INVESTIGATION INTO THE URBAN HEAT ISLAND EFFECTS FROM ASPHALT PAVEMENTS

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Abstract: The accelerated global activities in urbanisation and industrialisation have significantly altered the form and composition of the environment, particularly in the densely populated areas with engineered surfaces. These have contributed to changes in the respective micro climates with increased air temperatures in the urban areas than in the surrounding vegetated rural areas. Urban Heat Island (UHI) are urban and sub-urban areas that are significantly warmer than their surroundings. It is often warmer in the city than in surrounding rural areas during summer time and especially at night. Traditionally, highly absorptive construction materials and the lack of effective landscaping are the main causes. Concentration of high thermal capacity buildings, low-albedo asphalt pavements and increased urban surface area are some of the factors that lead to an enhanced absorption of solar heat that causes the changes in the microclimate. UHI effect studies are increasingly important all over the world in terms of increased energy consumption, reduced air quality and effects on human health and mortality, are becoming more pressing as cities continue to grow and sprawl. Asphalt pavements are widely used as a necessity in urban development. Temperatures in the asphalt pavements are dependent on pavement material's thermo physical properties such as albedo, thermal conductivity and thermal emittance. This paper reports investigations of such micro climate changes observed in two distinctly different Köppen climates viz; tropical and temperate climates. The tropical climate in Malaysia is comprise of a warm and humid region ith excessive rainfall and considerable sunshine. The temperate climate in UK is presumed to have four seasons with relatively less precipitation and lower mean temperatures and relative humidity The field monitoring of UHI effects from asphalt pavement within the Research Centre for Soft Soil (RECESS),Johor, Malaysia and Aggregate Industries (UK) Ltd. Leicestershire, United Kingdom are compared. LabVIEW programming was designed and adopted to read data from thermocouple sensors located at experimentally strategic depths in the experimental asphalt pavement to obtain continuous temperature - depth profiles that indirectly portray the diurnal storage of thermal energy. Environmental parameters such as groundwater level, air temperature, relative humidity, wind speed, and rainfall intensity were also observed where possible to assess their contributions to UHI. Different and innovative road pavement fabrics are also studied with a view to assess the potential to capture the clean ad renewable solar energy from the highly diffused radiation that makes vertical collection possible and in turn secure less impact on UHI. Both traditional and sustainable porous materials were considered in the assessment trials. Such measures and proper environment sensitive urban planning and design can positively improve the urban climate. One dimensional mathematical model to simulate heat transfer through and from a road pavement is also presented taking into consideration that the temperature profile at a point on the ground level shows a periodic variation.

***Keywords**:* Asphalt Pavement, field monitoring, micro climate, sustainability, urban heat island

INTRODUCTION

Urban heat island effect can perhaps be simply described as a situation in which the air in an urban area can be 2ºC to 5ºC warmer than surrounding forested or suburban areas [1]. Over the last 100 years, the earth has experienced an approximate 0.6°C (1.1°F) increase in global mean annual temperature [2]. The effect of global warming has significantly contributed to the increases in temperature in UK and Malaysia. The mass scale deforestation, the reduction in the green cover, the increase in built-up land, the use of construction materials such as concrete, asphalt and tar have significantly changed the energy balance of urban areas often causing the temperature to reach a relatively higher value than its surroundings (see Fig. 1)

Undoubtedly, urbanisation and industrialisation does improve the material lives and lifestyle of the society. However, the consequential secondary effects of Urban Heat Island can adversely impact the sustainability of regions. This phenomenon is now becoming a major problem in Asia [3]. In Malaysia, the high rate of urbanization and growth in the population, particularly in large cities such as Kuala Lumpur, Penang, Ipoh and Johor means that increasing numbers of people will be exposed to effects from heat islands in the future. London also generates its own microclimate, which can result in the centre of London being up to 10°C warmer than the rural areas around London. The overall UHI patterns are essentially similar for most cities apart from the minor differences due to climate and geography. As shown in Fig. 1 and 2, the temperature pattern is highest in the highly built up down town area and diminishes towards the edge of the urban areas and into the countryside.

Urban heat island promotes the recirculation of pollutants and heat which causes human discomfort as well as heat related illnesses. Additionally, urban heat island is a drain on public resources by increasing the demand for energy use (air conditioning of buildings) and pavement maintenance, for the management of storm water run-off and for the environmentally acceptable and sustainable disposal of waste.

The higher solar energy levels stored in pavements and buildings induces higher temperatures in urban centres than in rural areas. Other contributory man-made heating sources are such as heat from vehicle exhausts, air conditioners, engines and machinery. Furthermore, the colours and types of surface materials also determine the ability to absorb and release heat to the atmosphere. For example concrete, asphalt, and bricks absorb heat very quickly during the day while water, grass and trees absorb heat more slowly.

RESEARCH DRIVER

Scientists are conscious that human activities have triggered land use and land cover changes in the recent past to give high temperatures in urban areas that have modified the energy balance in cities. Density of buildings, high energy consumption, construction progress and transportation networking has made the potential for heat to be trapped even worse. Infrastructure and buildings are being demolished, built and rebuilt everywhere.

UHI is one of the many issues that rapid urbanization has triggered in the built environment. The UHI effect was first observed in 1833 by a meteorologist, Luck Howard in London [4]. Asphalt road pavements are necessary curvilinear facets in the urbanization that absorb heat during the day and radiate it back out at night time contributing to significant changes in micro climate . However, little scientific research has been carried out on appraising such temperature (UHI) effects from the layers of asphalt pavement.

AIM AND OBJECTIVES OF THE STUDY

This research aims to investigate the potential for storage, capture and subsequent extraction of thermal energy from various layers of asphalt pavements and to assess the consequent impact of the fabric of the road pavement on UHI and the associated benefit to human society. The consequent objectives for this research study are: (a) To setup a data logging system in the field and to design the LabVIEW programme to acquire and monitor the data from the thermocouples located within different layers of the asphalt pavement in order to identify this relationship in contributing to UHI. (b) To compare such observations measured in two climatic environments (tropical and temperate). (c) To propose energy capturing methods from the pavement for the benefit of the environment and engineering performance of the pavement.

LITERATURE REVIEW

For the reader’s convenience, a glossary of the UHI terminology in context to this paper is outlined in Table 1.

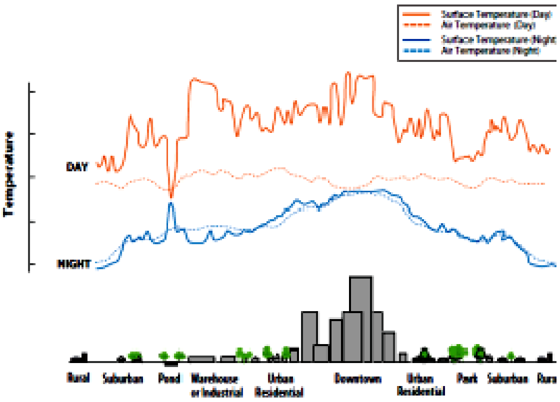

Figure 1: Typical temperature profile across an UHI [2].

