Reduction of Urban Heat Island Effect through Harvest of Heat Energy from Asphalt Pavements

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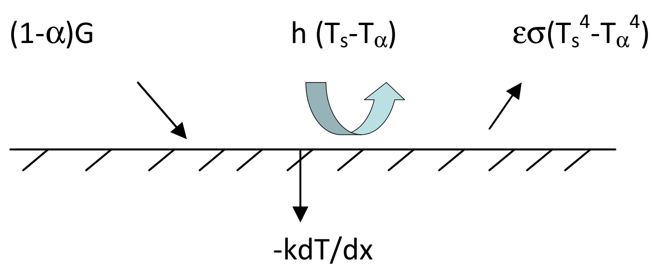
ABSTRACT

Asphalt pavement surfaces contribute significantly to the urban heat island effect. Their relatively high temperature, caused by absorption of solar energy, results in emission of heat to the surrounding air, leading to a rise in its temperature, deterioration of its quality, and an increase in energy consumption of the surrounding buildings. The proposed concept is that the heat from the pavement can be removed by flowing an appropriate fluid in a piping system combined with high conductivity layers, and this would lead to a reduction of temperature in the pavement, and lowering of heat emitted from the surface to the surrounding air. The concept, results of laboratory experiments and finite element modeling/simulation are presented. Comparison of results from the application of the proposed concept with those from changing the albedo of existing pavements is made. The conclusions are that a significant lowering of surface temperature and emitted radiation is possible, and the reduction in temperature is affected by the conductivity of the mix, the type of paint/layer on the surface, the heat-exchanger system, and the temperature of the fluid. The results could be used to engineer a system with optimum piping location and spacing, and properties of the fluid to achieve the desirable result.

Introduction

Solar radiation absorbed by an asphalt pavement raises its temperature. There are four predominant mechanisms in the transfer of heat to a pavement (Bejan, 1993): (Figure 1) solar radiation in and emitted radiation out of the pavement, conductive transfer of heat through the pavement, and convective transfer of heat above the pavement through wind.

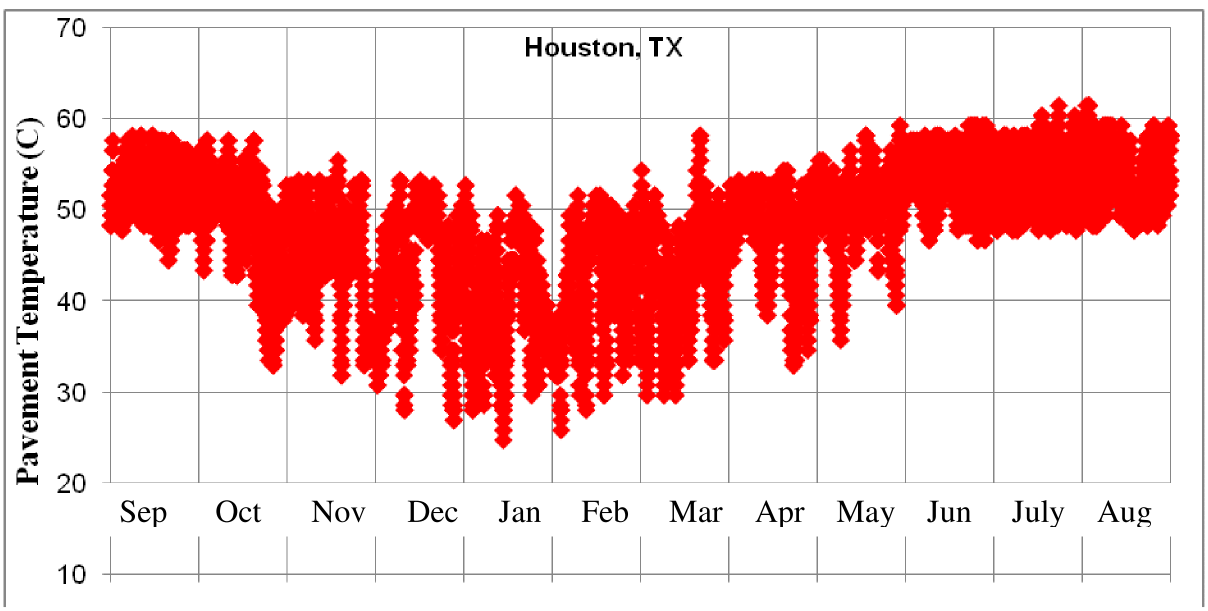
Figure 1: Thermal Problem Associated with Pavement Heating (G = irradiation, h = heat transfer coefficient, k = thermal conductivity, T_α = air temperature, T_s = surface temperature, T_{sur} = surrounding temperature; α = reflected component, ε = emissivity of the surface)



Due to the very nature of the material, an asphalt pavement has a high absorptivity (0.85-0.93, Solaimanian and Kennedy, 1993) of solar radiation. At the same time its low conductivity (0.76-1.4 W/mK, NCHRP, 2004) prevents the absorbed energy from being transported elsewhere. This, coupled with relatively high thermal capacity (921-1,674 J/KgK, NCHRP, 2004) of the asphalt mixture, allows asphalt pavements to store thermal energy and reach relatively high temperature – usually higher than the surrounding air.

Examples of high pavement surface temperatures (in ^{o}C) in a few selected cities in the southern/western part of the US are: Houston, TX: 62, Jacksonville, FL: 60, Albuquerque, NM: 61, Reno, NV: 61, Atlanta, GA: 61, Nashville, TN: 60, Los Angeles, CA: 59. (The temperatures are estimated on the basis of air temperatures (NOAA, 2008) using the emperical models developed and verified by Solaimanian and Kennedy, (1993), Huber, (1994), Solaimanian and Bolzan, (1993). The relationship is developed based on experimental measurements of air and pavement temperatures at different latitudes and developing a quadratic equation by fitting the data to it). Note that in large parts of southern USA, maximum pavement temperatures exceed 60^{o}C, while daily pavement temperatures reach 50^{0}C for a large part of the year. As an example, temperatures in an asphalt pavement in Houston are shown for one year, in Figure 2.

Figure 2. Maximum Pavement Temperature in a 12 Month Period



Heat islands are formed as vegetation is replaced by asphalt and concrete for roads, buildings, and other structures, which absorb - rather than reflect - the sun's heat, causing surface temperatures and overall ambient temperatures to rise (USEPA, 2009). The heat from asphalt pavements is a major contributor to the rise in temperature in areas with asphalt pavements, resulting in what is known as the Urban Heat Island Effect (Soderlund et al, 2008). The urban heat island effect is created by the high absorptivity of the pavement surface which subsequently leads to an elevated surface temperature and therefore higher emission from the pavement (Belshe et al, 2007).

The transfer of energy by electromagnetic waves is called radiation heat transfer. All matter at temperature greater than absolute zero will radiate energy. Energy can be transferred by thermal radiation between a gas and solid surface or between two or more surface. The rate of energy emitted by a surface is given by the Stefan-Boltzmann law:

$$E_b = \varepsilon \sigma T_s^{\ 4}$$

Where E_b is the rate of radiation of energy, ε is the emissivity of the material, and σ = Stefan-Boltzmann constant = 5.68x10^{-8} W/(m^2·K^4), and T_s is surface temperature, in units K. An ideal surface (black body) has emissivity equal to 1.

The emitted radiation intensity from the pavement surface to its surroundings is calculated as

$$q_r = \varepsilon \sigma (T_s^4 - T_{air}^4)$$

Where q_r = emitted radiation, ε is the emissivity of the material, σ = Stefan-Boltzmann constant = 5.68x10^{-8} W/(m^2·K^4), T_s is surface temperature in Kelvin, T_{air} is air temperature in Kelvin.

