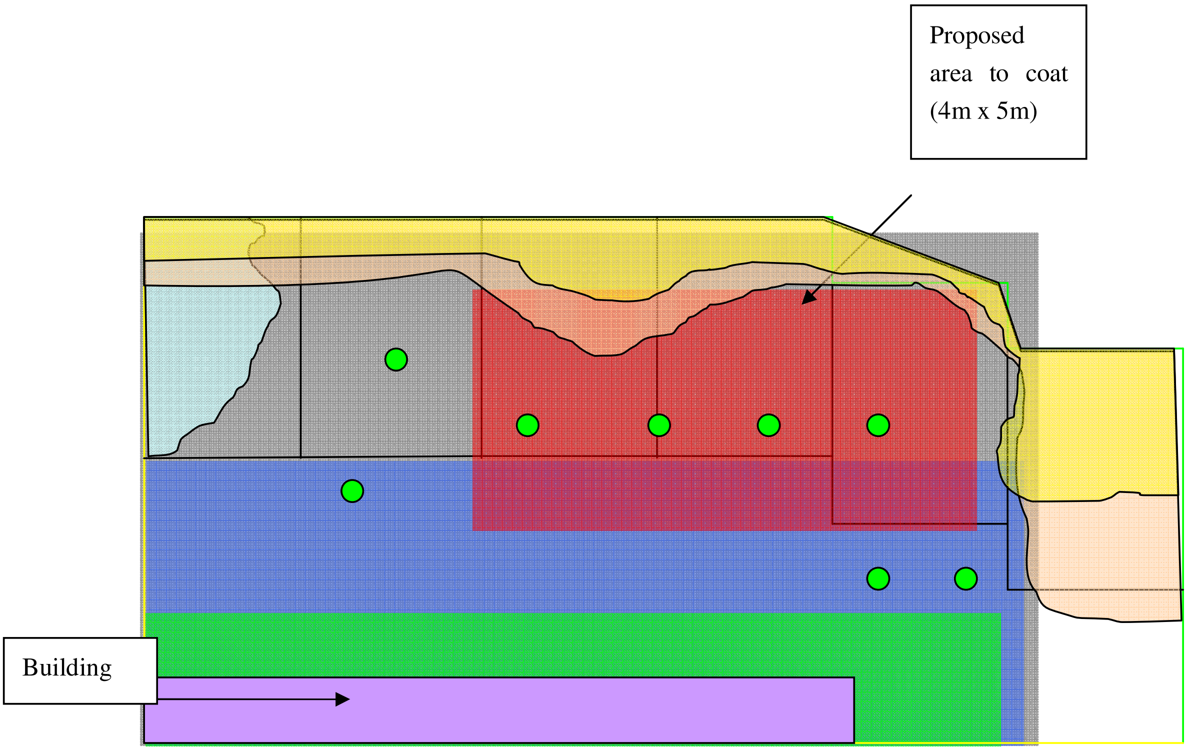

Figure 15. Overview of shading profile on the site. Pink is shading profile at 1030hrs. Yellow is shading profile at 1120hrs. Turquoise is shading profile at 1400hrs. Green is shading profile at

1500hrs. Blue is shading profile at 1600hrs. Gray is shading profile at 1700hrs. Green circles are proposed location of the stations installed, 4 at coated surface, 4 at asphalt surface.

4.4.6 The following heights were measured:

i.) 50mm below surface;
ii.) 10mm below surface;
iii.) 0mm on surface;
iv.) 10mm above surface;
v.) 300mm above surface; and
vi.) 600mm above surface

4.4.7 The method of installation of the equipments on-site is as explained in Annex B.

4.5 Site Survey

4.5.1 The objective of the site survey was to study, if any, the physiological impact *PerfectCool* coatings have. 30 randomly selected participants were asked to participate in this study. They were brought to visit all four test sites (2 sites at the school, 2 at the JTC) and were asked a list of questions pertaining to their thermal sensation when they are on each test site. For the questionnaire to remain independent, no prior information or knowledge was disseminated to the participants throughout the duration of the study.