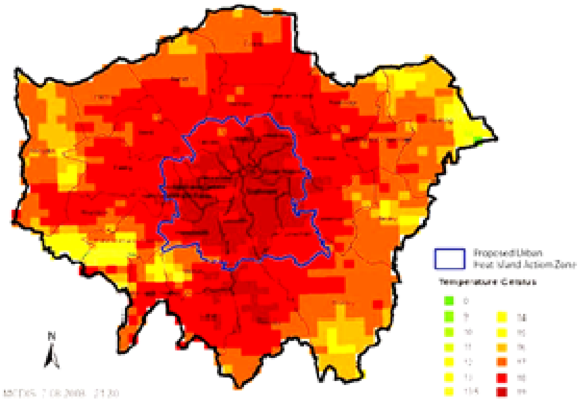

Figure 2: Surface temperature of London at 2130 hrs on 7 August showing the signature of urban heat island. Source: NASA

Table 1: Glossary of UHI Terminology

TERMINOLOGY	DEFINITION / INFORMATION RELEVANT TO THIS PAPER
Albedo, α̃	This is also called **solar reflectance** or **reflectivity**. "Reflectivity" of surfaces (albedo) is defined as the ratio of the amount of light reflected from the surface of a material to the amount of light incident on the material [5]. The higher the albedo value, the greater the energy reflected back to its surroundings which reduce the energy absorbed into the pavement. Conventional paving materials such as asphalt and concrete have a solar reflectance of 5 to 40 percent. It means that they absorb 95 to 60 per cent of the solar energy reaching them instead of reflecting it into the atmosphere [6]. Concentration of buildings, low-albedo asphalt and increased urban surface area like walls of tall buildings and pavements lead to excessive absorbed solar heat.
Anthropogenic Heat	This is the heat released from energy consumption in urban areas; generated from industrial combustion, air conditioners, traffic etc. These aggravate the Urban Heat Islands effect. Reduced surface evapo-transpiration capacity is due to reduced green area. The lack of evapo-transpiration cooling material such as vegetation and water body causes not only loss of beneficial cooling mechanisms but detrimental heat effects. The urban greenhouse effects from fine-particulate air pollution in the urban atmosphere due to industrial activities and transportation systems are also identified causes of urban heat islands.
Asphalt pavement	Asphalt, also called blacktop, is a sticky mixture of petroleum and bitumen [7]. Asphalt which is the most common material for creating driveways, parking lots, road pavements and streets, gets heated up by the sun. Asphalt pavements absorb more heat than other materials and also reflect less heat compared to other lighter coloured surfaces. The thickness of pavement also plays a role in contributing to UHI as it defines the amount of energy it will store. Thicker pavements will store great amount of heat than thinner pavements.
Climate	Climate is defined as the weather averaged over a long period of time, typically 30 years (as recommended by the World Meteorological Organization, WMO). Two types of climates are referred to in this study. First is a tropical climate; hot and humid throughout the year. It is located in the Research Centre for Soft Soils (RECESS), Johor, Malaysia. Hot and humid climates are characterized by high temperatures and high humidity. Annual mean temperatures are above 20ºC with mean values of relative humidity around 80%. Intensive periods of rainfall result in annual precipitation of 2000mm and more. The second study site is in a temperate climate. The location is at Aggregate Industries (UK), Leicestershire, United Kingdom. Temperate climates have seasonal temperature variations of being warm in summer and too cold in winter. Seasonal mean temperature range between a minimum of -15ºC and a maximum of 35ºC. Average temperatures of 20ºC are rarely accompanied by a relative humidity of greater than 80%. Precipitation is distributed in each season depending on temperature and humidity, with rain fog or snow in winter.
Heat Capacity, ρc.	This is a measure of the thermal mass in energy storage. Urban construction materials have a higher heat capacity and can store more heat than natural materials, such as trees, dry soil and sand. Sensible heat is stored in the building materials like concrete, bricks and asphalt due to their high heat capacity during daytime. The stored heat will then be released back to the environment at night and this causes high surrounding temperature at night.
Permeability, K	Permeability of the pavement is a measure of the flow of water, air, and water vapour capacity into and also through the voids of the pavement. The water draws necessary heat from the surround when it evaporates, which results in a temperature reduction.
Thermal Conductivity, k.	High thermal conductivity allows the heat gain from the solar radiation at the surface to be transferred away rapidly and consequently absorbed into the ground, which acts as a heat sink. Pavements with low thermal conductivity can heat up at the surface but eventually will not transfer that heat into the other pavement layers as fast as a pavement with higher conductivity.
Thermal Emittance, ε.	A material's thermal emittance determines how much heat is radiated per unit area at given temperature. A high emittance surface gives off its heat more readily.

Urban Canyon Geometry	Urban Canyon Geometry describes the urban morphology; its layout, dimension and spacing of the buildings within a city and it influences the absorption of heat by the pavements and other infrastructure.
Urbanization	Urbanization is understood as the growth in the proportion of the population living in urban areas. In fact, urban population has increased from 160 million to about 3 billion in just 100 years, and it is expected to increase to about 5 billion by 2025 [8]. As an indication of the impact of urbanization, almost 60% of world population living in the city enhances the derogatory environment effects.

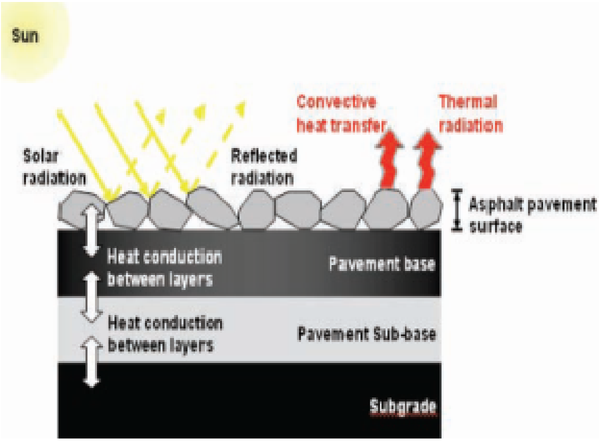

Figure 3: Heat transfer processes from and within a pavement [10]

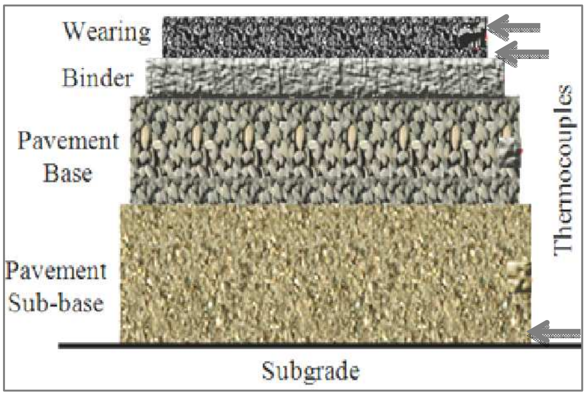

Figure 4: The asphalt pavement structure and location of thermocouples

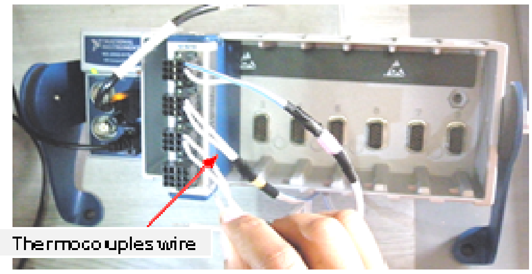

Figure 5: NI 9219 data logger.

