PASSIVE COOLING OF PAVEMENTS AS A PANACEA FOR MITIGATING URBAN HEAT ISLAND

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Abstract: Urban cities can be several degrees warmer than surrounding regions due to the built environment and concentration of human activities; a phenomenon known as Urban Heat Island. Pavements made of heat absorption materials are one of the major contributors to this effect by altering natural land cover over significant portions of the urban area. This research presents an experimental study aimed at evaluating the effect of water on outdoor pavements as a strategy to mitigate the rise in surface temperatures of pavements. The experiment quantify the thermal performance of three commonly used pavement materials within the study area before and after water was applied with respect to their surface temperature, air temperature and relative humidity above the pavement surface. These variables were observed manually using the Infrared thermometer and the Kestrel weather tracker. The data obtained were analyzed using statistical techniques. Results show that the surface temperature of the three pavements sampled were most elevated during the day, Asphalt was observed to be the hottest material with an average surface temperature of 58.28^{0}C, Interlocking concrete tiles was next with 44.14^{0}C and clay bricks was the coolest material at 39.87^{0}C. The evaporation rate from the wet surface was most rapid during the day; it took 20 min for asphalt, 30 min for interlocking concrete tiles, and 40 min for clay tiles. A significant difference in surface temperature was observed on all samples. However, asphalt was seen to have the best performance after water was applied; with a temperature difference of 12^{0}C. Thus this` study concluded that the surface temperature of pavement samples is significantly cooler in presence of water. In other words different pavements have different evaporation rates and classifying outdoor materials in terms of cooling effect is useful and will aid in mitigating heat gains of pavements.

Keywords: Panacea, passive cooling, urban heat Island

Introduction

Environmental pollution assessment in recent times is a consequence of the degradation of water environment, thermal environment and contamination in urban areas (Taniguchi *et al.,* 2009). Findings have shown that urban heat island in particular has become a serious environmental problem; with the expansion of cities and industrial areas all around the world (Oke, 1987; Golden, 2003). This phenomenon is a consequence of the nature of the fabric of cities; which are cladded with materials that absorb large amounts of solar heat radiation and release to the atmosphere ((Pomerantz *et al.*, 2000; Santamouris *et al*., 2008). The excess heat has become a tough and critical issue leading to thermal imbalance of the environment and high demand of passive cooling systems. There is a need therefore; to improve the urban fabric with new technologies for energy saving and improved thermal comfort (Naticchia *et al.,* 2010). Studies have shown Pavement materials heavily influence outdoor thermal environment (Lin *et al.*, 2007; Santamouris *et al.*, 2011; Asaeda & Ca, 2000; Didel & Ossen, 2011; Tan & Fwa, 1992; Pomerantz, *et al.*, 2000). They conceal about 25 - 30 percent of the urban land mark and conventionally get to a surface temperature of 48 to 67^{0}C (Pomerantz *et al.*, 2000; Doulos *et al.*, 2001; EPA, 2009). The heat rises up the ambient air and transfer to the overlying atmosphere. However, since expansion of the paved surface are inevitable within cities, feasible means of improving the thermal properties of pavements by minimizing the solar heat gains and maximizing heat loss of cities can never be overemphasized (Santamouris *et al.*, 2008) This include: the use of high reflective materials to reduce albedo of cities (Doulos *et al.*, 2001), and increasing the permeability of pavements which induce evaporation similar to evapotranspiration in plants (Santamouris *et al.*, 2011;Gartland, 2008). The evaporation of water provides an important counter to the heating effect, and so open parks and water surfaces are vital in urban areas for creating urban cool-island (Sproken-Smitt & Oke, 1999; Carrasco *et al.*, 1989).

