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Progress Report on

COOL PAVEMENT

PREPARED FOR:

Kanematsu Corporation,
Nippo Corporation and
MiraCool Co. Ltd

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Content

1. INTRODUCTION

1.1 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. It was reported that in 2000, only 53% of the world is not living in cities and this figure is expected to reduce to 20% by 2100. Consequently, when solar energy is absorbed into roads and rooftops, the surface temperature of urban structures becomes 10°C – 20°C higher than the ambient air temperatures. This is further aggravated when heat radiated from urban structures gets reradiated back to earth after being absorbed by Greenhouse gases in our atmosphere.

1.2 The primary root of UHI is an effect of urbanization which results in the replacement of natural landscape with hard surfaces that absorb and re-radiate the solar energy back to the environment. The increase in the rate of greenhouse gases emission also contributes towards hotter climatic conditions. The higher concentration of greenhouse gases in our atmosphere absorbs the infrared radiation from the earth's surface and reradiates part of it back to earth, further warming it up. Predictions have been made that by 2100, temperatures worldwide are expected to rise by 1.4°C to 5.8°C.

1.3 UHI impacts the environment both on the macro and micro-scale level. On a macro-scale, higher ambient air temperatures caused by UHI and climatic changes may result in land loss and flooding, water resources uncertainty, higher energy demand for cooling, heat stress and discomfort, resurgence of diseases and negative impacts on marine bio-diversity. At micro-climatic scale, higher ambient temperatures may result in the increase in human discomfort and increase the demand for cooling energy within buildings, which in turn adds up to additional cost in electrical bills to building owners and authorities, just to maintain indoor air temperatures at comfortable levels.

1.4 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℃. 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", slow progression of technologies in this area limits urban planners and building owners to plan ways to mitigate this problem.

1.5 A high albedo pavement coating, named "*PerfectCool*" has recently been co-developed by *Nippo Corporation Co,, Miracool Co. Ltd, Kanematsu Corporation Co., Public Works Research Institute* and the *Tokyo Institute of Technology*, Japan, to prevent pavements from excessive built up of heat. *PerfectCool* coatings are 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. Its low reflectivity in the visible light ensures that the pavement do not cause discomfort glare for pavement users.

1.6 The effectiveness of such *PerfectCool* coatings was investigated through a three-pronged approach: laboratory testing, controlled experiments and on-site field measurements. Each approach investigates various performance parameters of the coatings: the laboratory testing investigated the reflectance, conductance, and emittance properties of the coatings; the controlled experiments investigated how the coatings work; and finally, the on-site testing evaluated the performance of the coatings. Sensory surveys were also conducted to investigate the user's perception and how they felt when they were on the pavements. The results obtained were used as inputs for computational energy simulations to determine the potential cost saving and improvement in thermal comfort.

2. LITERATURE REVIEW

2.1 Introduction

2.1.1 Pavements, by definition, is a pathway made with the intent to sustain traffic, both human and vehicular. Throughout the years, the choice of surface material is critical, as it has to withstand wear and tear. Paving materials have evolved from simple stone blocks dating back to the 18th century, into the modern wide variety types, each specialized to cater to specific demands.

2.1.2 The modern common types of pavement surfaces can be classified as follows:

a. "Flexible" pavements, which are commonly built with asphalt. These asphalt concrete pavements (ACP), or hot-mix asphalt (HMA), are commonly used for highways, roads and street. It consists of an asphalt binder mixed with stone, referred to as aggregate. This has been widely used since 1920-1930, though in ancient times asphalt was already used for road-building.

b. "Rigid" pavements, which are commonly built with Portland cement concrete (PCC). The concrete consist of Portland cement mixed with water and aggregate and cured until it is strong enough to withstand traffic. Conventional PCC pavements are placed in fixed forms or by machines that includes traveling forms ("slipform paving") to create paving slabs; a variant of this material is roller-compacted concrete, which is rolled onto the surface like asphalt.

c. Pavers, or paving blocks (includes interlocking pavers), are generally in the form of pre-cast concrete blocks, are often used for aesthetic purposes, or sometimes at port facilities that see long-duration pavement loading. Pavers are rarely used in areas that see high-speed vehicle traffic.

d. Other types of pavements include bituminous surface treatments, road mixes, and macadam construction. These pavements are relatively thin and are mixed in place. In contrast with the examples above, these pavements are used on roads with lower traffic volumes and loads.