The emissivity of a material ε is the ratio of energy radiated by the material to energy radiated by a black body at the same temperature. It is a measure of a material's ability to absorb and radiate energy. A true black body would have the value of ε = 1 while any real object would have ε < 1. Emissivity depends on factors such as temperature, emission angle, and wavelength. Because surface radiation follows the Stefan-Boltzmann equation, which involves the fourth power of temperature, a slight increase in the surface temperature results in a significant increase in the emitted heat, most of which is in the IR spectrum. This leads to increase in air temperature, as absorption of air is high in the far IR spectrum and a subsequent increase in energy consumption of buildings surrounding paved areas in order to maintain comfort level. Additionally, studies have shown that air quality also deteriorates under increased temperature due to the heat island effect (Lawrence Berkeley National Laboratory, 2009).

Reduction of Pavement Temperature

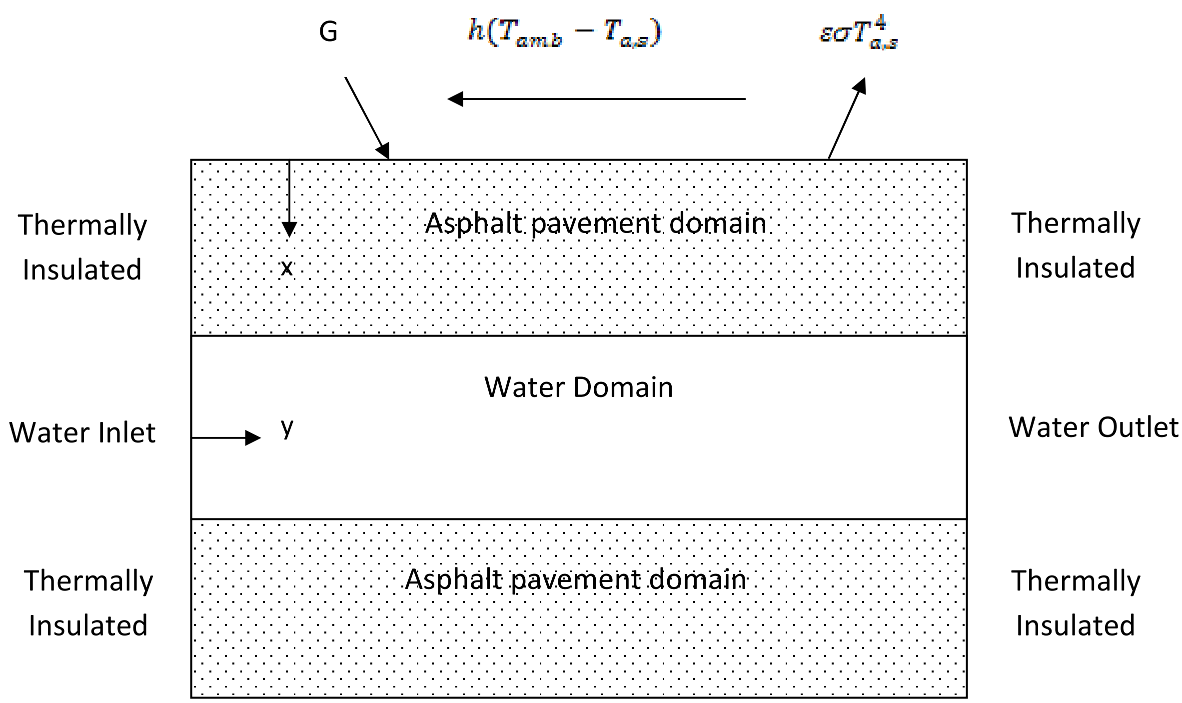
A significant amount of research has been conducted on lowering pavement temperatures. Traditionally, “cool pavements” have been proposed through alteration of albedo of the surface of the pavement. Albedo has been increased by either providing a light colored surface layer or paint, or light colored aggregates, or aggregates coated with light colored “thermal barrier or paint” as well as Portland cement concrete (Pomerantz et al, 2000, Kinouchi et al. 2004, Schindler et al. 2004, Kawakami and Kubo, 2008). This process has been found to be effective in reducing the air temperature – several researchers have estimated the decrease in pavement and air temperature due to an increase in the albedo of the pavement surface (Pomerantz et al, 1997, Pomerantz et al, 2000). However, there are certain issues related to this procedure, such as, requirement for extensive modification of the pavement surface color and/or materials to cause a significant drop in temperature, change in the surface layer properties as a result of wearing under traffic, cracking of surface layers, visibility issues and public opinion regarding aesthetics (Cambridge Systematics, 2005, Kawakami and Kubo, 2008). The provision of porous mixes enables the capture and storage of water in the pavement. The evaporation of water in the pavement could be used to keep the pavement cool (Asaeda and Thanh, 2000). However, porous mixes cannot be provided under different conditions, and other issues include need for extensive modification of mix, clogging of pores, and maintenance problems (Cambridge Systematics, 2005). Furthermore, none of these methods allow the harvesting of the heat energy that is stored in the pavements.

Proposed Approach

Based on Stefan- Boltzmann law, the variable that would reduce the back radiated energy is the temperature difference between the asphalt pavement surface and ambient temperature (air). The proposed approach is that the surface temperature of the asphalt pavement will be reduced due to the convective heat transfer of water flowing underneath it, which will decrease the back radiated energy emitted from asphalt pavement to the air.

Modeling and Simulation Work. The heat transfer problem is a coupled conduction-convection-radiation problem with appropriate boundary conditions at the pavement-air and pavement-water interface. The problem is illustrated in Figure 3. The problem has two domains - the asphalt mix domain where the transient conduction heat equation is solved and the water domain where the convective terms play an important role. The mean water velocity is obtained from the conservation of mass. Appropriate values for boundary conditions were used.

Figure 3. Theoretical Considerations



G = irradiance, h = heat transfer coefficient, k_a = thermal conductivity of asphalt pavement, T_{amb} = ambient temperature, ε = emissivity of asphalt pavement, α = absorptivity of asphalt pavement, σ = Stefan Boltzmann constant, $T_{a,s}$ = temperature of asphalt pavement surface, ρ_a = density of asphalt pavement, $C_{p,a}$ = specific heat of asphalt pavement, ∇ = gradient, t = time, T_a = temperature of asphalt pavement, ρ_w = density of water, $C_{p,w}$ = specific heat of water, T_w = temperature of water, $T_{w,i}$ = initial temperature of water, k_w = thermal conductivity of water, $u_{w,y}$ = velocity of water in y-direction

Boundary condition on surface of asphalt pavement

$$(-k_a \cdot \nabla T_a) = \alpha G + h(T_{amb} - T_{a,s}) + \varepsilon \sigma T_{a,s}^4$$

Governing equation (asphalt domain)

$$\rho_a \cdot C_{p,a} \cdot \frac{\partial T_a}{\partial t} + \nabla \cdot (-k_a \cdot \nabla T_a) = 0$$

Governing equation (water domain)

$$\rho_w \cdot C_{p,w} \cdot \frac{\partial T}{\partial t} + \nabla \cdot (-k_w \cdot \nabla T_w) = -\rho_w \cdot C_{p,w} \cdot u \cdot \nabla T_w$$

Boundary condition (interface between asphalt pavement and water)

$$(-k_w \cdot \nabla T_w + \rho_w \cdot C_{p,w} \cdot u_{w,y} \cdot T_w) - (-k_a \cdot \nabla T_a) = 0$$

Boundary condition (water inlet)

$$\mathrm{T_w = T_{w,i}}$$

Boundary condition (water outlet)

$$(-k_w \cdot \nabla T_w) = 0$$

Boundary condition of asphalt pavement below pipe:

$$(-k_a \cdot \nabla T_a) = 0$$

A pavement made of hot-mix-asphalt (HMA) was modeled, along with an air layer on top of it. In one case, a pipe was placed 40 mm below the surface and, in another case, a pavement without any pipe was modeled. The solar radiation was applied for a total of 8 hours, with water flowing after 4 hours of heat up of the pavement. Figure 4 shows plots of surface temperature versus time. The minimum reduction of the surface temperature due to water flow in the pipe is 10^{o}C (at the outlet), while the maximum is 20^{o}C (at the water inlet; incoming water temperature: 25^{o}C). Decreasing the pipe diameter or increasing the flow-rate would help lower the surface temperature, however it would lead to increased pumping power. Therefore, an optima has to be found eventually. Since the simulations show that there is a significant drop in pavement surface temperature with water flowing in a pipe, the next step was to look at a network of pipes to evaluate the effect of pipe spacing on reduction of temperature. The temperature distribution of a HMA pavement, with different spacing of pipes is shown in Figure 5. Note that the effect of pipe spacing is clearly visible – the closer the spacing, the better is the reduction of temperature.