Permeable pavements which allow the passage of water to the soil below induces evaporation to the atmosphere; this occurs as part of the net downward radiation is converted into latent heat , similar to the phenomenon which occurs on natural surfaces covered by bare soil or vegetation (Asaeda & Ca, 2000). This means that the temperature of permeable paved surfaces does not escalate as much and subsequently the underground heat storage and sensible heat exchange between the ground surface and atmospheres are lessened. It is evident however that most of urban fabrics are conventionally impermeable surfaces with high heat absorption capacities; the idea of retrofitting to the cooler permeable surfaces may not be feasible. Studies by Carrasco, *et al.* (1989) used a roof spray cooling system set up on an impermeable roof top; experiments were conducted to compare the sprayed and unsprayed conditions on the roof surface temperature. Results show that there was 60% reduction in the heat transfer through the roof and also a reduction in the indoor temperature. Further studies by Naticchia, *et al.* (2010) developed a water sprinkling system which was capable of reducing heat gains on impermeable walls. A proper insulating layer setup acted as a porous surface to store water sprayed by the system and then gradually release it when needed for cooling. The experimental analysis showed a decrease in the summer energy load on buildings by cancelling conduction loads. For the purpose of this paper the water sprinkling medium was employed on impermeable paved surfaces as a passive cooling medium to determine the cooling effect of water on the surface temperature of pavements and to mitigate the solar heat gains on pavement.

Materials and Methods

Field experiments were conducted from October 2010 - November 2010 at Universiti Teknologi Malaysia, located 20 km north of Johor Bahru ($1^0$29'N - $103^0$44'E of the equator). The experiment involved three samples of pavement materials used within the premises; Asphalt, Interlocking Concrete tiles and Terracotta Clay bricks. The experiment aimed at evaluating the thermal performance of the various materials and the cooling effect of water on the surface temperature. The samples were at different locations within the study area and the layouts of the samples are depicted in Fig. 1.

The surface temperature and metrological conditions such as air temperature and relative humidity were measured physically using the infrared thermometer and the kestrel weather tracker. The experimental apparatus are listed in Table 1.

A. Interlocking tiles B. Terracotta clay tiles C. Asphalt

Figure 1: Layout of the pavements samples

Table 1: Instrumentation and description of the experimental site

Boundary of observation		**Measuring Instrument**	**Accuracy**	**Variables to be measured**	**Position of instrument**	**Measurement intervals**
Dry Surface	Wet Surface	Kestrel weather Tracker	+/-1.0^0C, +/-1.8^0F +/-3%	Air temperature, Relative humidity	1.2 m above the surface	5 minutes
100 m^2	100 m^2	Infrared-Thermometer	±2^0C/±4^0F	Surface temperature	1.2 m above the surface	5 minutes
		Globe thermometer		Radiant heat	Directly above surface	20 minutes

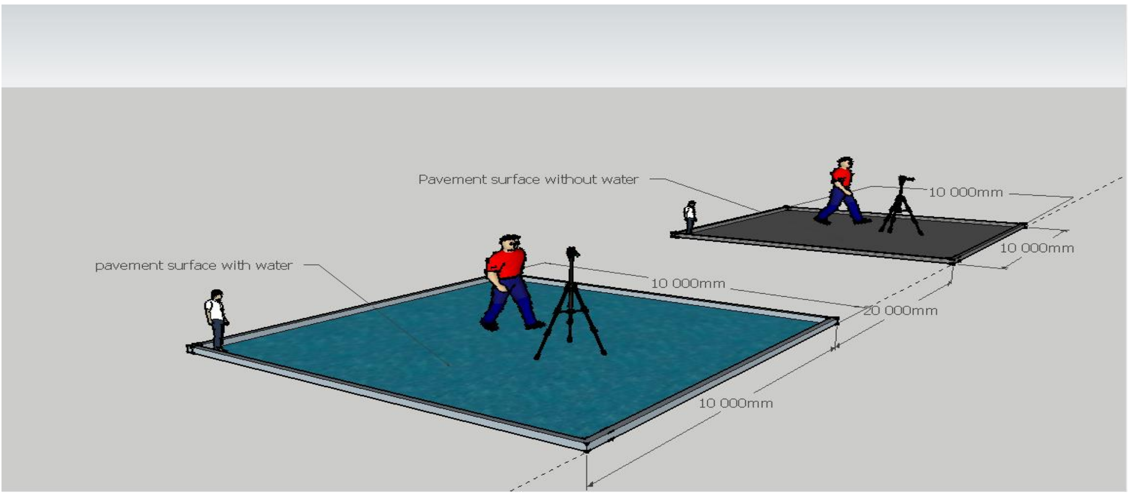


Fig. 2: A sketch of the mapped boundary with water 10 by 10 m and without water 10 by 10 m at 20 by 10 m apart