2.2 Urbanization, Pavements and Singapore

2.2.1 The status of a country is often hinged on how developed and urbanized she is. Countries have pumped a large portion of capita investments into major road projects (Poboon and Kenworthy, 1995) because a good transport system is often followed by a rapid development (website: www.wikipedia.com). Roads and parking spaces typically occupy 30 percent of the total land area of developed countries (Tanaboriboon, 1993), with major metropolis accounting up to 39 percent of the urbanized surface areas (Akbari, Rose *et al*, 1999, 2003).

Year	Expressway	Arterial Road	Collector Road	Local Road	Total
1990	104	529	260	1,905	2,798
1991	108	539	282	1,911	2,840
1992	109	554	305	1,915	2,883
1993	112	564	309	1,921	2,906
1994	128	565	315	1,935	2,943
1995	132	567	326	1,947	2,972
1996	139	565	330	1,953	2,987
1997	149	559	340	1,969	3,017
1998	150	561	350	1,984	3,045
1999	150	569	359	1,989	3,067
2000	150	571	375	2,004	3,100
2001	150	574	387	2,009	3,120
2002	150	575	410	2,015	3,150
2003	150	579	416	2,020	3,165
2004	150	579	426	2,033	3,188
2005	150	594	455	2,036	3,234
2006	150	604	468	2,040	3,262

Figure 1. Road length in kilometers. Acquired from Land Transport Authority "Facts and Figures". Source: http://www.lta.gov.sg/corp_info/index_corp_facts.htm

2.2.2 As Singapore aims to further strengthens her economy, additions of infrastructures such as pavements and roads becomes a necessity. From figure 1, it is noted that the total kilometers of roads have increased from 2,798km in 1990 to an astonishing 3,262km in 2006. With the rapid increase in the number of vehicles (website: www.lta.gov.sg), it is expected that the kilometers of road will continue to increase as Singapore progresses into the next century.

2.3 Urban Heat Island and Impact of Pavements

2.3.1 When a landcover is urbanized, such changes usually results in a environmental phenomenon commonly known as the Urban Heat Island. An Urban Heat Island (UHI) is a metropolitan area which is significantly warmer as compared to its rural areas (see Figure 2).

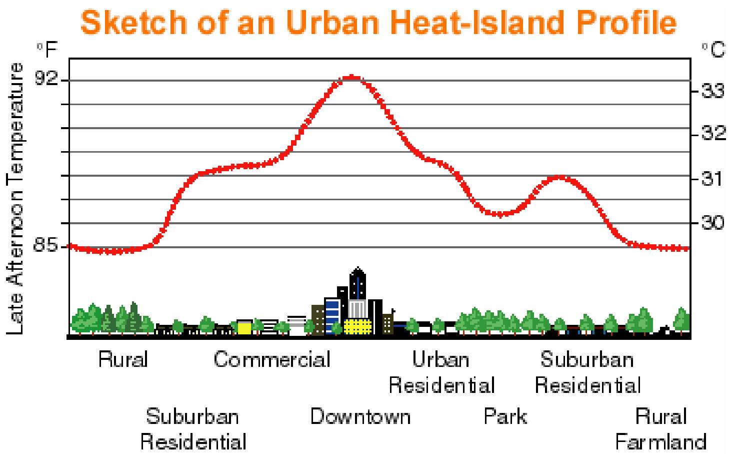

Figure 2. Sketch of a typical Urban Heat Island profile. Acquired from "Heat Island Group – High Temperatures". Source: http://eande.lbl.gov/heatisland/hightemps/

2.3.2 The impacts of UHI in Singapore have been explored through different methods (Wong, 2004). Figure 3 compares the temperatures in Singapore between the rural and urban areas during the day. It can be observed that the urban areas are hotter (more red) as compared to the rural areas (more green), with high temperatures at the Changi Airport (Eastern sector) and Tuas region (western sector).