Figure 4. Plot of Surface Temperature versus Time

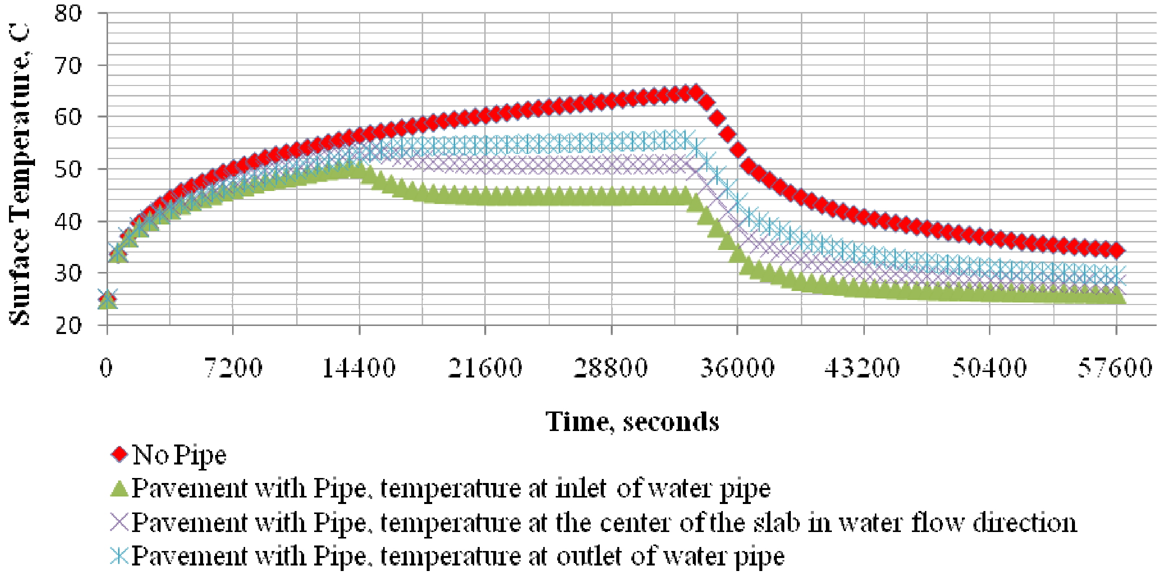
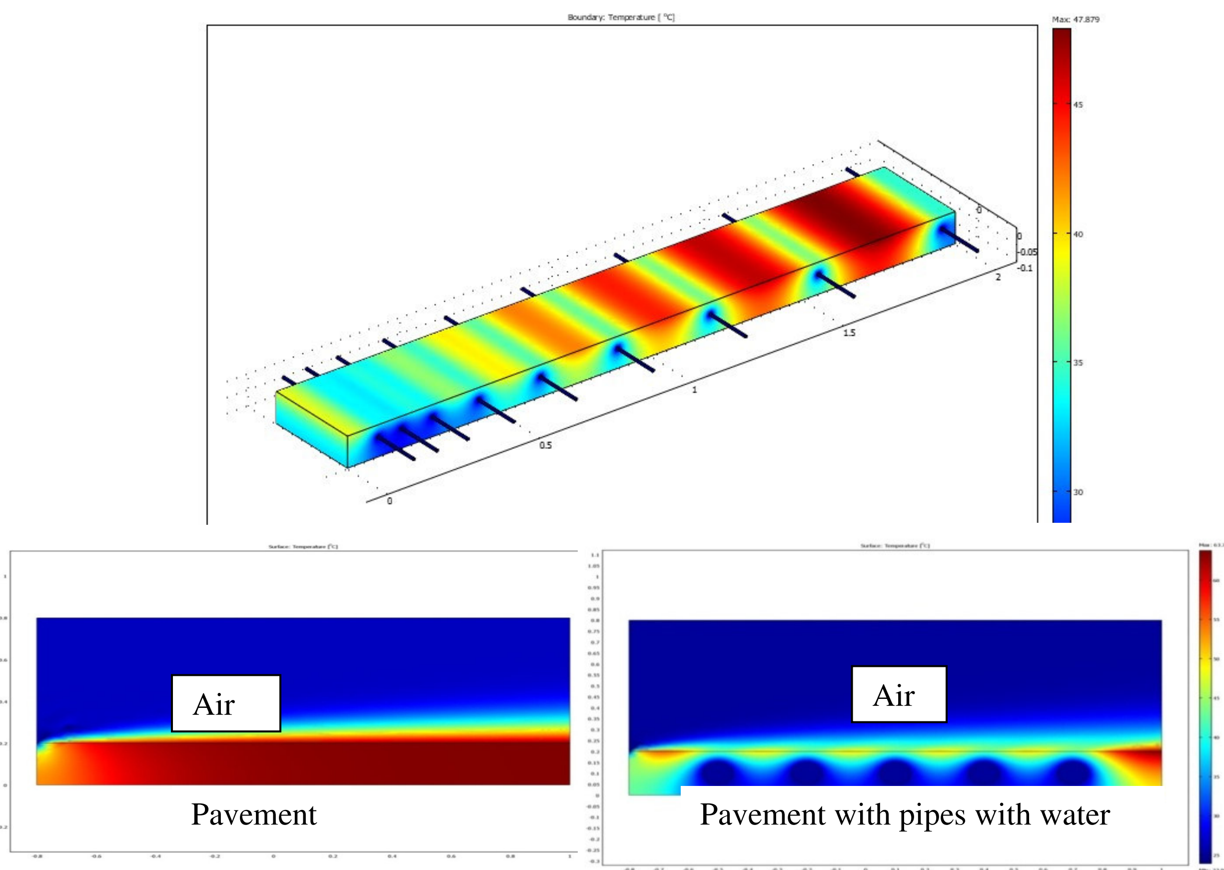
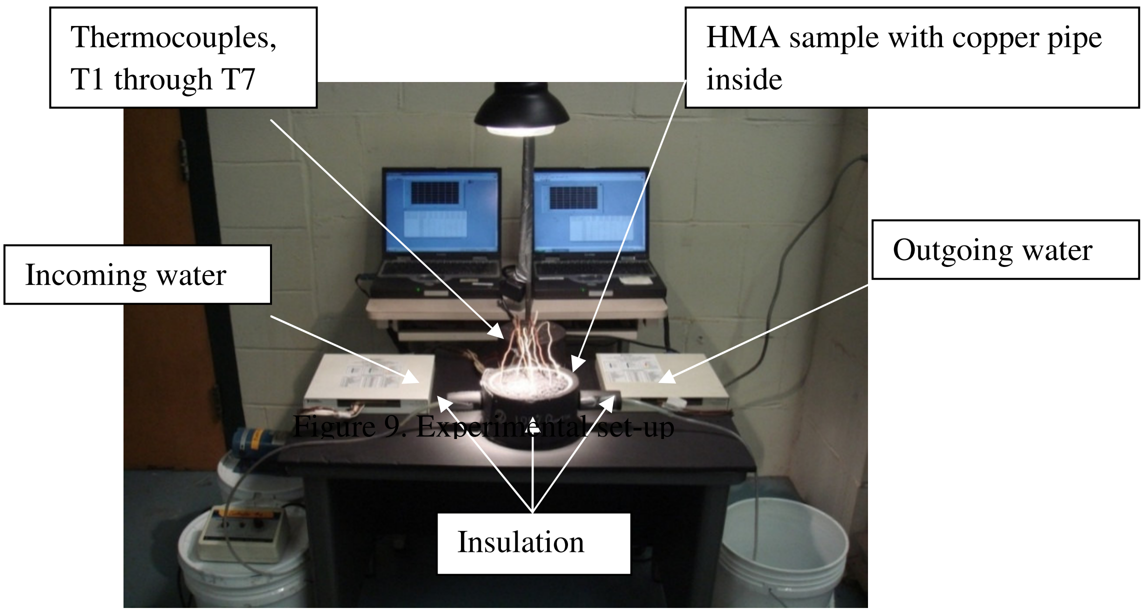