The three pavement materials used were: Interlocking concrete sample (A) made of concrete; they were assembled in moulds and interconnected on the surface. They were used conventionally for pedestrian walkways and vehicular parking lots. The second was Terracotta claybricks (B) made up of raw clay usually unglazed; used mostly indoor on floors and parking areas. Asphalt pavement sample (C) made up of a combination of mineral aggregates and bituminous surface treatment (BST). They are utilized on roads and car parks mostly in urban areas.

The weather forecast of Johor Bahru –Malaysia was used to predict three sunny and rainless days for the experiments to be conducted. During the experiment, 11 liters of water was used to spray the 10 x 10 m pavements, the dry area was also 10 x 10 m, for each pavement sample are separated by 20 m apart (Fig. 2). The experiment was carried out on different days during the: morning, afternoon and evening hours of the day. During the experiment, a weather tracker was used to measure relative humidity at 1.2 m above the ground and the ambient temperature at 1.2 m above the ground. The surface temperature was observed at 1.2 m above the ground using a hand held Infrared thermometer. For each session, the observations were carried out 10 times at 5 min interval. Readings for the sprayed and unsprayed areas were carried out concurrently under the same weather condition for each of the pavement samples, and the data documented manually. This was carried out on the three pavement samples.

Results and Discussions

Surface temperature variation of pavements

During the experiment it was observed that the heat budget on pavements depends mainly on the intensity of solar radiation.

Incident solar radiation has significant effects on the thermal performance of paved surfaces (Byer & Christian, 1994). The exposed surface of the pavement was seen as the most sensitive variable to the solar radiation incidence on it; escalating the temperature of the surface. According to Lin, Ho and Huang (2007), the surface temperature of paved surface is nearly 10^0C higher than the bare soil and green areas. The surface temperature of pavements gets as high as 42.7^0C in summer. Fig. 3 illustrates the surface temperature distribution of asphalt, interlocking concrete tiles and clay bricks. It shows the surface temperature of each of the samples for a whole day; the variation of surface temperature for each pavement was minimal during the morning and evening and significantly higher during the day especially on the asphalt pavements where a very steep slope was observed during the day.