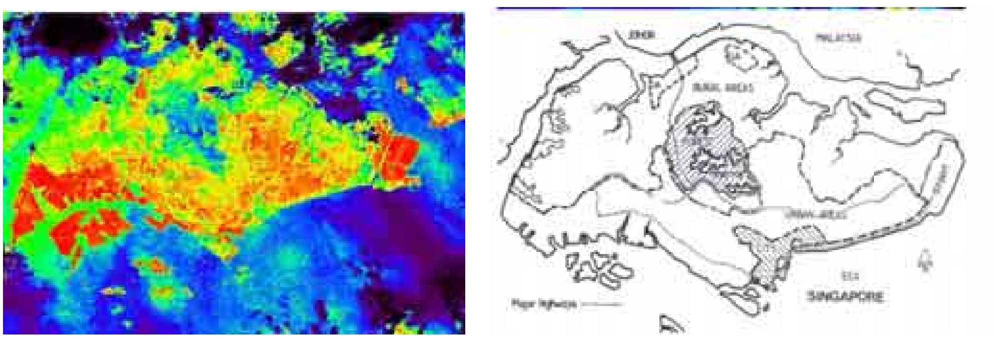

Figure 3. Relative temperature derived from thermal band of Landsat-7 ETM and the 'urban' and 'rural' partition of Singapore. Acquired from a research project funded by BCA "A study of Urban Heat Island (UHI) in Singapore" by Dr Wong Nyuk Hien.
Source:http://www.bca.gov.sg/ResearchInnovation/others/UHI%20_2004-001_%20rev.pdf

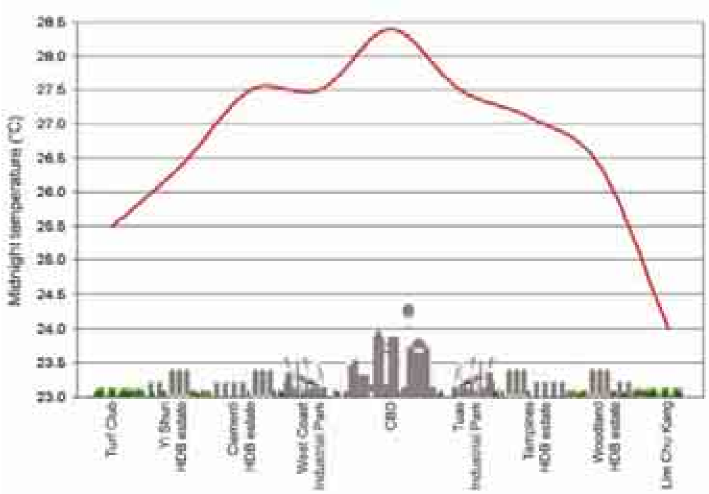

Figure 4. Urban Heat Island Profile of Singapore. Acquired from a research project funded by BCA "A study of Urban Heat Island (UHI) in Singapore" by Dr Wong Nyuk Hien.

Source:http://www.bca.gov.sg/ResearchInnovation/others/UHI%20_2004-001_%20rev.pdf

2.3.3 In A/P Wong Nyuk Hien's research project funded by the Building and Construction Authority (BCA), he has identified that the "hot" spots in Singapore are typically hard surface areas, such as the Central Business District (CBD), industrial areas and the airport. From the mapped out UHI profile of Singapore (see figure 4), the night temperatures of these "hot" spots can reach up to 28.5°C. A/P Wong has also identified that one of the major contributors of heat in these areas are the asphalt road pavements.

2.3.4 This finding coincides with another study which has identified that pavements contribute to the UHI effect by altering the surface energy balance (Cambridge Systematic Inc., 2005). When compared to a vegetation land cover, the material properties of the pavements caused them to absorb and store a larger amount of heat within the pavements. Due to the impervious nature of typical pavements, cooling by evaporation has been reduced drastically. This built-up of heat is slowly re-radiated back into the environment throughout the day and into the night. This results in an increase in the ambient air temperature within the UCL, and this effect is magnified in CBD and industrial areas, where vegetation cover is reduced to the bare minimum.

2.3.5 Thus, it leads to mind that if the surface temperatures of the asphalt roads can be significantly reduced, it is potentially possible to achieve a much cooler environment in these "hot" spots, comparable to areas such as Lim Chu Kang with midnight temperatures of 24℃ (see figure 3).

2.4 Cool Pavement

2.4.1 With the global temperatures expected to rise up to 5.8℃ (Website: www.earth-policy.org), the need to implement cooling technologies becomes more and more important. Cool pavements strategies seek to control the temperature of the pavements, thus reducing heat transfer to the air above and their overall contribution to the UHI effect. There are three main ways pavement researchers seek to reduce their heat contribution to the environment: increase the pavements' reflectance of solar radiation; increase the pavements' ability to cool at night; and finally cool the pavements though evaporation (Cambridge Systematic Inc., 2005).