4.5.2 A thermal sensory survey questionnaire was developed to study on the thermal sensations felt by each participant. A new questionnaire was handed out to each participant at each location. The questionnaire was generally 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.

4.5.3 A comparison study was also conducted between the two pavement types at each location. The participants were asked to compare between the Pavement type 1 and 2 at each location and gauge which is hotter.

4.5.4 A sample of the survey questionnaire is attached as Annex C.

4.6 Energy Simulation

4.6.1 An energy simulation was conducted to study the possible benefits *PerfectCool* coatings have on the environment and internal cooling loads of a typical development.

4.6.2 The software, Integrated *Environment Solutions <Virtual Environment>* (hereinafter "IES (VE)"), was used to simulate a typical flatted factory and its possible energy savings. IES (VE) is a comprehensive, integrated suite of thermal analysis tools which is able to assess the effectiveness of a building and its energy systems. IES (VE) offers a comprehensive, interoperable range of thermal analysis tools for various simulating scenarios.

4.6.3 A typical factory, 45m by 30m by 8m high was modeled. The internal space are divided into a 2 storey office space, where one storey is 10m by 30m by 4m high, and a open space which is 35m by 30m by 8m high. The external wall is assumed to be a standard wall construction, the internal wall is assumed to be a 105mm thick brick wall with 13mm thick plaster on both sides, and the external glazing is assumed to be low-e double glazing (6mm+6mm). The factory was completed with a pitch roof top and a 20m wide asphalt road along the perimeter of the factory.

4.6.4 The energy simulation aims to investigate the possible energy savings which can be achieved through the application of *PerfectCool* coatings along the asphalt roads along the parameters of a typical factory. The asphalt is taken to have the following parameters: an albedo (solar reflectance) of 0.15 (Lovell *et al*, 2005), and an emissivity of 0.93 (source: website "Cole-Parmer"). For comparison, the results of *PerfectCool* coating CP40, both solar reflectance and emissivity, will be gathered from the laboratory results.

4.6.5 The occupancy load for the factory is assumed to operate from 0800hrs to 1800hrs, where it achieves 50% load capacity during 0800hrs to 0900hrs (assumed half of occupants arrives to office at 0800hrs and remainder comes at 0900hrs), 1200hrs to 1400hrs (lunch time, assumes half of occupants goes for lunch), and 1900hrs to 2000hrs (assumes half of occupants leaves at 1900hrs and remainder leaves at 2000hrs), where the maximum occupancy load is assumed to be limited at 10m^2/person. The working hours are assumed to be Monday to Friday, where Saturday, Sunday and public holidays are assumed to be closed. The lighting is assumed to be on from 0800hrs to 2000hrs.

4.7 Urban Heat Matrix

4.7.1 The intent of the Urban Heat Matrix (hereinafter "UHM") aims to be a simple and accurate matrix system, independent of any dynamic influences such as wind conditions, and time of the day. The UHI should ideally consider parameters which are controllable by planners. Localized wind conditions were not considered because they dependent heavily on a few factors: prevailing monsoon wind directions; obstructions within vicinity; terrain features; and, geographical locations, for example, seaside or inlands. Although such factors directly impacts on the downstream cooling effect of greenery (Honjo and Takaura, 1990/91), they are uncontrollable by planners. An average day temperature was used to standardize the fluctuating temperature at different times of the days.

4.7.2 To ensure that the UHM was simple to use, a self-computing equation was derived consisting of parameters/factors which the owners/planners were familiar with. The parameters considered had to be information which owners/planners either have easy access to, or/and have an influence upon. To ensure that the parameters are "localized", each parameter chosen was supported by literature reviews/ journals conducted/studied locally. The interactive relationships between the parameters were also investigated/researched to identify any possible overlapping influence.

4.7.3 The various parameters selected were than equated into a formula, and the overall ambient air temperature was calculated.