Figure 5. Effect of Pipe Spacing on Reduction of Surface and Near Surface Air



Experimental Work. Surface temperatures of asphalt mix samples with and without flowing water (in pipes inside samples) were obtained from small scale experiments (Chen et al, 2009). The 150 mm diameter, approximately 100 mm high HMA samples were subjected to radiation from a halogen lamp (for simulating solar radiation), as shown in Figure 6. An example plot of the results of the surface temperature measurements at different locations on the samples with and without flowing water is also shown in Figure 6. Reduction in surface temperature at the location of the different thermocouples is also shown (inset). These results clearly indicate that a lower temperature can be achieved at the surface of the pavement at locations directly above the pipe by flowing water. Reasons for difference between experimental and model values (as noted in Figure 4) could be consideration of fully developed laminar flow and homogeneous material in modeling. It is clearly evident from the above experiments that the reduction in temperature will be higher if more closely paced pipes are used. This was confirmed with the use of serpentine piping (Figure 7).

Figure 6 Small Scale Laboratory Setup and Result



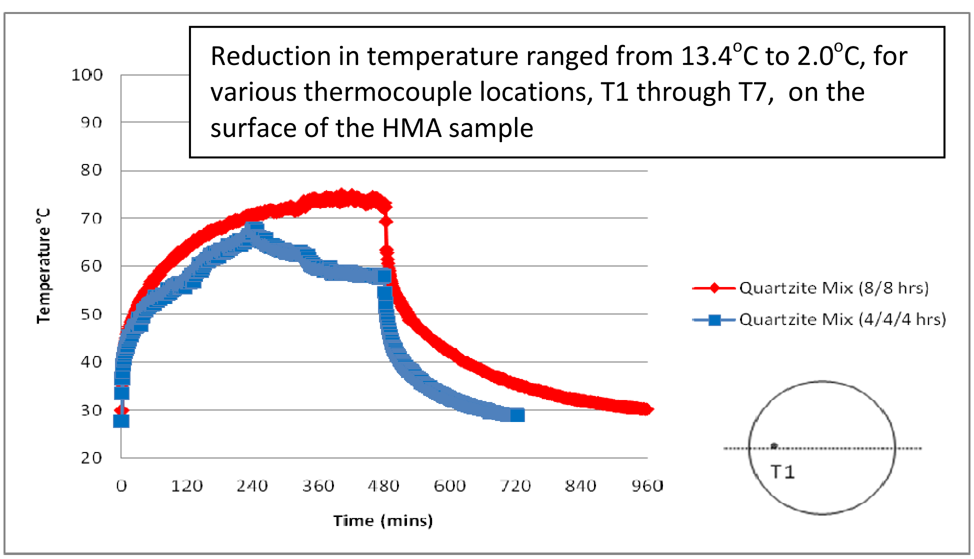
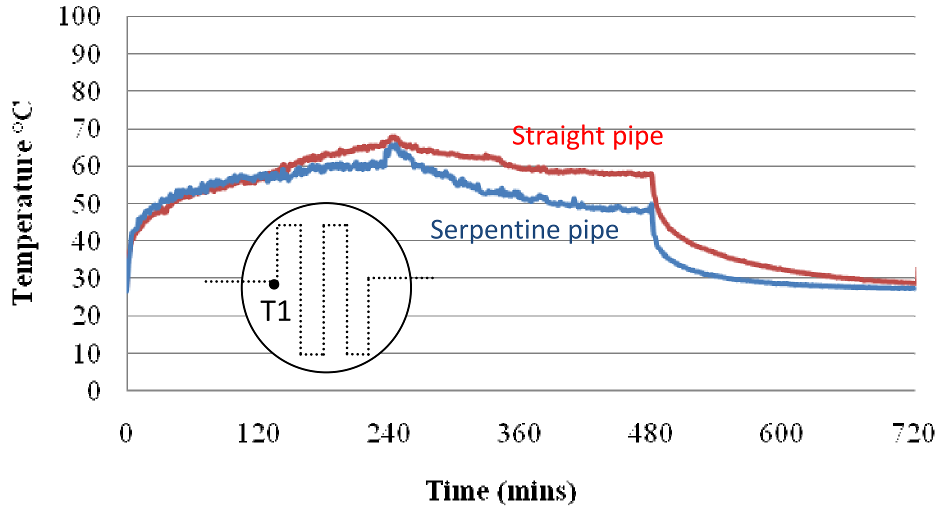


Figure 7. Difference in Surface Temperature of Asphalt Samples with Straight and Serpentine Pipes



Large Scale Experimental Work. A slab was prepared with a 120 mm thick HMA layer, with a frame of copper tube (Figure 8) embedded inside (Mallick et al, 2008). The copper tubes were provided for pumping water (heat exchanger) through the slab. Thermocouples were inserted along the depth and at various points in the slabs, including points in line with the copper tube locations, and inlet and outlet points of the water flowing through the copper tubes (Figure 8). Copper tube frames with multiple tubes along the width and one tube along the length were placed approximately 50 mm below the surface in both slabs, during placement and compaction inside wood carts. First, before flowing any water, the slabs were kept in the sun for approximately two hours, and temperatures at the various depths at the center of the slabs were recorded. Next, water was pumped at 1, 2, 3 and 4 l/min through both slabs at the same time, and temperature of the slab at the middle copper tube location as well as incoming and outgoing water were measured.

Wind speed and solar radiation were measured using an anemometer and a pyranometer, respectively. The solar radiation data was modeled with time and the results are shown in Figure 9. The values ranged from approximately 255 W/m^2 to 800 W/m^2. The data for the wind speed versus time is shown in Figure 10. The experimental setup was modeled in Finite Element Method (FEM) to determine the temperature at the different points. Even though three copper pipes were present in the slab, only one, through which water was flowed was modeled in the FE method. The time dependent solar radiation was used in the model. An average wind speed of 1.05 m/s was used to determine the convective heat transfer coefficient. Note that although the wind direction could have changed, the data from the anemometer does not indicate the direction.