2.4.2 The following properties of the pavements of surface materials are able to have a direct influence of the way the pavements absorb, store and re-radiate heat:

a. **Albedo**. Albedo, or solar reflectance, is defined as the ratio of reflected solar radiation to the total amount that falls on that surface, also known as incident solar radiation (Concrete Pavement Research & Technology, 2002). Albedo represents the ability of a surface to reflect short-wave radiation. Fresh asphalt concrete has an albedo of 0.05 (Pomerantz, 2003), which means about 95% of sunlight is absorbed into the surface. Therefore, it can be concluded that the greater the albedo, the less solar energy is absorbed, the cooler is the pavement.

b. **Permeability**. The permeability of pavements is dependent on how much water is allowed to pass through and/or stored within them. Using similar concepts as how the human body cools itself, permeable pavements take advantage of the water flowing through or stored within them to cool down via evaporative cooling, thus removing heat.

c. **Conductivity**. Conductivity measures the rate at which heat is transferred through the pavement. A pavement with lower conductivity will transmit less heat through the material as compared to a pavement with higher conductivity.

d. **Emissivity**. Emissivity of a pavement is the ratio of energy radiated by the pavement to energy radiated by a constant black body at the same temperature. It measures the ability of the pavement to absorb and re-radiate the heat.

2.4.3 Besides heat mitigation, other benefits of cool pavements includes:

a. Able to give users a cooler sensation as compared to lower albedo pavements through the mitigated heat conducting through the feet and upward long wave radiation (Kinouchi, 2004).

b. Increase in the durability and lifespan of the pavements. As the surfaces of pavements remain cooler, the asphalt is less softened; therefore less rutting (Loustalot *et al*, 1995) occurs. With a cooler surface, roads are also able to maintain their flexibility for a longer period (Monismith *et al*, 1994). This will lead to a reduction in maintenance and replacement costs (Pomerantz *et al*, 1997).

c. With reduced resurfacing, there will be lesser emission of volatile asphalt fumes, thus contributing to the reducing in smog (Pomerantz *et al*, 1997).

d. If roads are cooler, softer (presumably cheaper) grades of asphalt may be used (Pomerantz *et al*, 1997).

e. Whiter roads surfaces would require less night-time artificial lighting to maintain the required visibility for pedestrians (Pomerantz *et al*, 1997), offering the possibility of using fewer or less powerful street lamps. Better illumination not only enhances visibility on the road, it also increase awareness to surroundings especially traffic signs and pedestrians, thus reducing accident rates and cost of automobile insurance.

f. Significant energy savings could be observed, through the reducing of hourly peak electricity demand (Taha, 1997)

2.4.4 Types of Cool Pavements

2.4.4.1 In this report, the types of cool pavements will be categorized into three main categories: construction system, water-retaining system and coating system.

a. Construction System

i.) The conventional Portland Cement Concrete (PCC) pavements have been proposed as a cool pavement due to its light color and high reflectivity (Pomerantz *et al*, 2003) as it has bee successfully documented that conventional PCC pavements are much cooler than normal asphalt of the same age. To enhance the performance of the conventional PCC pavements, additives such as slag cement and white ash have been proposed to be added in the mixture during construction process of the pavements to improve their performance during their service life span. PCC can also be added on to existing asphalt pavements as a form of maintenance or resurfacing. This process is known as “whitetopping”.

ii.) Traditional chip seals and rubberized asphalt are able to reduce the UHI effect. Chip seals are originally used as preventive maintenance and for rehabilitation. As it is a preferred practice in pavement management to prolong the lives of aged or damaged asphalt concrete pavements by resurfacing with thin coatings, chip seals are commonly used in San Jose (Pomerantz *et al*, 2003). Rubberized asphalt, primarily used to reduce tire-pavement noise, was found to be cooler at night than adjacent PCC pavements (Cambridge Systematic Inc., 2005). Although detailed data of such benefits are still not yet available, Phoenix, Arizona, has begun to use it.

b. Water-Retaining System

i.) Water-retaining systems are pavements designed to be porous so as to “absorb” and retain water within them. water-retaining pavements have lower heat capacity than conventional pavements. The void spaces within the pavements lowers the overall density of the pavements, thus reducing the heat absorbing capacity of the pavements. The pavements are cooled even further due to the water trapped in the void spaces.

ii.) Experiments conducted with porous ceramic blocks suggest that small pores do result in cooler surfaces (Asaeda *et al*, 2000). When the water that is stored in the void spaces within the pavements evaporates, it removes heat from the pavement, thus cooling it down through a process called evaporative cooling. Other benefits of these pavements include the ability to suppress tire noise (Hugues *et al*, 1995; Lefebvre *et al*, 1995).