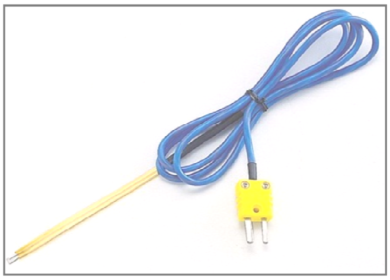

Figure 6: Apparatus for thermocouple

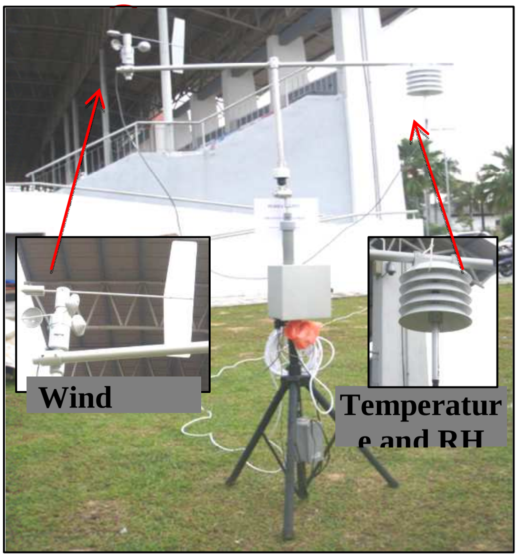

Figure 7: E-Sampler Equipment installed at site.

Figure 8: Instrumented Road Pavement Test Site – Aggregate Industries UK [6].

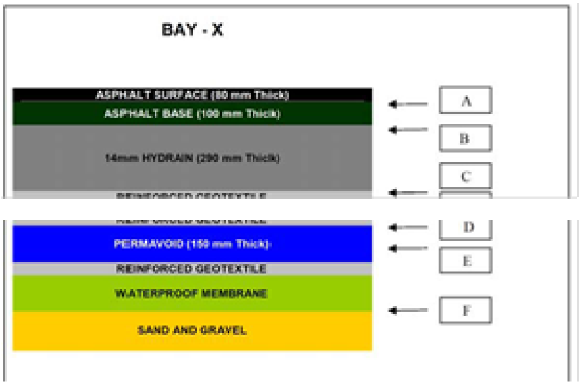

Figure 9: Cross section details of the pavement in Bay X.

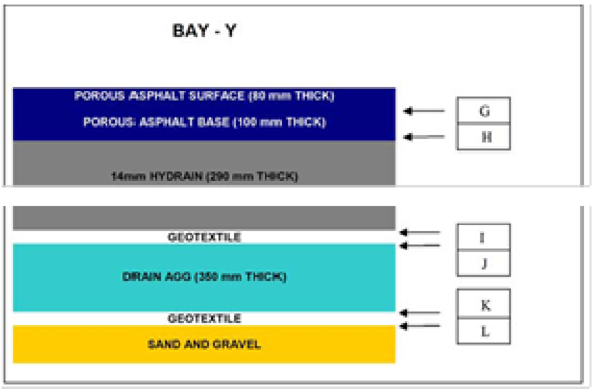

Figure 10: Cross section details of the pavement in Bay Y

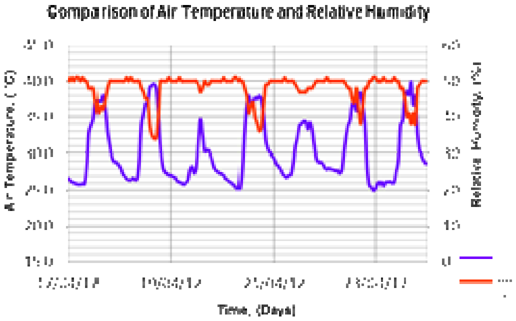

Figure 11: Comparison of Air Temperature at 2 m Height and Relative Humidity Profile.

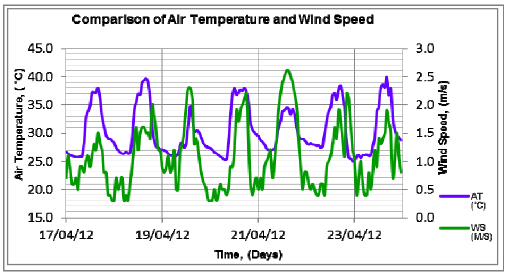

Figure 12: Comparison of Air Temperature at 2 m Height and Wind Speed Profile

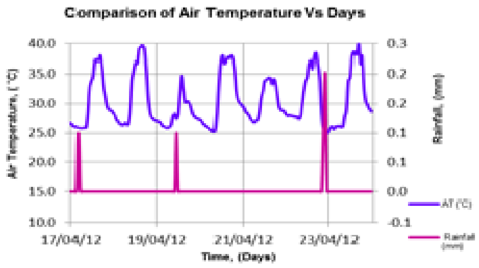

Figure 13: Comparison of Air Temperature at 2 m Height and Rainfall Profile.

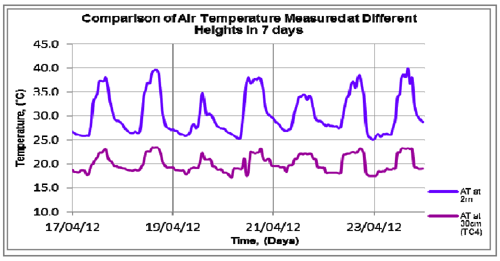

Figure 14: Comparison of Air Temperature at 2 m Height and 30cm Height

Table 2: Water Table Observation

Day	Date	RW (27.0m from thermocouples point), (cm)	Corrected Depth after levelling work,(cm)
1	**17/04/2012**	**12.0**	**17.0**
2	**18/04/2012**	**13.0**	**18.0**
3	**19/04/2012**	**14.0**	**19.0**
4	**20/04/2012**	**14.0**	**19.0**
5	**21/04/2012**	**14.0**	**19.0**
6	**22/04/2012**	**14.5**	**19.5**
7	**23/04/2012**	**15.0**	**20.0**

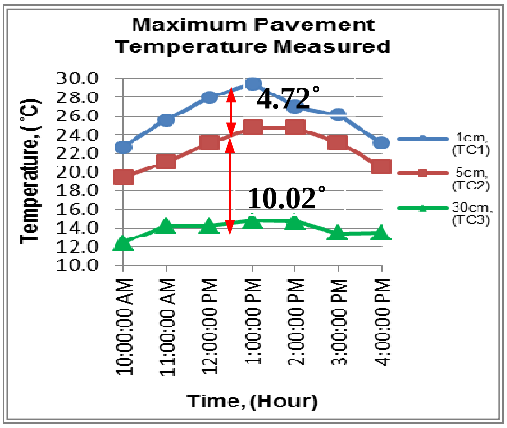

Figure 15: Comparison of Maximum Temperature in different layers of Asphalt Pavement.

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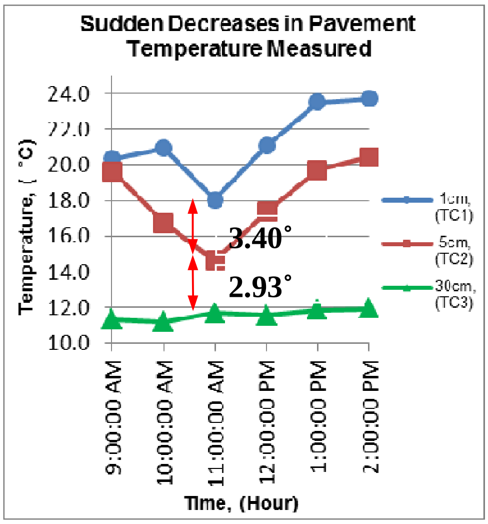

Figure 16: Comparison of Sudden Temperature Drop in different layers of Asphalt Pavement.