Temperatures were collected at several points in the slab (shown in Figure 11), of which those at the surface and 25 mm below the surface, at two locations, are shown in Figure 12. The timing of the different events is as shown in Table 1. Comparison of the temperatures from the actual case and the simulated models are shown in Figure 12. Note that in all cases agreements between results from the field measurement and FE simulations are within ± 10%. The results clearly show the drop in temperature at the surface and 25 mm below the surface with the flow of water, and that the reduction in temperature is affected by the location of the pipe. As expected, the results for the surface locations have higher difference between the measured and FE temperature. This is most likely because of the difference between the actual and simulated wind/convection effects.

Figure 8. Slab, Copper Tube Frame inside Slab and Thermocouple On The Slab

Figure 9. Data for Solar Radiation versus Time

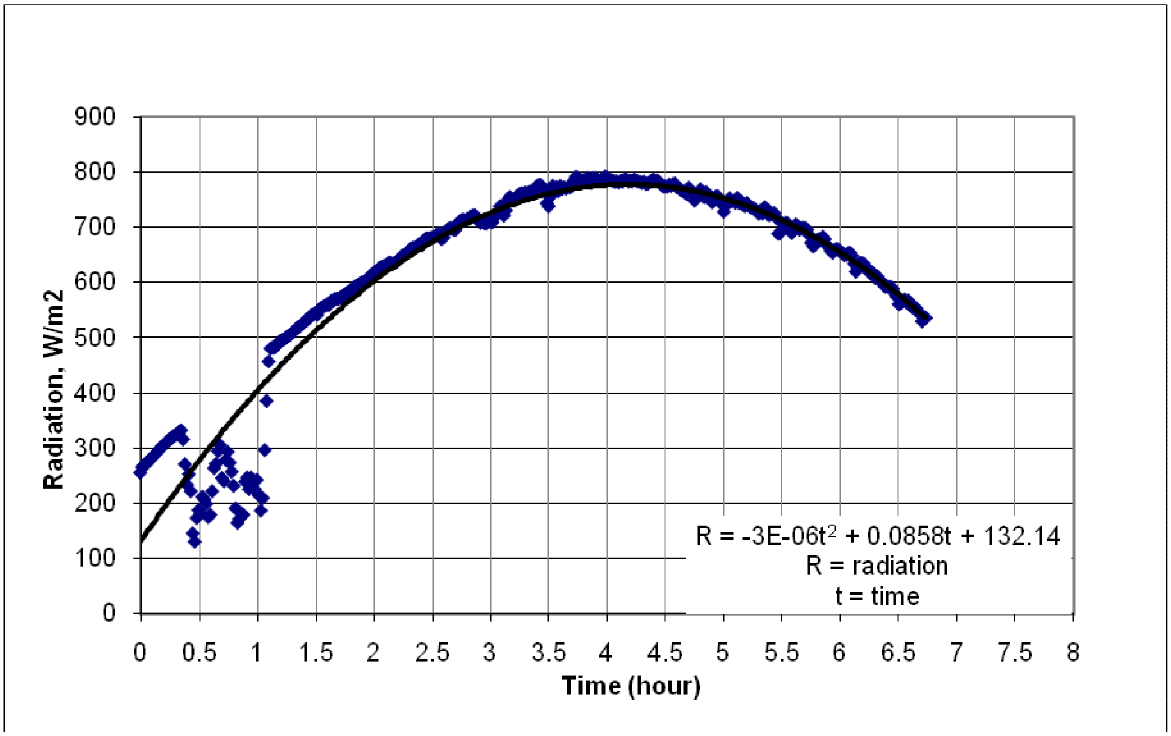


Figure 10. Data for Wind Speed versus Time

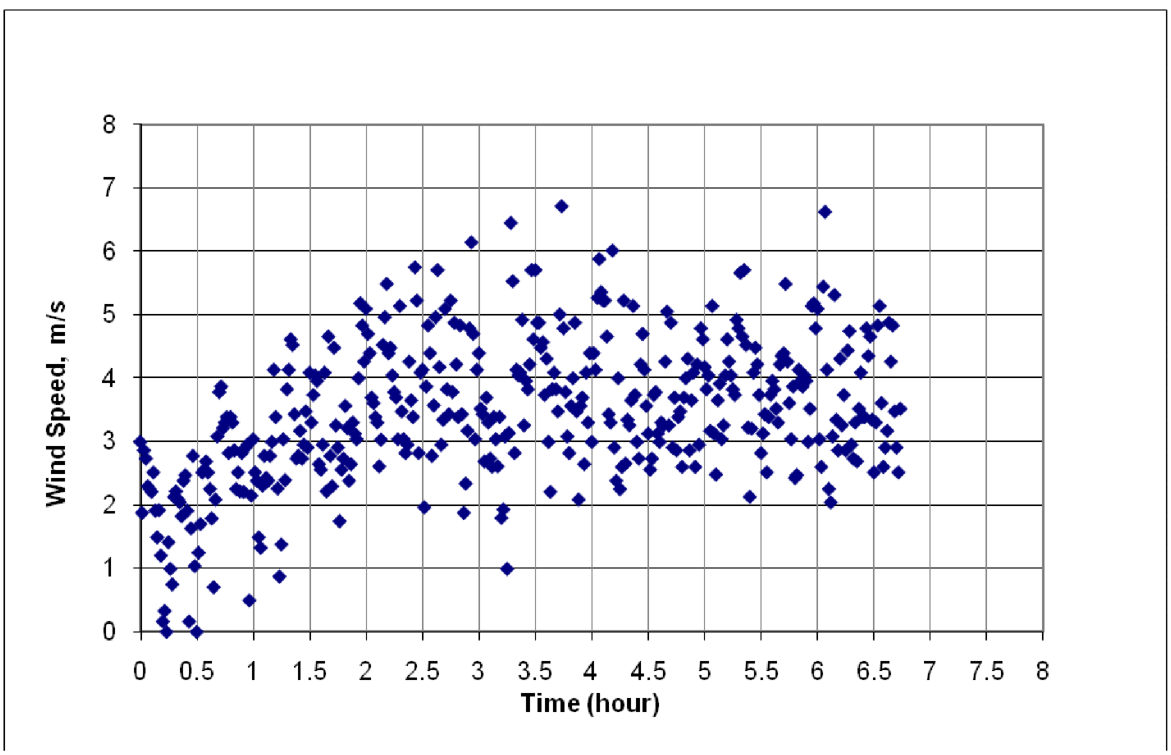


Figure 11. Location of Temperature Measurements

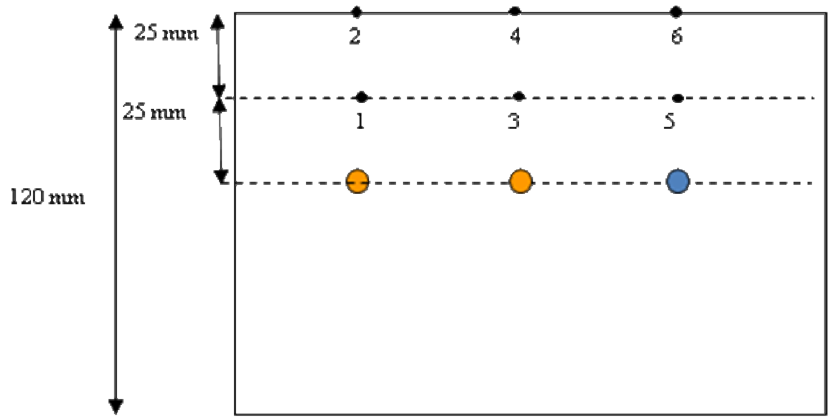
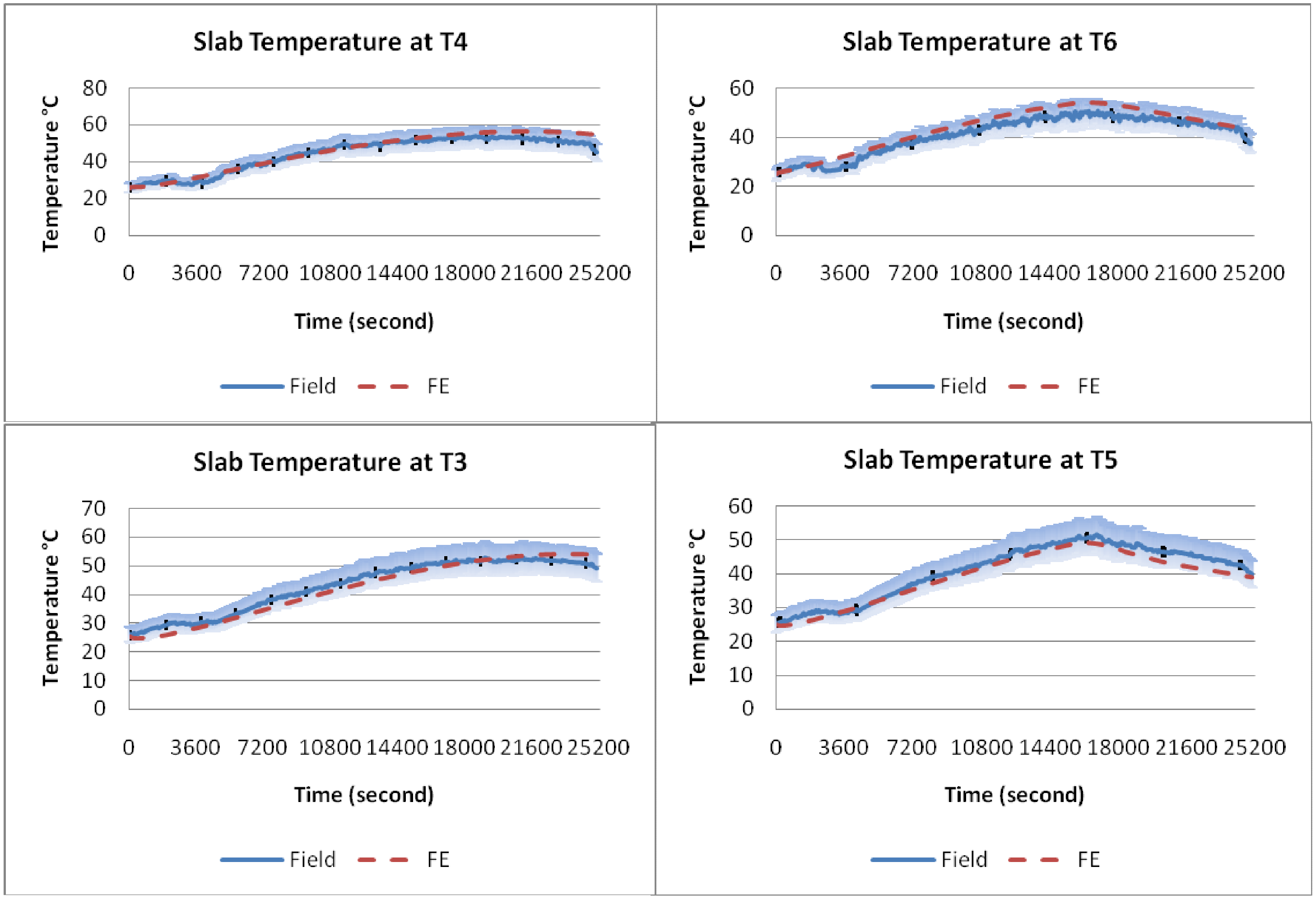


Table 1. Sequence of Events

Time (hour/seconds)	Event
0 (0)	Start of solar radiation and wind
4.7 (17,040)	Start of water flow at 1 l/minute
5.3 (19,200)	Change flow of water to 2l/minute
5.8 (21,180)	Change flow of water to 3l/minute
6.5 (23,400)	Change flow of water to 4l/minute

Figure 12. Temperatures at the Surface and 25 mm Below the Surface at Locations Above and Beside the Water