c. Coating System

i.) The coating system is based on application method. Studies by Pomerantz have shown a reflective top layer is required to reduce the overall temperature of the pavement. By applying a layer of durable paint coating with high albedo and low brightness to the surface of conventional asphalt pavement, it is possible to reduce pavements' surface temperature and sensible heat flux. The low brightness would enhance driver's safety and visibility of lane markers (Kinouchi *et* al, 2004).

ii.) The coating system is the most applicable in Singapore because it can be readily applied onto existing pavements. As Singapore's efficient infrastructure is already in place, it becomes increasingly difficult to replace asphalt roads with concrete or install water-retaining road systems. Coating systems are generally cheaper and thus more economical per square meter to install a reflective layer as compared to changing an entire system

2.4.5 Introduction to PerfectCool Coating

2.4.5.1 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 darked pigment coating with high albedo. The concept was to develop a surface coating to restrict the heat exchange process in a conventional pavement (see figure 5). Through numerous studies, the pavement coating (named "*PerfectCool*") was developed.

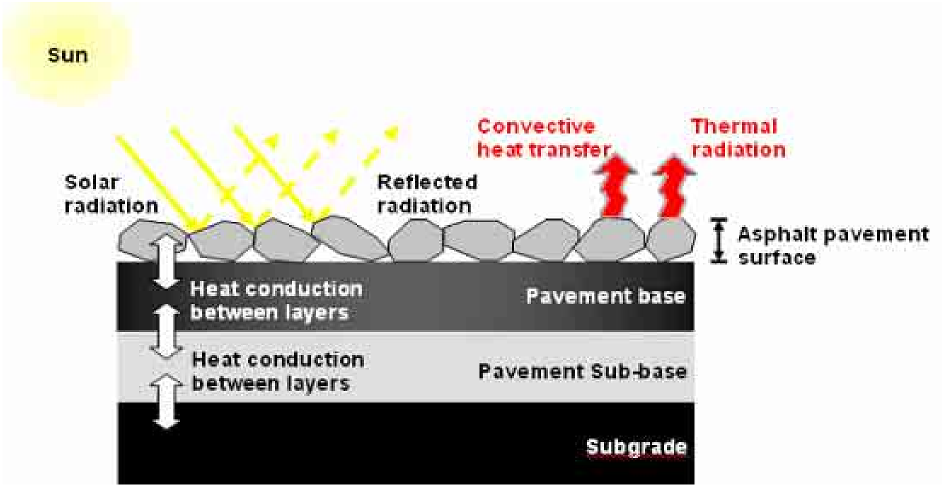

Figure 5. Heat exchange process in a convention pavement (Source: www.Nippo-c.co.jp).

2.4.5.2 *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 reflectivity color pigments mixed with high infra-red heat reflective fine hollow ceramic particles to reducing thermal conduction and heating of the paints (see figure 6).

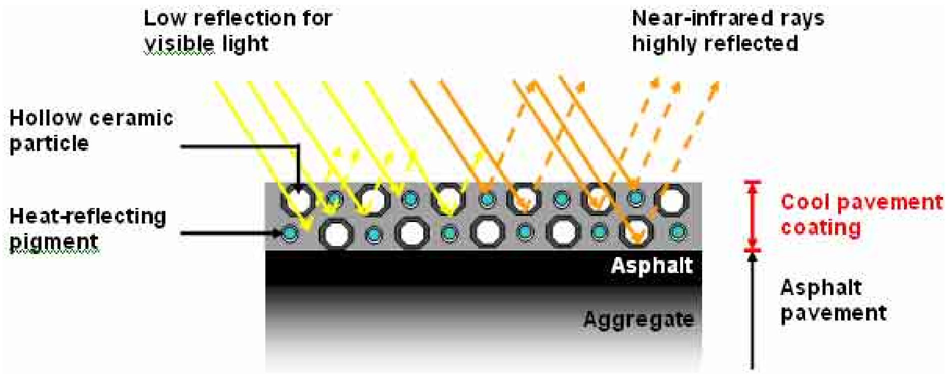

Figure 6. Close-up view of coating layer above the asphalt mixture (Source: www. Nippo-c.co.jp).

2.4.5.3 Figure 7 compares the reflectance percentage of *PerfectCool* as compared to normal paint types and asphalt. *PerfectCool* has low reflectance in the visible light region (lower the reflectance, darker the color) yet high reflectance in the near-infrared red region.