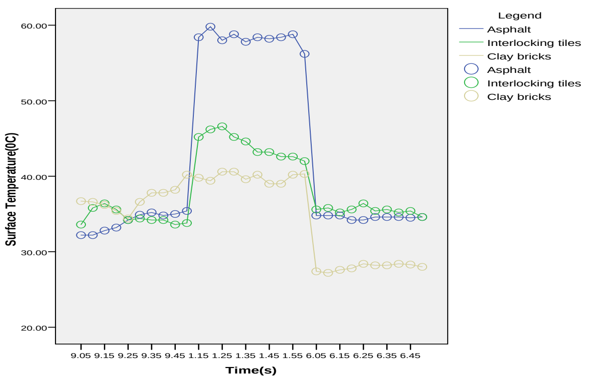


Fig. 3: Surface temperature variations for the three pavements

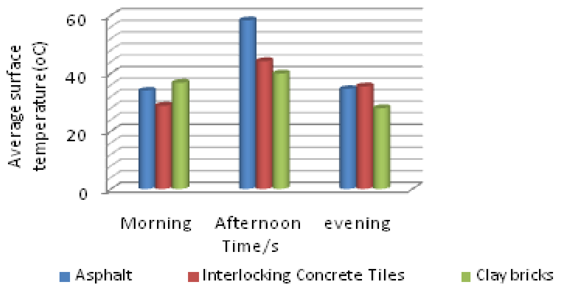


Fig. 4: Average surface temperature of three pavement samples

Figure 4 shows the average surface temperature of each pavement during the three practical periods of the day. The average surface temperature evaluated for all samples shows that the temperatures were most elevated during the day. Asphalt was seen to be significantly higher with a temperature of 58.28^0C. This was mainly due to its low reflectivity and consequently high absorption rate of solar radiation as being documented by (Brentz *et al.*, 1997) which reported that a material with low solar reflectance when exposed to solar radiation will experience higher surface temperature than materials with high solar reflectance. The interlocking concrete tiles had a higher reflectance capacity; as it was lighter in color, it had an average surface temperature of 44.14^0C. Clay bricks records the lowest average surface temperature of 39.87^0C as compared to other materials sampled. The values of the surface temperature displayed show Asphalt as the hottest with 60^0C; with other materials 10^0C lower than asphalt. The above findings revealed that the average surface temperatures of the pavements were most pronounced during the day and had less heat output in the morning and evening. The albedo of the materials determined to a large extent the level of reflectivity of the various materials and its thermal performance.

Ambient temperature variation of pavements

A study by Lin, Ho and Huang (2007) on the seasonal effects of pavements revealed that surface temperature is one of the closest variable related to air temperature followed by the globe temperature and solar radiation. Wind velocity they stated, rarely affects the air temperature in all seasons and periods of the day. Fig. 5 displays the variation of ambient temperature carried out at 1.2 m above each of the pavements type sampled carried out at 5 min interval. The variation of air temperature was seen to be minimal in the morning and evening of a typical sunny day with low heat output to the outdoor space. According to reports from the metrological data in Senai Johor climatic profile (yr), it indicates that air temperature in the month of April rises from about 23^0C in the early morning to 30^0C in the afternoon. For the period of this experiment, the variation of air temperature was seen to be 29^0C on an average in the morning and evening of a typical sunny day. During the day it was slightly higher with an average temperature of 32^0C as shown in Fig. 6. Similar to the case of the surface temperature, however the surface temperature of each pavement was seen to be significantly higher than the air temperature in all cases.

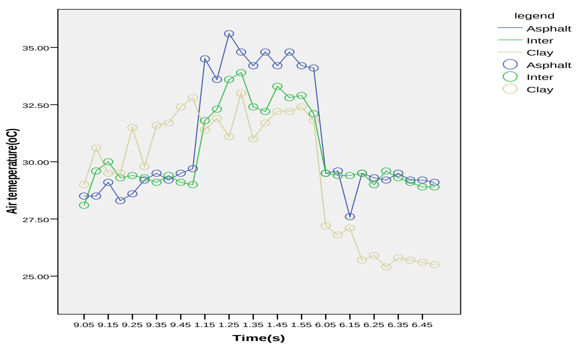


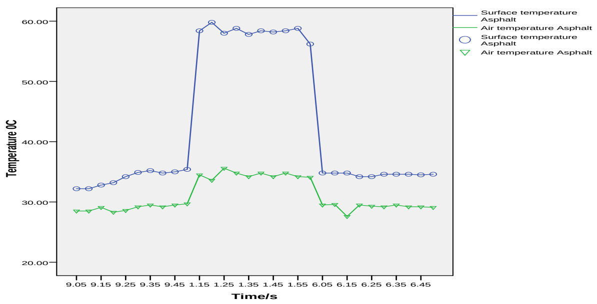
Fig. 5: Ambient temperature variation of three pavement samples