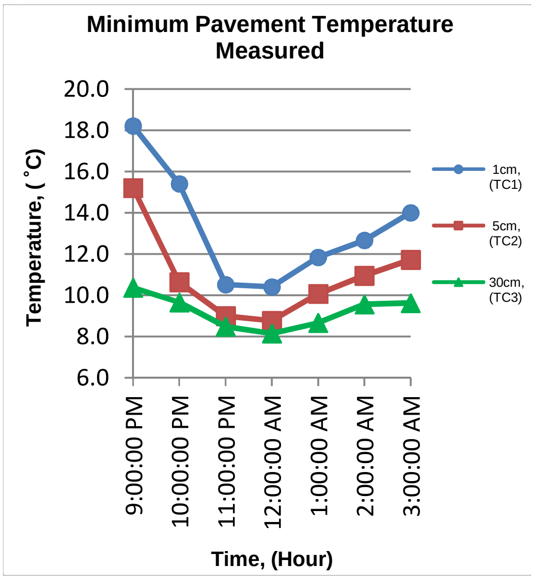

Figure 17: Comparison of Minimum Temperature in different layers of Asphalt Pavement

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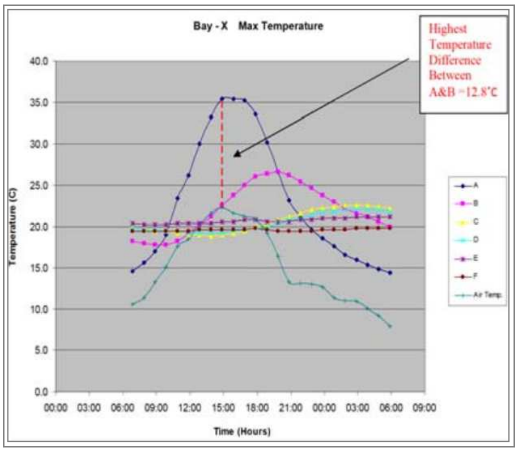

Figure 18: Temperature Vs Time on 14-15 August, Bay - X.

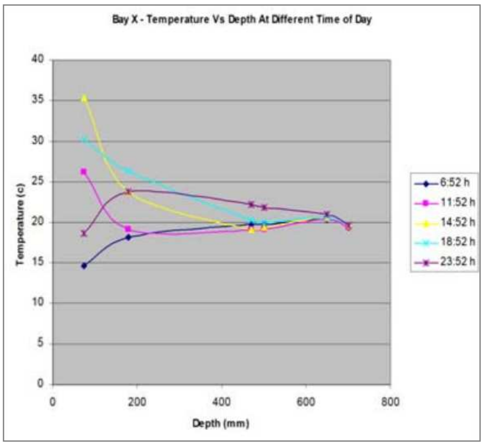

Figure 19: Temperature Variation Vs the Depth of Pavement at different time of the day for Bay – X

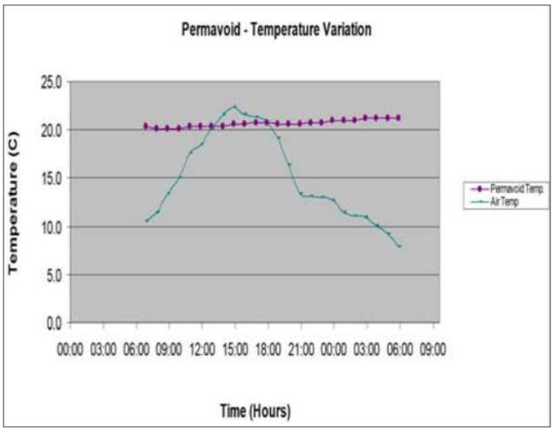

Figure 20: Temperature Variation for Permavoid and Air on 14-15 August, Bay - X.

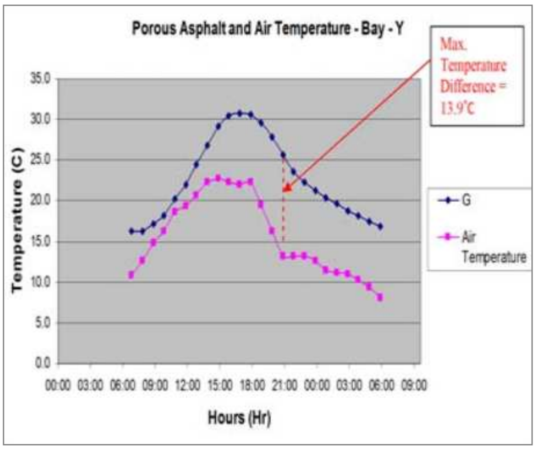

Figure 21: Normal Asphalt and Air Temperature Variation on 14-15 August, Bay –X.

Urban Heat Island

Fig. 2 is an image of the Land Surface Temperature (LST) distribution over the London area as observed on 7th August 2009. Fractional vegetation cover modulates the proportions of vegetation and ground visible to a sensor. The temperature differences (generated by the radiated thermal energy) between the vegetation canopy and the ground affect the measurement of LST. In non vegetated areas, LST measurements typically represent the radiometric temperature levels of bare soil. With increasing amounts of vegetation cover, the temperature levels recorded by a LST sensor reflect more closely the temperatures of green leaves, and the canopy temperature. Therefore such LST observations need to be carefully scrutinized to separate the contributions from each part of the hybrid shaded and sunny vegetation-ground system. For any surface material, certain thermal properties, such as heat capacity, thermal conductivity and thermal inertia, significantly govern the transient temperature state of a body with its surroundings. These thermal properties vary with soil type and its moisture content. Dry, bare, and low-density soils have a relatively low thermal inertia. The thermal emissivity (via the combined thermal processes of conduction, convection and radiation) of soils is also dependent on soil moisture conditions and the density.

Though the temperature differences between the urban and countryside regions is obviously evident at midday, the UHI effect causes the greatest temperature difference to occur two to three hours after sunset. The latter effect results from the gradual release of the heat stored during the day by the asphalt and concrete structures. Most building materials are impermeable and watertight, which does not therefore facilitate the ready dissipation of the sun's heat. Dark Construction materials in concert with canyon like configurations of buildings and pavements collect and trap more of the sun's energy. Temperatures of dry dark surfaces exposed to direct sun light can reach up to 88ºC during the day, whereas the vegetated surfaces with moist soil under similar conditions might reach only 18ºC. Anthropogenic heat or human produced heat, slower wind speeds and air pollution in urban areas also contribute to heat island formation [5].

Pavement effect on urban heat island (UHI)

Heat transfer in asphalt pavement involves different processes of thermodynamics (refer to Fig. 3). In addition to the processes, there are thermophysical properties, such as solar radiation, solar reflectance (albedo) material heat capacities, surface roughness, heat transfer rates, thermal emittance and permeability that contribute to UHI [6].

Permeability and volumetric heat capacity of pavement layers greatly influence its heat exchange. Impermeable pavements reduce evaporation. The high heat capacity causes negligible flow of water or cooling air through them. These generate high night time air temperatures described as a nocturnal urban heat island [11]. Average summer temperatures are predicted to increase by 2.5^o to 3^o C by the 2050s together with a high CO2 emissions scenario leading to an increase of 5-10 days per year of exceptionally hot days (>30^oC). This hotter air contributes to the acceleration of smog (ozone) production, which is a major health and environmental concern [12].