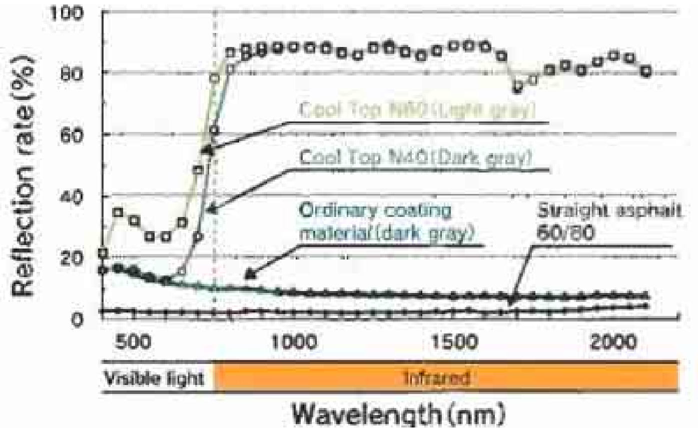

Figure 7. Reflective properties of various coatings. Both *PerfectCool* coatings have high reflectivity in the infrared-red region, as compared to the ordinary coating and asphalt. (Source: www. Nippo-c.co.jp).

2.4.5.4 With the high reflectivity in the infrared-red region, *PerfectCool* is able to significantly reduce surface temperatures of pavements. The reflectivity coatings were able to reduce air temperature and long-wave radiation emitted from the pavement surface, while still maintaining low albedo in the visible region (Iwama *et al*, 2006).

2.4.5.5 Other benefits of *PerfectCool* includes, good weatherability, good adhesion with a variety of pavement types, good torsional resistance, good resistance to rutting (Road Technology Research Group, 2003) and good permeability (Iwama *et al*, 2006).

2.4.5.6 Although Iwama *et al* have recognized that the reflected infrared-red rays might increase surrounding building wall temperatures; they have shown through energy simulation that the increase in wall temperature is slight, and the overall area-weighed 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.

2.5 Other Methods to Combat Urban Heat Island

2.5.1 Besides enhancing pavement properties, another highly popular alternative to combat the rising temperatures in urbanized areas is greenery. They have been considered as ecological measures to combat the problems of the concrete jungle (Wong N.H., Chen Y., 2005). The green areas are able to lower the surface's Bowen ratio[1] by converting incoming solar radiation into energy meant for transpiration and photosynthesis.

2.5.2 The cooling effects and impacts of greenery have been widely studied throughout the world. On a macro level, Saito studied the relationship between meteorological elements and green distribution in Kumamoto City in Japan and concluded that the air temperature distributed was closely related to the distribution of greenery within the city. At micro level, Jauregui (1990/1991) conducted in-depth field measurement and found that the ambient air temperature of Chapultepec Park in Mexico City was 2-3°C lower than the surrounding built-up area.

2.5.3 Locally, studies were also conducted to study the influence vegetation has over ambient air temperatures. Wong *et al* (2007) super imposed a thermal satellite image and thermal satellite image of a campus in Singapore and observed that the "hot" spots are typically observed on the buildings, while the "cool" spots were noted at the dense vegetations (see figure 8). Wong and Chen (2005) conducted a mobile survey island wide and have found a strong correlation between the decrease of temperature and the appearance of large green areas, recording a

[1] Bowen Ratio: proportion of sensible heat to latent heat leaving a surface. Ranges from <0.1 for moist surface to >10 for dry surface.

maximum difference of 4.01℃ between the "urban" and "rural" areas.