Surface and Air temperature comparison pavement samples

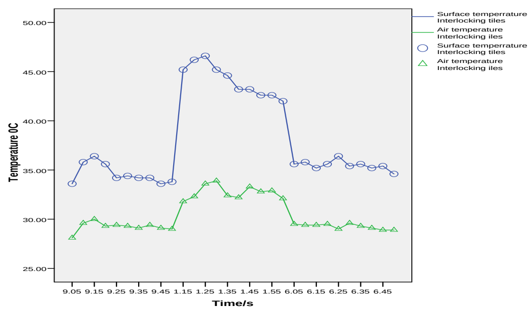
The elevation of air temperature was seen to be a consequence of the surface temperature of the surfaces with the closest proximity to it. Study by Osanyintola and Simonson (2006) indicates that the air temperature distribution inside a street canyon is a function of the optical and thermal properties of materials used on buildings and streets. The surface temperature difference was measured across the street reaching about 30^0C and this favored the overheating of the lower air levels and subsequently the atmospheric temperature. Fig. 6 illustrates the responses of the ambient temperature measured 1.2 m above the surface to the temperature of the 3 paved surfaces. Fig. 6a shows that the air temperature was appreciably lower than the surface temperature for asphalt pavement; it however maintained an average temperature of 29^0C during the morning and afternoon observation where the average surface temperature was 33.9^0C. During the day however, the surface temperature raised to about 58.28^0C, thereby increasing the ambient temperature to 32.73^0C. This occurred as a result of the intense solar radiation experienced during the day. Fig. 6b illustrates the surface and air temperature of interlocking concrete tiles, similar to asphalt pavement, the surface and air temperature were seen to be most prominent during the day; it had a lower average surface air temperature of 44.14 and 32.73^0C, respectively. While figure 6c illustrates the response of clay bricks to the surface and air temperature; it shows that the morning and afternoon sessions were relatively the same.

It records an average surface temperature of 39.87^{0}C during the day and 36.68^{0}C in the morning, the air temperature was also 31.21 and 31.87^{0}C, respectively. However during the evening observations, rainstorm were experienced which moderated the heat gains on the pavement, it had an average surface temperature of 27.95^{0}C and air temperature of 25^{0}C.

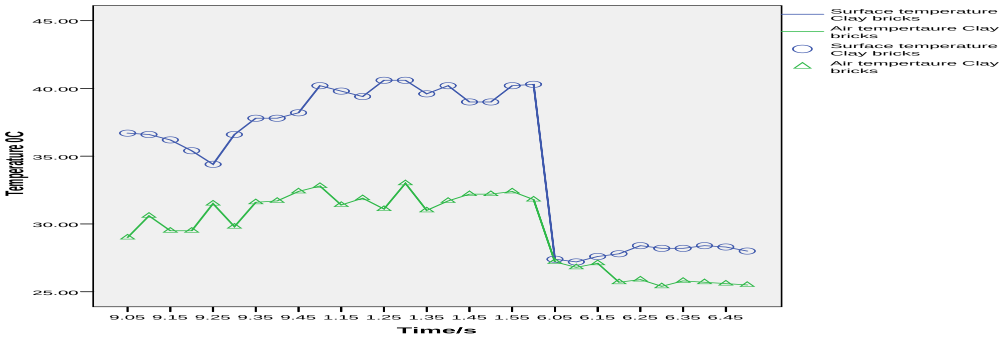
This shows that on an average, the surface temperature of the pavement samples were appreciable higher than their ambient temperature; however any variation in the surface temperature affects the ambient temperature.



(a) Asphalt



(b) Interlocking conc. tiles



(c) Clay terracotta tiles

Fig. 6: Comparative analysis of surface and air temperature of three pavement samples

Paired sample comparison of sprayed and unsprayed surface temperature

ASHRAE laboratory indicated that room temperature must be maintained in order to minimize the inward heat flow of absorbed solar radiation. Experiments show that roof sprays were seen to improve substantially the comfort of the occupant indoor and outdoor. In this study the spray mechanism was employed to evaluate the degree of surface temperature reduction when water was sprayed on a pavement surface. Results show a significant difference in surface temperature after water was sprayed on each of the pavement samples especially during the day as shown in Fig. 7.

To evaluate quantitatively the difference in temperature observed; the paired sample test was used to compare both scenarios and compute the variation at a significance level of 5% (Table 2). The test showed a change in surface temperature for all pavement materials sampled. The most significant difference was observed during the day. For asphalt, its average temperature reduced by 11.48^{0}C after water was sprinkled at a significance value of $P< 0.05$, t=8.16; it has an average temperature of 58.20^{0}C before water was sprinkled and 46.80^{0}C after-wards. Terracotta clay tiles on the other hand, having good insulation capacity maintained a cooler state than other pavement materials. During the day the average surface temperature was 39.87^{0}C before sprinkling and 38.77^{0}C after sprinkling which gave a difference of 1.09^{0}C at a significance $P< 0.05$ t=5.15; This showed no trivial variation in temperature after water was sprinkled, hence clay tiles are cooler in its natural state making it a suitable material to be used for pavements.