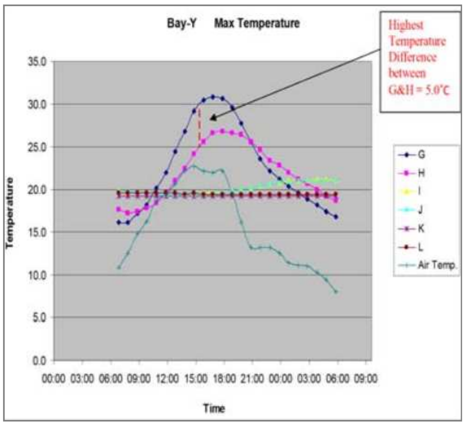

Figure 22: Temperature Vs Time on 14-15 August, Bay – Y.

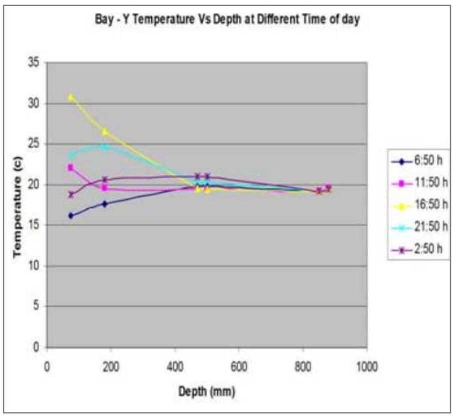

Figure 23: Temperature Variation Vs the Depth of Pavement at different time of the day for Bay - Y.

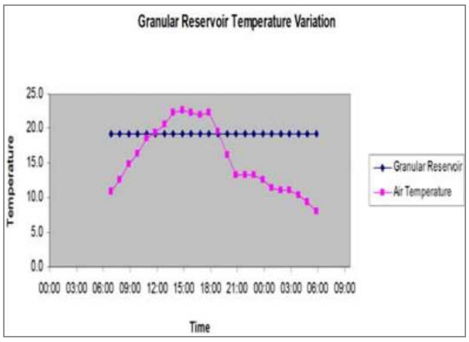

Figure 24: Temperature Variation for Granular Reservoir and Air on 14-15 August, Bay - Y.

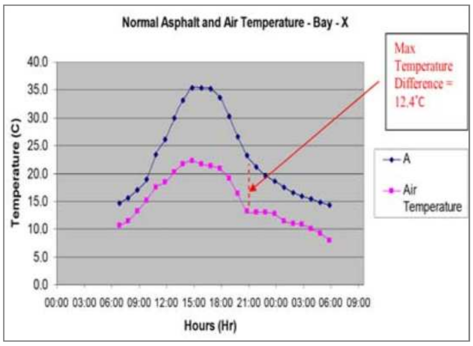

Figure 25: Porous Asphalt and Air Temperature Variation on 14-15 August, Bay – Y.

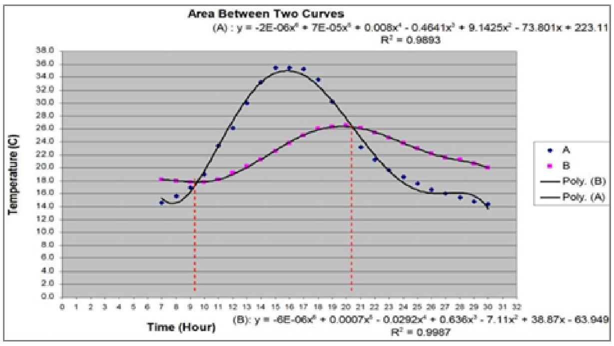

Figure 26: Curve fitting and Equation of Curves for top Asphalt layers, Bay – X

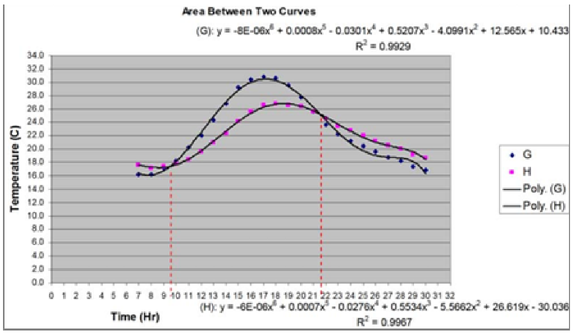

Figure 27: Curve fitting and Equation of Curves for Top Porous Asphalt layers, Bay – Y

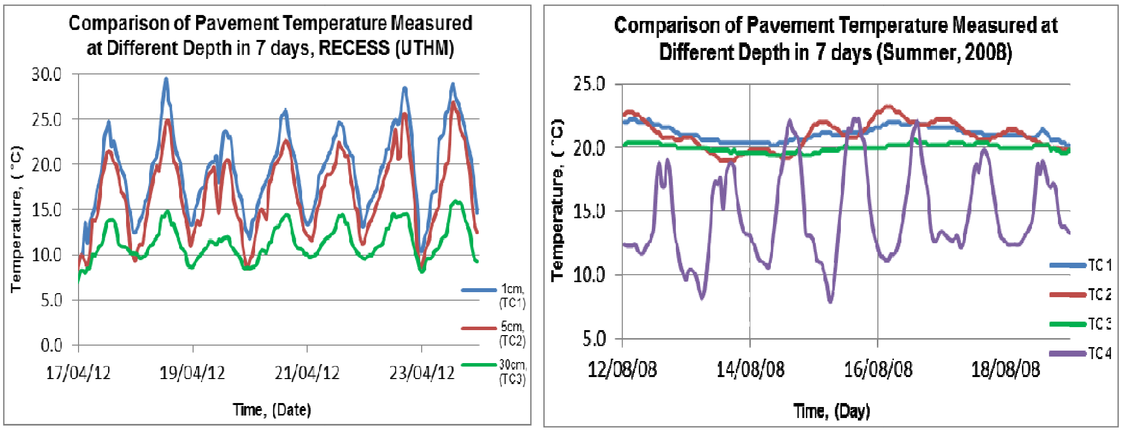

Figure 28: Comparison of Asphalt Pavement Temperature between RECESS, UTHM and UK (summer data).

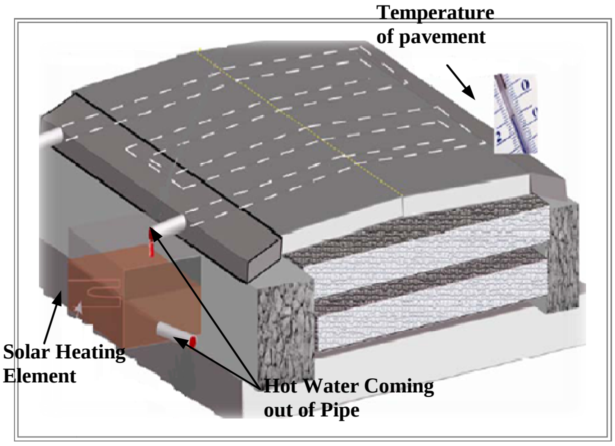

Figure 29: Concept of harvesting energy from Pavements and Reducing Pavement Temperature [13].

Shady tree canopies retard the solar radiation from reaching the asphalt pavement. Grass or plants utilize solar radiation for evapo-transpiration. Contrastingly, bare asphalt pavement surfaces absorb heat and then radiate the heat back to the atmosphere leading to an increased temperature of the air around asphalt pavement surfaces which contributes to the urban heat island effect. According to Freed [7] asphalt poses problems such as: (a) Asphalt is made of a non-renewable resource. (b) On a hot day, an asphalt parking lot can increase the temperature around a building by up to 8°C. (c) When rainwater hits asphalt, toxic chemicals soak into the water polluting it.