What happens if the thermal conductivity of the pavement layers is improved? The thermal conductivity of the HMA can be improved by using aggregates with higher thermal conductivity, such as quartzite (containing high percentage, >90%, of quartz). Laboratory tests were conducted using different types of aggregates, using the set-up shown in Figure 6, and the difference between incoming and outgoing water was considered as an indicator of the efficiency of the heat energy removal process. Laboratory test results (Mallick et al, 2008) show that the difference between incoming and outgoing water (through asphalt pavement) was increased by 100% by replacing limestone aggregates (thermal conductivity, K = 2.15 W/m.K) with quartzite aggregate (Source: New Ulm Quarry, Sioux Falls, MN; K = 5.38 W/m.k) (Figure 13). However, note that such aggregates are available only in some areas of the country.

Effect of piping material. A range of different piping materials has been used to determine the effect on the amount of energy that can be harvested (and hence the reduction in temperature). Four different types of pipes, including copper, were utilized in a small scale experiment with a HMA slab (Figure 14). The pipe was placed 40 mm below the surface, the surface of the slab was heated by halogen lamps, and water was flowed from one end to the other. The difference in temperature between in the inlet and outlet water for the different cases is shown in Figure 14. The experimental setup and relevant information regarding the different pipes are also shown in Figure 14. It consists of an approximately 1.8 m long, 300 mm wide and 90 mm deep HMA slab, with thermocouples inserted at various locations (with respect to the pipe carrying water) on the surface as well as at a depth of 25 mm below the surface. The relatively good performance of the PEXAL pipe, in comparison to copper (10^{o}C versus 13^{o}C rise in temperature) shows the prospect of using piping materials other than copper (which is relatively costly). The pipes used in this experiment are currently used for hydronic radiant heating and snow melting purposes.

Figure 13. Plot of Aggregate Type versus Difference between Incoming and Outgoing Water