Interlocking tiles which was the second hottest material tested after asphalt with an average surface temperature of 44.14^{0}C before water sprinkling and 40.19^{0}C after water sprinkling giving a difference of 3.95^{0}C at a significance $P< 0.05$ t = 5.30. Finally, findings show that water is a feasible cooling medium on paved surfaces with heat absorption properties. This will help in mitigating the solar heat gain on pavements transferred to the overlying atmosphere.

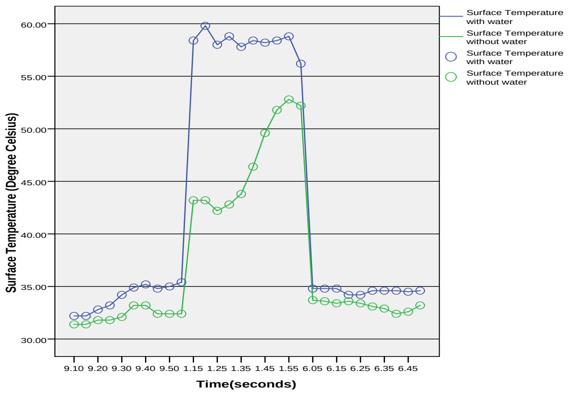
Relative humidity and water evaporation rate

Previous studies have shown the porous state of some building materials aid in moderating indoor air relative humidity amplitudes. It helps in reducing passive cooling loads and improving the thermal comfort sensation of building occupants (Osanyintola & Simonson, 2006). These materials are able to exchange moisture within the environment; a condition known as Relative humidity. Relative humidity according to (Padfield, 1999) is the amount of water vapor concentration in the atmosphere. At saturation a dynamic equilibrium exist between the rate of condensation and evaporation. Studies shows the evaporation rate of moisture depends on the solar heat available, the water capacity of the material and the time scale in which the process takes place (Padfield, 1999). Fig. 7 shows the ambient relative humidity of three samples as it responds to the level of moisture in the atmosphere, during the experiment 25 liters of water was sprinkled on the surface of the three samples observed. Results show that the extra heat during the day caused dryness and increased the evaporation rate and in turn lowered the relative humidity.

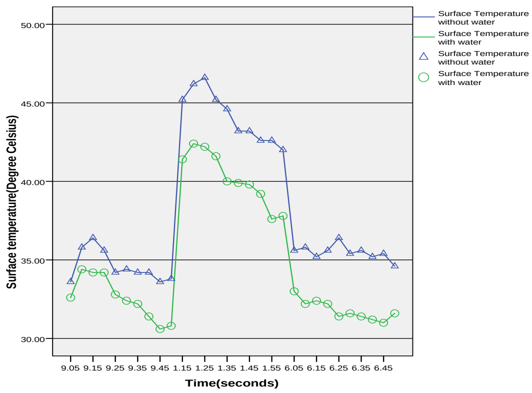
Observations illustrated in Figs. 8a and 8b afternoons show a similar consequence for Asphalt and Interlocking concrete tiles; the relative humidity reduced after water was sprinkled and within a period of 20 min the water completed evaporated from the surface and went dry. However Fig. 7 shows the surface still remained cooler than the dry surface till the 20 min experiment elapsed. Terracotta clay cricks on the other hand had low relative humidity during the morning and afternoon. Evaporation rate was predominantly the same for whole day during the three practical periods Fig. 8c. Evaporation from the surface was relatively slow and the surface temperature of the sprinkled area did not vary significantly like in the case of asphalt and Interlocking concrete tiles.

The study involved observing the thermal performance of impermeable pavement under a typical sunny day condition and in its wet state after water had been sprinkled on the surface. Findings from the experiment show that water evaporation and permeability has an important counter to the heating effect on pavement as well as the materials used; the presence of moisture or water induces evaporation and in turn cools the surface of pavements. Permeable pavements or periodic water sprinkling over impermeable pavements will aid in improving the thermal performance of pavements. Materials used were also seen to aid in the perceptible rise in temperature caused by pavements due to the solar reflectance.