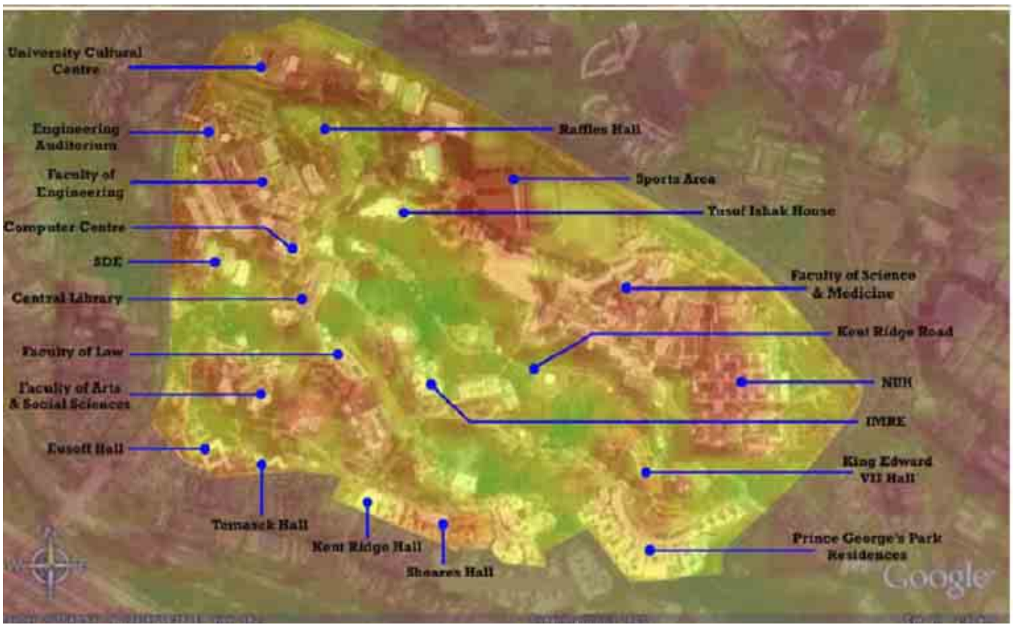

Figure 8. Satellite image of a Singapore Campus with a thermal satellite image superimposed on it. It is observed that the vegetation areas are typically cooler (green) as compared to the buildings (red). Source: Wong *et al* (2007) "Environmental Study on the Impact of Greenery in an Institutional Campus in the Tropics".

2.5.4 Extensive field measurements were also conducted at a variety of locations for a micro view of the impacts of vegetations. Wong *et al* took measurements at various locations with varying density of greenery within an institutional campus in Singapore. It was highlighted that the peak temperature difference of 4℃ was noted between a densely vegetated area (water tank) compared to a sparsely vegetated area (PGP Canteen) (See figure 9). Figure 10 shows the overall average temperatures measured over the 15-day duration. From the figure, it can be observed that the temperature difference between the densely and sparsely vegetated areas (water tank as compared to PGP Canteen) for the maximum, average and minimum temperatures were 3℃, 2.7℃ and 1℃ respectively.

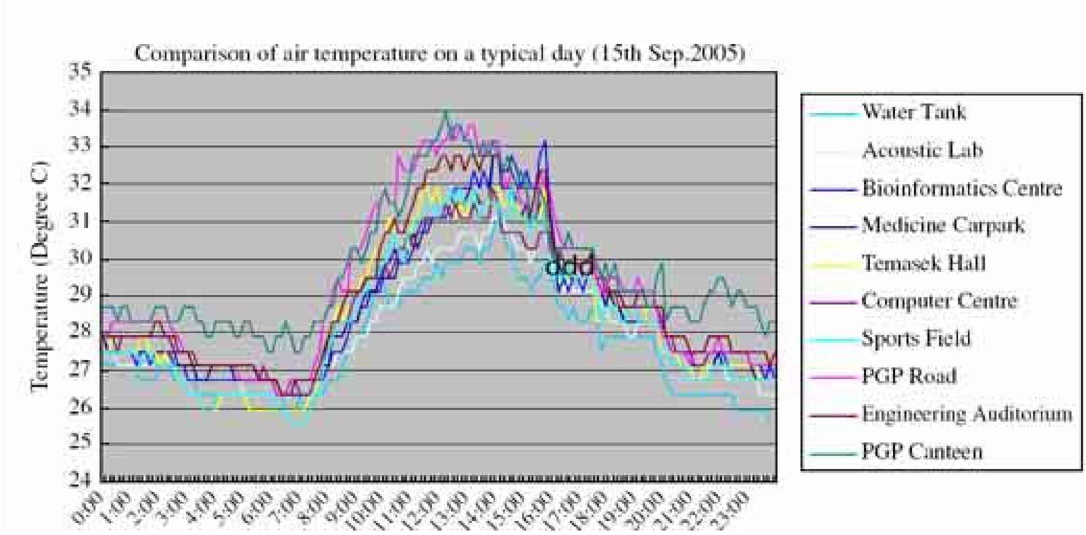

Figure 9. Comparison of temperature profiles of various locations within a campus in Singapore. Source: Wong *et al* (2007) "Environmental Study on the Impact of Greenery in an Institutional Campus in the Tropics".