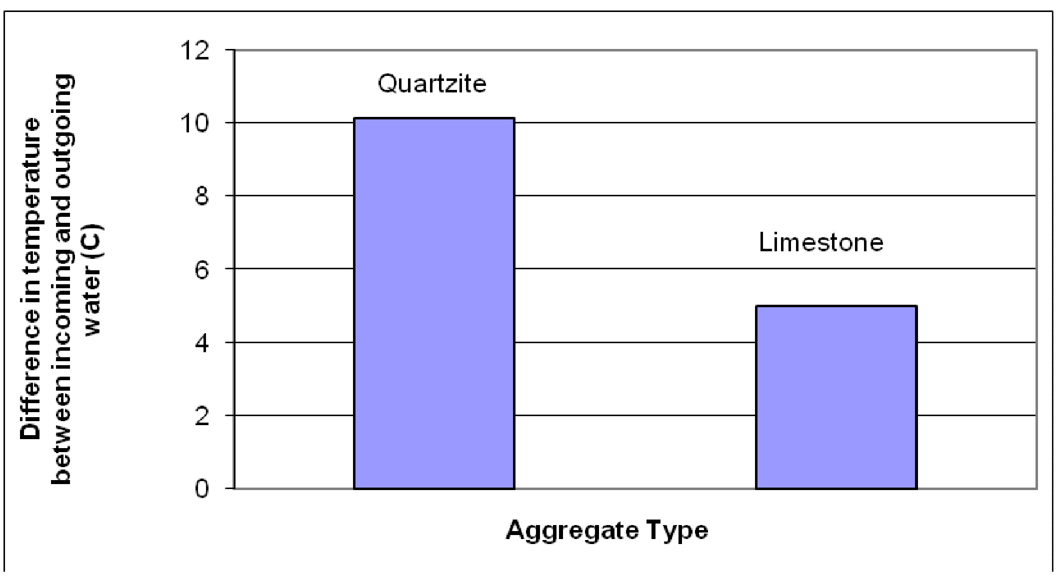
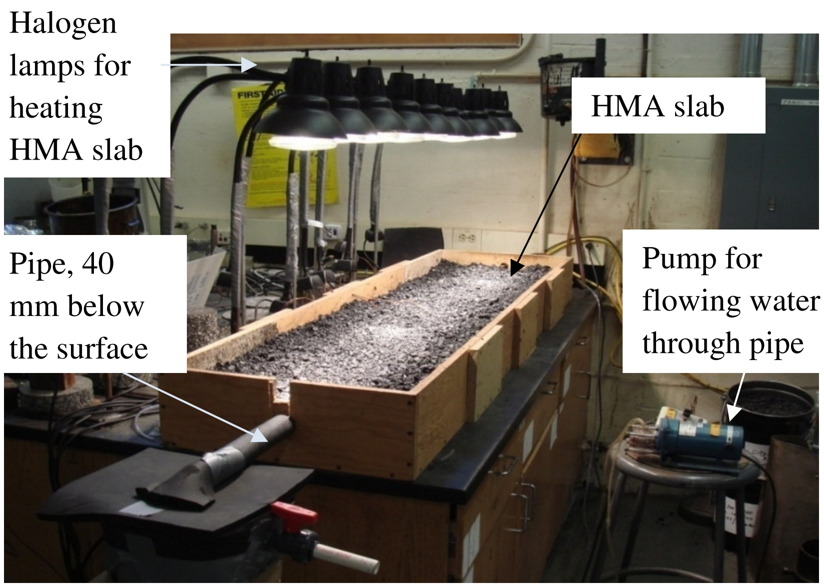
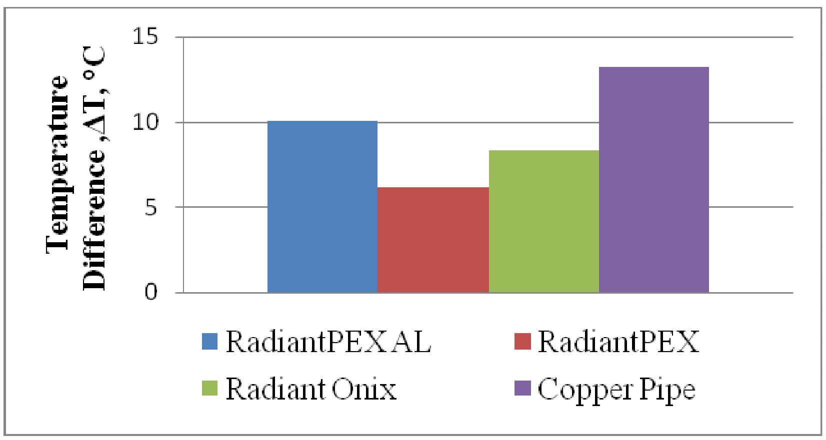


Figure 14. Temperature Difference between Inlet and Outlet Water for The Different Piping Materials



Experimental Set-up



Note: Radiant PEX AL – cross linked polyethylene, with aluminum layer; Radiant PEX - cross linked polyethylene; Radiant Onix - Ethylene propylene diene M-class rubber (EPDM) with Aluminum oxide layer

Effect of Reducing Temperature of Pavement

One can determine the effect of reduced near-surface air temperature (caused by a reduction of the pavement temperature) using the Urban Heat Island Mitigation Impact Screening Tool (MIST), (Sailor, and Dietsch, 2005). Indirect benefits include savings in energy consumption in buildings as well as lowering of ozone concentration, and hence improvement in air quality. For example, in Houston, savings in energy consumption in post 1980 residential buildings can be as high as 22%, and reduction in 8 hour ozone concentration can range from

2.5 to 4.2 ppb, for a reduction of 5°F (2.7°C) in air temperature, caused by a reduction of pavement surface temperature (Table 2). As a comparison, results from a change of pavement albedo by 0.5 are also shown.

Table 2 Effect of Reduction in temperature
Reduction in 5°F Air Temperature on Energy Consumption and 1 Hour/8 Hour Ozone Concentration (From MIST)

Inputs
Location: Houston; Mean Temperature: 73.4°F; Cumulative Degree Days (CDD): 2,810
Heating Degree days (HDD): 1,552; Typical maximum 1 hour ozone (ppb): 182
Typical maximum 8 hours ozone (ppb): 138
Outputs:
Savings in energy consumption:
Post 1980 buildings
Electricity heated buildings: residential: 22%; office: 11%; Retail: 13%

Reduction in ozone concentration
For 1 hour ozone concentration -5.6 to -3.4 ppb
For 8 hour ozone concentration: -4.2 to -2.5 ppb

Increase of albedo by 0.5
Outputs:
Savings in energy consumption:
Post 1980 buildings
Electricity heated buildings: residential: 20%; office: 9%; Retail: 12%

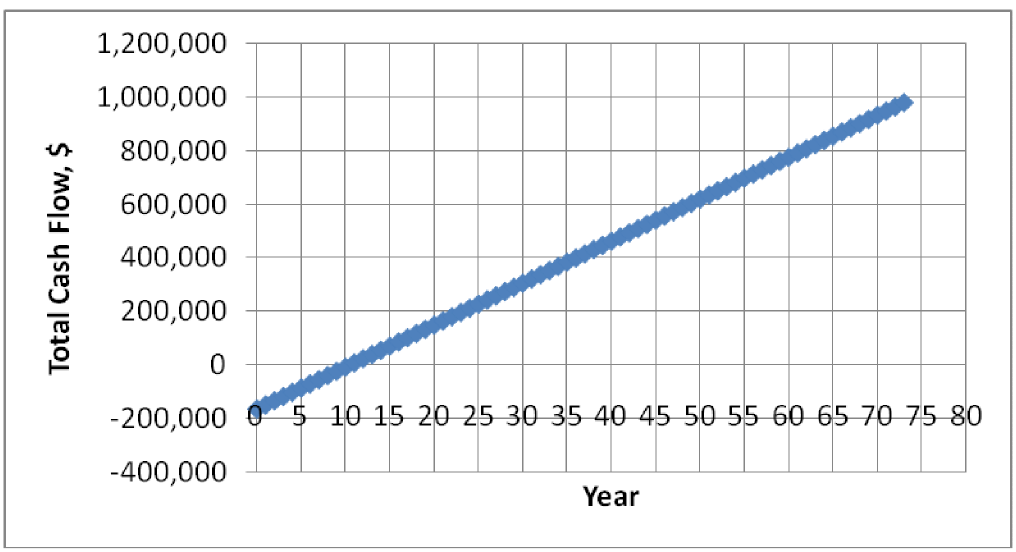
Reduction in ozone concentration
For 1 hour ozone concentration: 9.5 to -4.3 ppb
For 8 hour ozone concentration: -7 to -3.1 ppb

Additional benefits of extracting heat from pavements: Feasibility of Extracting heat from pavements. Extracting the heat stored in pavements can be used for process heating, feedwater for other applications or as a heat exchanger fluid for heating cycle. The water at high temperature could be stored in insulated chambers. Considering the high temperatures shown for southern US (for example, Houston, as shown in Figure 2), water at 50°C can be obtained for a number months during a typical year. This water can be stored in underground insulated chambers and subsequently used for heating buildings. Water at 50°C is acceptable for heating buildings. In fact, radiant heat in floors has to be kept lower than this to avoid uncomfortably hot floors for people walking on it, and to avoid thermal damage to flooring materials. So at the very least, this captured heat would be useful for hydronic heating of buildings during heating seasons. And many industrial processes need elevated temperatures. For example - cleaning/degreasing/rinsing of metal parts is more effective at higher temperatures. Many food processing operations are done at elevated temperatures. The temperature is low for pasteurization, but might be good for other food processing. Anaerobic methane generation needs elevated temperature, greater than 30°C, to work (commonly used to "treat" wastewater high in organics). So the hot water produced could be directed to internal or external heat exchangers in anaerobic methane generators. Also, a heat exchanger could be used to use the water to preheat domestic hot water in buildings – for example, hot water for sinks and showers. The temperature of the water coming in to the building (more than likely at a temperature significantly below room temperature) could be raised before the water enters the water heater.