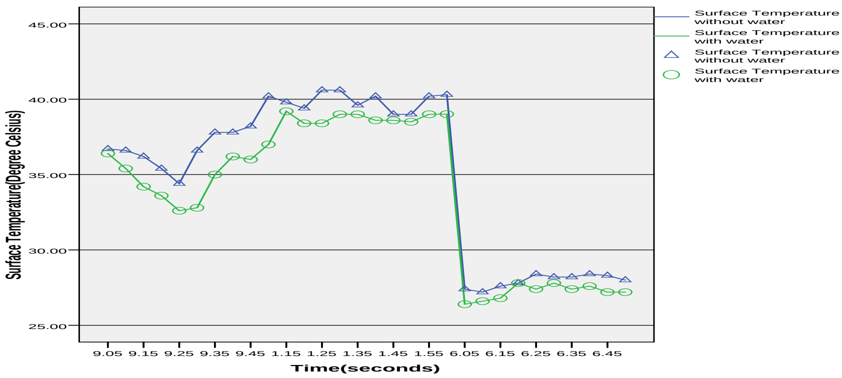
Solar reflectance is the measure and ability of a surface to reflect back solar radiation incident on the surface. Therefore materials with higher reflectivity absorb less solar heat gains while materials with lower reflectivity attract and absorb heat on the surface. The color shade of pavements was the main determinant of solar reflectance; light colored materials such as concrete with higher reflectivity have lower surface temperatures than dark colored materials such as asphalt with lower reflectivity. Asphalt being the darkest among the other materials observed, experienced the highest surface temperature especially during the day with 58.20^{0}C with a solar reflectance of 5- 10%, interlocking concrete tiles being a lighter color experienced a lower surface temperature of 40.19^{0}C and a solar reflectance of 20-30%, on the other hand the thermal mass and moisture of clay tiles aids it to absorb and release heat slowly and thus keeps its surface temperature cooler than other pavement materials.



(a) Asphalt



(b) Interlocking concrete tiles



(c) Clay bricks

Fig. 7: Surface temperature variation of three pavement samples before and after water sprinkling

Table 2: Paired sample statistics

Pavement type	Period	Average surface temperature Condition Dry surface (B)	Wet Surface (A)	Average Temp Difference (B-A)	T values for T-test
Asphalt	Morning	33.99^{0}C	32.21^{0}C	1.78^{0}C	3.96**
	Afternoon	58.20^{0}C	46.80^{0}C	11.48^{0}C	8.16**
	Evening	34.58^{0}C	33.57^{0}C	1.38^{0}C	8.84**
Interlocking Tiles	Morning	34.58^{0}C	32.56^{0}C	2.02^{0}C	3.75**
	Afternoon	44.14^{0}C	40.19^{0}C	3.95^{0}C	3.68**
	Evening	35.48^{0}C	31.8^{0}C	3.68^{0}C	15.4**
Clay Tiles	Morning	36.99^{0}C	34.92^{0}C	2.07^{0}C	2.92**
	Afternoon	39.87^{0}C	38.77^{0}C	1.09^{0}C	5.15**
	Evening	27.95^{0}C	27.22^{0}C	0.73^{0}C	3.56**