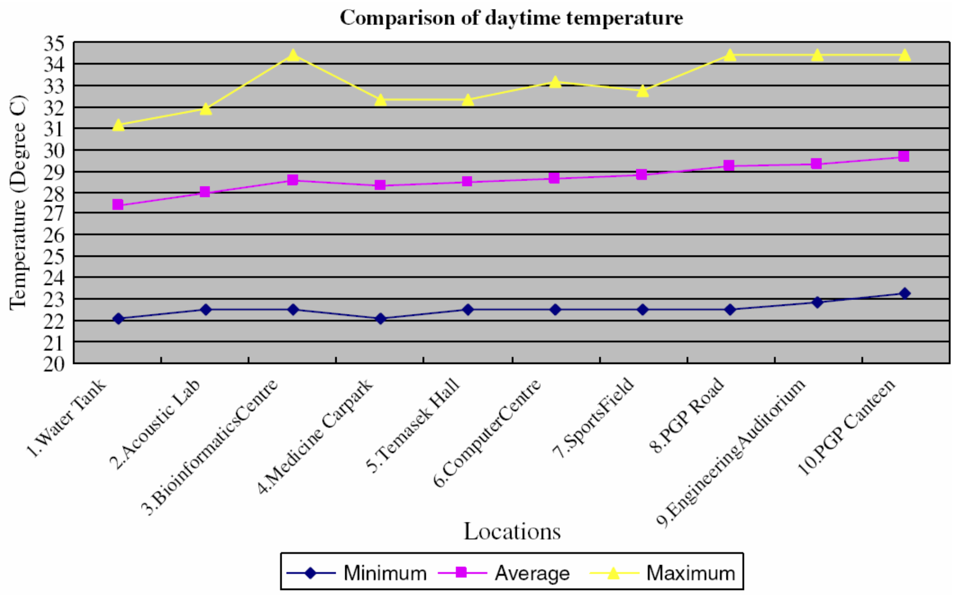

Figure 10. Comparison of daytime temperature profiles of various locations within a campus in Singapore. Source: Wong *et al* (2007) "Environmental Study on the Impact of Greenery in an Institutional Campus in the Tropics".

2.5.5 The landscape type also influences air temperatures. The water tank was described to be densely shaded by trees, while the sports field mainly consists of turf areas. From the results displayed in figure 10, it can be seen that the differences in maximum, average and minimum between the both areas are approximately 1.8℃, 1.5℃ and 0.5℃ respectively. A typical day temperature profile of the sports field is also consistently higher than the profile recorded for the water tank (see figure 9). From both figures, it demonstrates that the choice of types of landscape clearly has an impact on ambient air temperatures.

2.6 Predicting the Impacts of Various Mitigating Measures

2.6.1 With such intense studies and experiments conducted and documented on various heat-mitigating technologies/strategies, various attempts were made to predict the potential impacts they have on the urban environment. With the advancements in environmental modeling softwares, the potential impacts of heat-mitigating strategies were demonstrated through numerous computer simulations. In 1992, Rossi Avissar studied the potential effects of vegetation with the use of a mesoscale atmospheric model. He concluded that if vegetations were planned carefully, it is possible to mitigate some of the anthropogenic effects generated by the development of urban areas in the atmospheric planetary boundary layer. Honjo and Takakura (1990/91) investigated on the intensity of the effects (defined as the difference in temperatures between maximum of urban area and the minimum of the green area) and its range of effects (limited to wind downstream direction) vegetation with varying areas and locations. Through the numerical models, they suggested that smaller green areas with sufficient intervals are preferable for effective cooling of surrounding areas.

2.6.2 Locally, various researches were conducted to identify current conditions, contributors of heat and various strategies to mitigate build-up of heat. Priyadarsini *et al* (2008) conducted a microclimatic study of the Central Business District (hereinafter “CBD”) area to identify possible causes of the build-up in heat and have suggested various mitigating strategies. Wong and Steve (2007) showed through simulations that after the implementation of the NUS Master Plan, the average ambient air temperature of the campus will increase by 1℃. They followed to suggest and show, through simulation, on measures which are able to lower the ambient air temperature through various strategies such as vertical greenery and rooftop gardens.

2.6.3 Unfortunately the complexity of using these simulating softwares proof to be a major hindrance for urban planners. The time-consuming modeling process hinders not only the fast pace decision-making processes which the industry is so used to, the dynamic results from the simulation also means that the models created are unique on its own – each model cannot be reused, and has to be re-modeled for another location. Thus calls the need for a simple yet accurate matrix system, independent of dynamic influence, and applicable in almost all situations.