It would save energy needed for the water heater (electricity, natural gas, oil). Lastly, in many areas the hot fluid (for example, glycol based, with a low freezing point) could be stored and utilized for deicing pavements in winter months.

Economic Feasibility. Detailed economic analyses based on the compiled temperatures of several cities in the US were conducted. An example is shown for here for the city of Houston, TX. The calculations indicate a payback period of 10 years. The initial costs of installation, as well as recurring maintenance costs were considered. The results are summarized in Figure 15. The temperatures were predicted on the basis of currently used models (Solaimanian and Kennedy, 1993) with air temperature data from NOAA (NOAA, 2008). The calculations were done in the following steps: 1. Considering a specific location (Houston) predict pavement temperatures that can be utilized (generally maximum pavement temperature is approximately 20 mm below the pavement); 2. Compute the total energy for every hour of a year (actual data from 2007), as a result of heating of incoming water (at 10°C, 6 liters per minute) to the temperature of the pavement at every hour; 3. Calculate the energy harvested throughout a year (sum of amounts calculated in step 2 for every hour of a year); 4. Assuming a cost of 10c/kWh, calculate the savings in $; 5. For investment, for a 50 m by 50 m area of a pavement, consider copper pipes ($7 per meter), installation and paving of $44 per square meter, pump of 0.25 hp capacity ($200) and operating and installation cost of $1,000 per year; 6. Note that for a total length of 400 m, the pumping power required was calculated to be 0.2 W (Fox and McDonald, 2004). For comparisons, the total energy harvested in one year is 166,811 kWh, whereas the pumping energy required is 6,374 kWh, and the total energy required to raise the temperature of the same amount of water (as considered in calculation of energy harvested) from 10°C to 50°C is 146,677 kWh. The cost of installation will be significantly less if an area that has already been selected for rehabilitation/paving can be utilized.

Figure 15. Plot of Total Cash Flow versus Time



Inference from Preliminary Studies

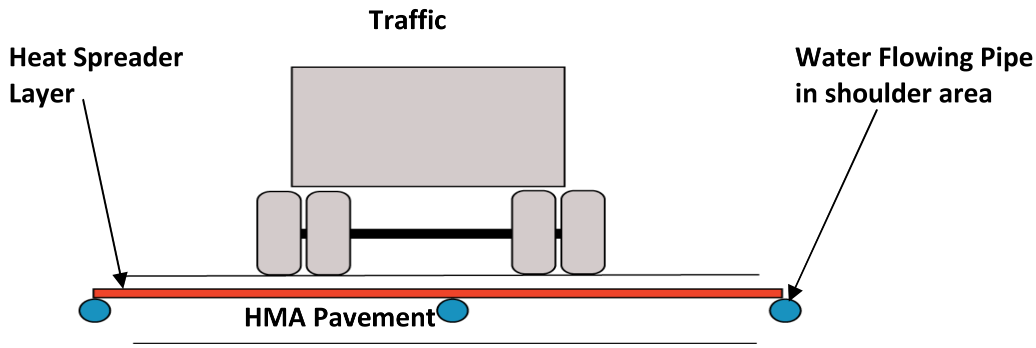
Harvesting of heat from heated asphalt pavements is possible, and such harvesting could lead to a significant drop in the temperatures of the surface and in lower layers, and such a process of harvesting can be improved significantly by using layers of higher conductivity. Furthermore, the reduction in temperature depends significantly on the location of the point with respect to the pipes, and closer the spacing of the pipes, better is the reduction in temperature. Some work in this area has been conducted by other researchers demonstrating the feasibility of the concept (in Japan, Hasebe et al, 2006, Kawakami and Kubo, 2008 and Kinouchi et al, 2004 and Netherlands, Bijsterveld et al, 2001). Note that work conducted in the Japanese studies focused on electricity generating system, and on two different systems: one on water-retaining pavement systems, and the other with altered albedo of the surface material, while the Dutch study focused on determination of stresses around pipes for a system for storing hot water in aquifers. However, one relevant fact is that the Dutch study by Bijsterveld et al (2001) ends with the conclusions and recommendations that stresses in pipes could be excessive, and that research on thermal and other properties of cooling system without tubes (such as using layers) should be conducted.

Practical Problem

Although the concept of removing heat away from the pavement is a valid one, the use of an extensive piping network below the pavement may not be entirely practical. Some of the challenges include effect of pipes on pavement performance, effect of traffic and pavement load on the pipes, maintenance of piping system, and resistance of the piping material (say plastic) to high temperature of lay down of HMA (150-175^{0}C). Note that some of the problems have also been noted by Bijsterveld et al (2001).

Solution. Ideally, a system of minimum number of pipes along with highly conductive layer (henceforth referred to as heat spreader) could be used to transmit the heat both horizontally as well as vertically throughout the pavement, especially in areas that are susceptible to rutting, such as intersections bearing heavy traffic, in hot climatic areas (Figure 16). Conceptually, the spreader would be equivalent to a fin surface extending from the pipe. Depending on the pipe diameter, the number of spreaders should be determined to optimize fin effectiveness. Obviously, metallic fins with high conductivity are ideal for enhanced fin effectiveness. However, for asphalt pavement heating they may pose a number of challenges. Problems with laying down the spreader, and expansion and contraction due to temperature changes can pose major problems. Therefore, a planar non-metallic sheet, (similar to commonly used geogrid in pavement reinforcement) could be used. The material must possess high conductivity, particularly in the lateral direction. In addition a key feature necessary for the system to work is enhanced contact between the heat spreader and the pipe. The interface between the two will constitute a vital part of reduction in surface temperature. As a starting point a currently available graphite product (SPREADERSHIELD, GrafTech International, 2009) has been identified. This material has a high lateral plane conductivity (300 to>500 W/m.K) that is orders of magnitude higher than the cross sectional conductivity. Different grades of the product (with different thermal conductivity) can be manufactured. The hypothesis is that when this material is coupled to a pipe with flowing water, it will act as a fin and help to cool the pavement further. Numerical simulations and experimental work are underway to verify the applicability of heat spreaders.

Figure 16. Proposed Concept of Using a Combination of Heat Spreader and Pipes



CONCLUSIONS AND RECOMMENDATIONS

The authors have proposed a system of using pipes and high conductivity layers underneath asphalt pavements to harvest heat energy, and reduce the temperature of the pavements. The reduction in temperature of the pavement will lead to a reduction in the contribution of asphalt pavements towards the heat island effect. The following major conclusions and recommendations can be made on the basis of the work conducted so far:

1. Both finite element modeling and experimental results have proven the feasibility of using heat energy harvesting as a good method of reducing pavement temperature.
2. Reduction in the temperature of the pavement is dependent on the location and spacing of pipes.
3. Reduction of temperature can also reduce the potential of rutting and hence enhance pavement life.
4. The location and spacing of pipes required for optimum results are of practical concern.
5. Use of high conductivity layers can be used to reduce the number of pipes and provide effective results.
6. Full scale studies in the areas with high solar radiation are needed to understand practical issues and optimize the various components of the proposed system.

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