**p-Value 0.05

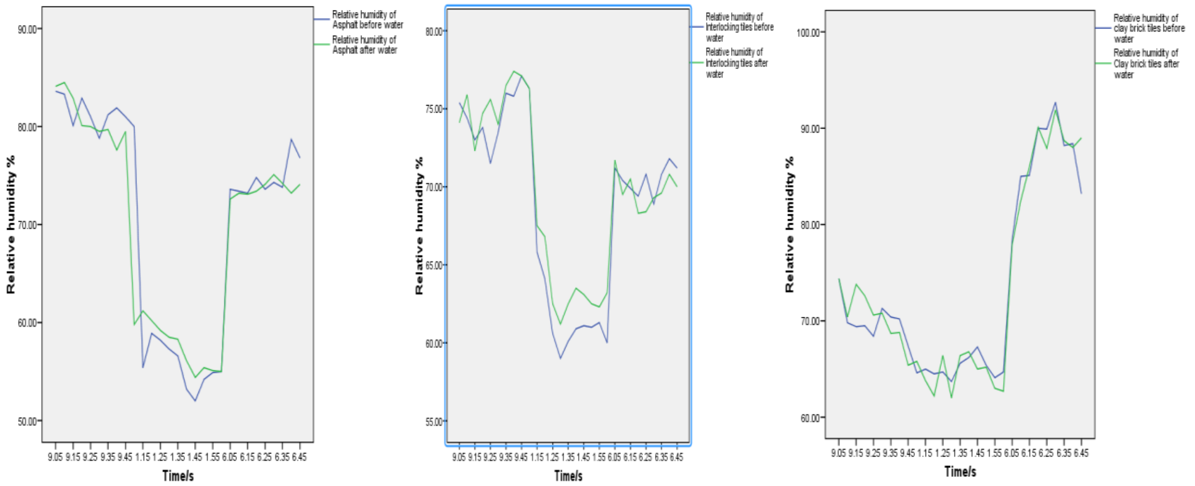


Fig. 8(a) Relative humidity of asphalt (b) Relative humidity of Interlocking tiles (c) Relative humidity of clay brick tiles

Water sprinkled on pavements was seen to significantly reduce the surface temperature of pavement materials sampled. During the experiment the most significant difference was observed during the day and the evaporation rate was seen to occur rapidly due to the presence of heat available during this period. The surface temperature of all pavements was observed to have dropped after water was applied on the surface the t-test for independent samples evaluated a significant difference in temperature during the three practical periods of the day (morning, afternoon and evening) after water was applied. During the day, water evaporation was observed to be faster and was most rapid on asphalt pavement. However, after water went dry the pavement still remained cooler than the dry surface. The t-test for Independent samples evaluated an average temperature difference for all samples during the day after water application. During the evening hours the evaporation was observed to be slow in the absence of heat from solar radiation. However, a temperature difference was equally observed on all pavement samples. Clay brick tiles had a slower rate of evaporation as compared to other samples however it remained the coolest materials under all weather conditions. The application of water to induce evaporative cooling on impermeable pavements has been confirmed during the course of this research to be a feasible heat softening strategy a phenomenon experienced throughout the world. In reducing the surface temperature of pavements this will improve the immediate ambient temperature of the pavements and the comfort index of the inhabitants. However, *asphalt was seen to have the best performance after water was applied; with a temperature difference of 12^{0}C.* Findings also show that the quantity of water applied determines the extent of cooling so the more the water the better the cooling effect.

Conclusion

The heat budget of pavements depends mainly on the intensity of incident solar radiation. During the day the solar heat was more severe; pavements absorb heat and releases to the atmosphere. The physical features of pavements examined shows that the albedo of paved surfaces determines to a great extent the solar heat absorption rate. Dark materials such as asphalt attract and absorb more heat than light colored materials such as concrete. Among the materials tested asphalt was observed to have experienced a surface temperature of 58.20^{0}C during the day while terracotta was the lowest with 39^{0}C. The heat settled on these materials was instantly released to the ambient environment making the air warmer than normal. As such the surface temperature was seen to be the closest variable related to ambient temperature. Any variation in surface temperature affects the ambient temperature.

During the experiment, Water evaporation was seen to be an important counter towards minimizing the inward heat flow of radiation. The surface temperature for all pavement samples became cooler after water sprinkling. The most significant difference was observed on asphalt which reduced by 11.48^{0}C after water was applied on the surface. The amount of moisture present determined the evaporation rate and was seen to be faster during the day due to high solar intensity. Results show that the extra heat during the day caused dryness and increased the evaporation rate and in turn lowered the relative humidity. This research concludes water sprinkling on pavement surface can significantly optimize the solar heat gains on pavements and reduce the surface temperature. The study recommends passive cooling for mitigating excess heat released by pavements to the outdoor environment.

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