METHODOLOGY ADOPTED IN THE RESEARCH

Full scale field monitoring was carried out focussing on temperature distribution within asphalt pavement layers in order to get a better understanding of the UHI and asphalt pavement behaviour. This involved installation of thermocouples in the pavement fabric and a data logger for periodic logging enabled through LabVIEW programming at the test sites located in two different climates.

TEST SITE IN A TROPICAL CLIMATE; RECESS, JOHOR, MALAYSIA

Thermocouple sensors were installed in the 10m buffer zone (standard asphalt pavement without any further additional materials or layers), on the research test road in RECESS. Fig. 4 shows the layering within this standard asphalt pavement comprising of the wearing course, binder course, base course and sub base course.

In addition to the thermocouples a rain gauge and E-sampler was used at the site with continuous data logging. All these apparatus were appropriately calibrated and checked regularly to avoid inaccuracies. The data logger contained a Universal Analogue Input Module (NI 9219) supplied by National Instruments. This is an electronic device that recorded data every 1 hour over the whole time (Fig. 5). Generally data loggers are small, battery powered, portable, and equipped with a microprocessor, internal memory for data storage, and sensors. In this study, the data logger was used to record the temperature data at various depths of the asphalt pavement.

Fig. 6 shows thermocouples used as the thermal sensor (refer to Fig. 6). An advantage of thermocouples is that the sensing elements were very small, allowing thermocouples to be inserted into very small spaces so that a rapid response of localised temperature changes was obtained. The data logging Rain Gauge used was battery-powered and enabled rainfall data collection with a recording system which included the HOBO Pendant Event software. The E-Sampler provided real-time particulate measurement through near-forward light scattering to gather environmental data such as air temperature, relative humidity and wind speed. When installed on the standard tripod, the E-Sampler inlet was positioned two meters above the ground. The E-Sampler inlet was located at a position, one meter radius away from any other objects that may influence airflow characteristic, including other field instruments (see Fig. 7).

The research test road pavement in RECESS consisted of several sections with different materials installed in the pavement layers. Therefore, the authors chose a site in the 10m buffer zone so that reliable and representative temperature data from a typical asphalt pavement was acquired. Thermocouples were embedded into the pavement at depths of 10mm, 50mm and 300mm (subgrade-virgin ground). A further important environmental aspect that was monitored at the site was the ground water level using monitoring wells. The local ground water level is very high and near to the ground surface.

TEST SITE IN A TEMPERATE CLIMATE; AGGREGATE INDUSTRIES (UK) LTD., LEICESTERSHIRE, UK

Wijeyesekera et. al [6] describes the field monitoring of the urban heat island levels within an array of different pavement materials. It consisted of 5 different test pavement bays constructed at the Aggregate Industries (UK) site. The temperature distributions within the test bays (see Fig. 8) were data logged continuously to accommodate the UHI monitoring. The heat flow characteristics through the pavement constituents, including thermal energy input and output were also assessed.

In this study too, temperature sensors in the form of thermocouples were located at the boundaries of the various pavement fabrics. The finding of the UK study showed that the temperatures within the pavement layers remain consistently higher than that of the air temperature which is conventionally measured at a height of 2m above ground surface. There was also observed evidence that the porous pavement fabrics had low thermal storage with indications of up to 60% reductions in thermal gradients.

UHI monitoring was carried out at the road pavement testing site from August 2008 to February 2009 at the Aggregate Industries Research Centre based in Hulland Ward, UK (Fig. 8). Two out of five different pavement bays made of dissimilar traditional and sustainable materials were analysed to study the influence of the different material used (Fig. 9 and 10). Sustainable materials including Charcon Permavoid, Hydrain granular gravel reservoir bed, reinforced and unreinforced geotextiles were used in these test bays as portable thermal barriers and porous layers to identify the effectiveness and influence on UHI. Charcon Permavoid is a plastic open geocellular load bearing structure while Hydrain is a porous concrete. The asphalt surface and asphalt base were dense impermeable asphalt. Temperature sensors in the form of thermocouples were located at the boundaries of the various pavement fabrics. Thermocouples were read hourly and data logged continuously from August 2008. Some of these observations are discussed in this paper.

RESULTS AND DISCUSSIONS

Comparison of Air Temperature at 2 m Height and Relative Humidity Profile

Fig. 11 illustrates the results from this investigation to correlate between air temperatures and relative humidity measured over seven days. The lower solid (blue) line shows the fluctuations of the air temperature while the upper solid (red) line represents the corresponding variation of relative humidity. The highest air temperature, recorded was

39.6^{o} C on 18.04.2012 at 4.00 pm. The lowest air temperature recorded was 25.0˚C on 22.04.2012 at 11.00pm. The fluctuations in relative humidity are clearly contrary in direction to the air temperature variation. The average relative humidity obtained was 51 per cent over this seven day period and the lowest relative humidity was 34 per cent (as observed on 18.04.2012 at 4.00 pm and 5.00 pm). Furthermore, the profiles show that as the air temperature dropped after 7.00 pm with sunset while the relative humidity readings were shown to remain constant, with an average relative humidity between 49 and 51 per cent as the air could not hold any more moisture.

Comparison of Air Temperature at 2 m Height and Wind Speed Profile

Fig. 12 shows the comparison of the air temperature with wind speed over the same observation period of seven days. Typical observations made on 21.04.2012 from 10.00 am to 7.00pm showed the wind speed to be in the range from 1.9 m/s to 2.6 m/s as the air temperature remained relatively moderate between 30.9 ˚C to 34.4 ˚C. However on 18.04.2012 the air temperature recorded was high in the range 33.9 ˚C to 39.6 ˚C but there was no apparent change in wind speed which showed an average speed of around 1.2 to 1.6 m/s.

Comparison of Air Temperature at 2 m Height and Rainfall Profile

Fig. 13 showed a drastic drop in air temperature followed by a recorded rainfall. Typically, on 22.04.2012 there was a sudden drop in air temperature resulting from 0.2mm rainfall. This approximate 0.9˚C fall in air temperature can be attributed to the rainfall. Rain does the cool the environment with the cooling of the ground and the environs.

Comparison of Air Temperature measured at 2 m Height and 30cm Height

The air temperatures were measured at 2 different heights; 30cm and 2 m above the ground (see Fig. 14). During the seven days of observations discussed in this paper, it showed that air temperature at 2 m is always higher than air temperature at 30cm regardless of whether it is during the daytime or night time. It is known that in the absence of any other constraints hot air rises. The authors believe that in addition during this test period there were occasions when the testing area was flooded during rainy days due to the low permeability sub base, high water table and also there being no densely spaced buildings in the vicinity. These factors kept the air temperature at 30cm at a relatively lower range of 17˚C to 24˚C. Contrastingly, the air temperature at 2m height was always higher than that measured at 30cm height even at night with an average range of 25˚C to 40˚C. As a conclusion, the authors are prone to believe that this test area does not pose an Urban Heat Island problem as the air temperature at 30cm height is consistently lower than that at 2m height. This is because the root cause of Urban Heat Island effects on the built environment is that the absorbed heat from the sun during daytime will be released back to the surrounding environment and warms the ambient air temperature near to the asphalt pavement at night.

Monitoring Wells –Observation of Water Table

In this study, it was very important to check the variations in the ground water level every day to consider its influence on the pavement temperature. The RECESS site has a high water table. An initial plan was to make an observation well on the pavement itself for monitoring the water table. However, the authors faced difficulty such as the research road was intermittently flooded and it was hard to obtain reliable measurements since the hole would then always be filled with water. Therefore, the water table measurements were taken from existing monitoring wells in RECESS. Since the the distance between the thermocouples points on the test road and the monitoring well was 27 m, appropriate corrections were made to the observations. From the observation made over these seven days, it was concluded that the water table depth ranged between 17cm to 20cm (Table 2) which is actually less than the 30cm depth (asphalt pavement thickness). This means that the water table could have significantly affected the asphalt pavement temperature.

Comparison of Maximum Temperature in Asphalt Pavement

Fig. 15 is a temperature distribution profile in the asphalt pavement over the seven days observation made at depths; 1cm (asphalt), 5cm (asphalt) and 30cm (original ground). The day 2 observations gave a very high temperature profile; at 1cm (29.51˚C), 5cm (24.79˚C) and 30 (14.77 ˚C). The temperature difference between 1cm and 5cm layers is about 4.72˚C (in a 4cm thickness of asphalt pavement). Meanwhile in comparison with the observations at 5cm and 30cm showed a10.02˚C difference (in 25cm thickness) change in temperature of asphalt pavement). This clearly showed that asphalt layer stored more heat than the crusher run layer as the albedo characteristic of asphalt ranged from 0.05 – 0.20.

Field Monitoring; RECESS - Analysis of Asphalt Pavement Temperature within the Pavement Layers

Relating these profiles with the environmental data gathered; typically on 18.04.2012 at 1.00 pm shows that the air temperature at 2 m height was very high

(36.8˚C), the air temperature at 30cm height was 22.54˚C with a Relative Humidity of around 45 per cent and the wind speed was 1.5 m/s. With moderate Relative Humidity and wind speed reading (and additionally with no rainfall recorded) these environmental parameters did help to maintain constant the high temperature through out the afternoon. However, the temperature started to drop at 7 pm (20.59˚C) when the sunset occurred.

Sudden Temperature Drop in Asphalt Pavement.

There was a sudden drop in asphalt pavement temperature monitored (Fig. 16) on a typical day, 19.04.2012 at 11.00 am. At 1 cm depth, the temperature recorded was 18.04˚C with a 2.89˚C temperature drop. Meanwhile for 5 cm depth, the temperature was 14.64˚C with a 5.00˚C of temperature drop. However, at the 30 cm depth (original ground- subgrade), there was no significant change in temperature. The temperature difference between 1 cm and 5 cm (4cm thickness of asphalt pavement) was about 3.40˚C, while that between 5cm and 30 cm layers (25cm thickness of asphalt pavement), was only 2.93˚C. The environmental records showed that there was a rainfall of 0.1mm at 11.00 am. This rainfall caused the air temperature at 2 m height to drop to 27.4˚C (with a drop of 0.9˚C) and the air temperature at 30cm height was 19.12˚C (drop of 0.12˚C). The air temperature at 30cm height did not show much change due to the release of the stored heat from the asphalt pavement back into its vicinity as the rain cooled the pavement. Furthermore, the relative humidity and wind speed which were high at 50 per cent and 1.6 m/s which respectively did actually help in cooling the surrounding area.

A Further Sudden Temperature Drop in Asphalt Pavement

Fig. 17 shows the minimum asphalt pavement temperature measured within the seven day period of observations. The minimum temperature recorded was on 23.04.2012 at 12.00 am as the temperature at 1 cm depth was 10.40˚C**,** 5 cm depth was 8.76 cm and at 30 cm (original ground) was 8.16˚C. The differences between 1 cm and 5 cm (4cm thickness of asphalt pavement) was 1.64˚C, while between the 5cm and 30 cm layers (25cm thickness of asphalt pavement), the temperature difference was only 0.6˚C. The air temperature at 2 m height was 25.2˚C and the air temperature at 30cm height was 17.49˚C which was relatively low compared to other air temperatures recorded over the seven days of monitoring. The relative humidity at 12.00 am was at a maximum of 51 per cent showing that the air contained more moisture as the wind speed also showed a low speed of only 1.0 m/s. The cause for the temperature of the asphalt pavement and air to be low was that a heavy rainfall of up to 0.3mm fell on 22.04.2012 from 9.00 pm to 11.00 pm (earlier that night). This heavy rainfall managed to keep all temperature consistently low throughout the night.

Field Observations from Aggregate Industries (UK) Ltd test site in Leicestershire, UK

Analysis Of Field Test Data Of Pavement Bays X And Y

Figures 18 to 27 show observations of the temperature variation at different locations for the pavement bays – X and Y respectively. Thermocouples referenced A, B, C, D, E, and F are from bay – X, whereas thermocouples C, D, E, F, G, and H are from bay – Y. These figures the maximum temperature of the asphalt surface in bay – X reached a value of 35.4 ˚C which is higher than the 30.8˚C for bay - Y. This observation showed that normal asphalt layers are readily susceptible to solar radiation and allow heat conduction quickly, and that the normal asphalt layer also started gaining and storing the energy at higher rate than porous asphalt.

Materials used in both test bays had different thermophysical properties and therefore their response to heat gain-loss is different and depends on these properties. From the observations, it can be further envisaged that even though some of the layers are common between these two bays, use of pervious layers has significant importance for reducing overall pavement temperature. Consequently effects of pavement in UHI can be reduced and may help to alleviate the urban heat island effects. The pervious layers used in both bays are porous asphalt, granular reservoir bed, permavoid, reinforced geotextile, geotextile and porous concrete layer. Combined effects of two or more permeable media under the traditional normal and porous asphalt represent distinct performance differences under the different environmental condition. Individual effects of each material alone would have positive impact on air temperature; but here as in actual practice, the effects, when combined with other pavement layers, has been investigated.

The analysis carried out here showed that the use of other porous layers such as reinforced geotextile, geotextile, and porous concrete helps to lower the heat storage in the lower part of the pavement bay. Reinforced geotextile and geotextile are generally used as infiltration layer above and below porous media to filter the solid allowing the water to pass quickly through porous media. It can be indentified from Fig. 20 and 24 that until the evening, these porous layers did not show any signs of absorbing large amount of heat and at later stage in the evening, they attempt to gain as little energy as possible from layers above and remain at reasonably constant temperature.

It means these layers have lower heat levels than any other materials but again their effect is based on their usage with different type of other pavement materials. Permavoid is used as a porous layer in bay – X. Permavoid is made from base material of polypropylene and it is a pre-formed geocellular sub-base replacement unit used as a storm water management system.

Fig. 22 shows that this layer appears to be useful in reducing heat gain and storage because it has not shown much temperature fluctuation (20.2˚C to 21.2˚C) during the worst day in August. Similarly, the Granular Gravel bed, used as a porous medium in bay – Y, also revealed a comparatively better thermal performance (see Fig. 26). The temperature in the granular bed remained constant (19.2˚C) throughout the day. This layer is made of open graded-uniform sized aggregate and therefore it has a high volume of voids and it can also retain a high volume of water (compare the high ground water table effect in RECESS). This ultimately helps to replace hot air trapped inside the void with water and thereby maintain a reasonably constant temperature for a long time.

Figures 28 and 29 represent the area between two curves for bay – X and for bay – Y respectively. An area calculation of these two curves helps to evaluate the thermal conductivity of each bay. The calculated thermal conductivity (k) for bay – X is 1.42 W/m.˚C while for bay – Y, it is 2.30 W/m.˚C. The thermal conductivity calculated in this way clearly shows that normal asphalt has lower thermal conductivity than that of porous asphalt. It means that the denser asphalt layer retains the energy for long time, once it is absorbed from solar radiation and takes long time to cool again causing higher night time heat island effect.

Comparison of asphalt pavement temperature observations made in Malaysia and UK (summer)

RECESS (UTHM, Malaysia) has average temperature ranging between 22 ˚C to 32˚C with an annual rainfall intensity averaging 200 cm to 250 cm. Solar energy can be utilised in tropical countries like Malaysia because of the high reception of solar radiation. Optimum temperature, sufficient sunshine and urban development always keeps the asphalt pavement temperature high even at night. The pavement temperature at different depths measured over seven days of site monitoring showed that the temperature near the asphalt surface (1 cm depth) was always higher than other asphalt layers with a maximum temperature of 29.51˚C observed on 18/04/2012 and minimum temperature, 10.40˚C recorded on 23.042012. Overall, average temperatures of asphalt pavement in all layers of asphalt pavement in RECESS were above 10˚C. This is because during the day time the solar radiated and asphalt pavement stored heat while during the night time when the surrounding temperature started to drop the heat was emitted back to the atmosphere which keeps the temperature near the asphalt surface slightly higher even at night. However, it was also noted that the air temperature at 2m height was always higher than the air temperature at 30 cm and temperature of asphalt pavement at 1 cm depth.

Aggregates Industries, UK is located in a temperate climate. The site was windy and without excessive temperatures. This means that it had mild temperatures not much lower than 0ºC in winter and not much higher than 32ºC in summer. During summer in August, the mean daily duration of sunshine is six hours with an average temperature ranging from 12˚C to 21˚C. Temperature observation from the summer season was chosen so as to compare with temperature in RECESS because the temperature profile in summer ranged from 5˚C to 25˚C almost similar with RECESS temperature observed ranging at 5˚C to 30˚C. However only the air temperature shows fluctuations between 7˚C to 22˚C compared to the other 3 layers (Thermal Couple 1, 2 and 3) consistently ranging high between 18˚C to 23˚C. From the analysis the authors can conclude that UK did actually face UHI effects as the pavement temperature is always higher than the air temperature at 1.5m height. Besides, the pavement layer temperatures always remained high and did not show much change in temperature between day time and night time.

Recycling Urban Heat Island (UHI) - Energy Capturing

The search and growth of interest in new alternative and renewable sources of energy should be focussed on utilising the vast amounts of solar energy that can be captured from heated roads which has a larger catchment than the currently targeted solar panels that are fitted on roofs. The black top asphalt has been shown in this study to have excellent storage capacity for solar thermal energy.The concept of using differential temperatures for thermoelectric generators using the solar thermal energy in Highway Road pavements is another direction for further thought.

Harvesting Energy from Asphalt Pavement and Reducing the Heat Island Effect is a concept introduced by Chen et al [13] with an appropriate fluid flow through a network of pipes below the asphalt pavement to reduce the temperature of the asphalt pavement. Even small efforts to control the heat transfer from the pavement have a valuable benefit on environment sustainability. Using fluid in pipes to harvest energy (heat) from asphalt pavements thus reducing the temperature of the pavement is outlined in Fig. 29. Circulating an appropriate fluid through a network of pipes below the asphalt pavement will help to reduce the temperature of the asphalt pavement and at the same time reduce the amount of heat that is radiated back from the pavement surface to the atmosphere.

Reducing the asphalt temperature gives longevity for the useful life of the road and deters premature wearing surface failures.

It is also gives an improvement to the air quality and Urban Heat Island Effect. Furthermore, this concept will extend the life of the pavement meanwhile lower temperature of the near surface air will lead to savings in energy consumption of adjacent buildings. The material of the heat exchanger system which consists of pipes should have a high conductivity and the layout should be such as to allow the exposure of the pipes to the pavement for sufficient length to allow the fluid to reach the maximum temperature achievable in the system.

The working fluid inside the pipe should be fluid that can be pumped easily, absorb energy quickly and should ideally have a low boiling point. Initial temperature of the fluid should be low enough, in comparison to the temperature of the pavement, such that the there is significant difference between the two, and hence a significant rate of flow of heat into the fluid. The energy that is captured from the pavement is in the form of heat energy.

CONCLUSIONS

RECESS, Johor, Malaysia

Basically the profile of temperature distribution monitored for seven days in asphalt pavement at RECESS (UTHM) showed that temperature near the asphalt surface (1 cm depth) was always higher than that at 5cm and 30 cm depth. Maximum temperature differences between 1cm and 5cm layers are about 4.72˚C in 4cm thickness of asphalt pavement. However, comparison between 5cm and 30cm show that there is a 10.02˚C change in temperature of asphalt pavement for 25cm thickness of pavement. This clearly showed that an asphalt layer which is black in colour has high tendency to absorb more heat during the daytime compared to other layers.

The stored heat will be released back to the surrounding environment at night and supposedly causes higher air temperature at 30cm height from the ground throughout the day compare to air temperature at 2 m height due to more clear circulation of air movement.

It cannot be denied that the presence of other climatic parameters such as relative humidity, wind speed and rainfall did influence the temperature readings of the pavement. The most important one was the high ground water level at RECESS helped keep the temperature constant below the water table depth and also influenced the asphalt pavement temperature.

Aggregate Industries, Leicestershire, UK

The use of sustainable materials creates the platform for protecting the environment, which would otherwise adversely affect the urban heat island events in the coming years. Higher temperatures in urban areas due to the traditional impermeable pavements support the formation of ground level ozone and smog, resulting in human discomforts and serious health problem. The analysis of the granular gravel reservoir bed indicates that there is no sign of heat storage in this layer and it denotes constant temperature value throughout the day. And therefore its use as heat barrier and as a storm water retention basin can be envisaged in the porous pavement construction and it can be one sustainable measure to mitigate urban heat island effect. Permavoid is a renewable material and can also be considered as a heat barrier to alleviate heat storage in the pavement.

Bay – X includes layers of permavoid and other porous materials but the top layer is formed of normal impermeable asphalt and therefore it shows higher temperature near the surface of pavement than that of bay – Y. The porous pavement such as bay – Y, which includes the granular gravel reservoir bed, not only reduces the temperature but also acts as a recharge bed for stormwater. Consequently, it helps increase evaporation, replacing the process of heat release, back to the atmosphere around the pavement. Therefore, bay – Y performed better in the efforts to abate the urban heat island effect especially in an area like London where highly populated land is being increasingly covered by engineered paved surface. Even small efforts to control the heat transfer from the pavement can have a valuable benefit.

During the summer season, UK does meet with UHI effects as the pavement temperature is always higher than the air temperature at 2 m height. The temperature difference between pavement layers for UK always remains high and did not change significantly between day time and night time. This is actually a basic characteristic of UHI effect as the temperature of the pavement is higher than the surrounding. It is projected that by the middle of the century, the average summer will be as hot as a heatwave (defined as hotter than 32°C) today (Nickson, 2011). For RECESS site testing, the pavement did not apparently contribute much to the surrounding temperature.

The authors believe there is potential of harvesting stored energy from the asphalt pavements, as a new source of alternative energy that will benefit the human life. In other words reducing the asphalt temperature helps to improvement the air quality and Urban Heat Island Effect.

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