Cool Pavements Study

Submitted to:

City of Chula Vista
Engineering Department
276 Fourth Avenue
Chula Vista, CA 91910

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Final Report

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Submitted by:

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EXECUTIVE SUMMARY

In an effort to promote the use of innovative energy efficient opportunities, the City of Chula Vista is investigating potential tools to reduce air conditioning demands in buildings. One such tool would be to take measures to mitigate high air temperatures caused by the Urban Heat Island (UHI) effect.

The UHI effect is a condition that has become a growing concern for many cities in recent years. As cities continue to develop, more open land and vegetation is replaced by impervious, heat absorbing structures such as buildings and pavements. During the summer, exposure to sunlight causes these structures to absorb and retain heat and consequently heat the surrounding air. Human activity in urban areas contributes to heat emissions via sources such as air conditioning, vehicles, and industry. For these reasons, air temperatures in urban area can be significantly higher than nearby rural areas. This phenomenon is known as the UHI effect, and *cool pavements* is a strategy that helps to mitigate the effects of UHI contributed by pavements.

To be more precise, cool pavements describe a collection of various technologies that helps reduce temperatures of new and existing pavements. Conventional asphalt pavements produce a dark and impervious surface that can easily absorb and retain heat from solar radiation. These characteristics are the primary reasons for high surface temperatures on conventional asphalt pavements. Darker surfaces have low albedo (solar reflectance) and can easily absorb heat from sunlight. Impermeable surfaces cannot retain moisture, which prevents cooling by means of evaporation. Also, conventional asphalt pavements have moderate heat conductivity, which is the ability to transfer heat through the pavement and into the underlying soil. Heat conduction is a factor in how much heat can be stored in the pavement and thus affects how quickly the pavement cools at night.

Consequently, cool pavement strategies focus on technologies that improve albedo, enable evaporative cooling, and/or reduce heat conduction. Improving the albedo is typically the simplest and most effective method. This can be achieved by selecting pavements or surface treatments that alter the surface to appear lighter in color. The most common comparison between newly paved conventional asphalt and concrete pavement demonstrates that concrete pavements can have a cooler surface due to its lighter color. For this reason, the use of conventional concrete is often considered a cool pavement strategy. There are several such strategies presented in this report, many of which simply modify existing paving technologies with unconventional lighter colored materials. The albedo of conventional (gray cement) concrete, for example, can be further improved by using lighter colored aggregates, white cement, concrete additives, and/or titanium oxide. The report also discusses the use of porous pavements, rubberized pavements, vegetated and non-vegetated pavers, various surface treatments, and shade trees as cool pavement technologies.

There is a range of costs associated with each of the technologies that is dependent on the existing pavement structure, the extent of construction, and the cost of the cool pavement technology itself. Given the wide range of materials, techniques, and application, it was not possible to conduct a traditional quantitative cost benefit analysis. Rather, a qualitative assessment was developed to rate the UHI impact for selected cool pavement technologies.

A cool pavement option with a high UHI impact does not necessarily cost more than the conventional alternative. For example, the use of a light colored fly ash or slag cement to replace portland cement in a concrete pavement will increase the pavement solar reflectance and often is cost neutral or even reduces costs. Alternatively, some cool pavement alternatives have high initial cost, such as clear resin binders with light colored aggregates or titanium dioxide photocatalytic cement. There are also broader impacts (e.g. ease of implementation, longevity, air quality, noise reduction, storm water management) that should be considered when evaluating cool pavement technologies.

Finally, our recommendations include are two-tiered, and uses the ease of implementation as the primary criterion. In the short term (2 to 3 years), it is recommended that:

1. The City review current decision-making processes for selecting maintenance and rehabilitation strategies. A more comprehensive decision making process that incorporates both the UHI effect as well as the broader impacts previously discussed should be considered and then institutionalized.

2. Modify existing treatments to reduce UHI for those strategies with an “Ease of Implementation” rating of 3 to 5 (see Table 6.)

For short term projects, there is no need to change the existing criteria for selecting pavements since the treatments are essentially the same. For instance, the criteria for chip seals currently include arterials and collectors with a Pavement Condition Index (PCI) between 70-100

For the longer term (3 to 5 years), it is recommended that:

1. The City implement a pilot program to construct pavements with the newer strategies e.g. coatings, pigments, pervious concrete, titanium dioxide cement, all of which are relatively new and few agencies in California have implemented them. These have an Ease of Implementation rating of 1 to 2 (see Table 6.) The pilot program will allow the City to “work out the bugs” in developing specifications as well as during the construction and inspection process. It will also allow the City to attract contractors with experience in these products, or at least build up the experience of local contractors with larger scale projects.

2. New maintenance practices may be required for some of these strategies. For example, porous or pervious pavements will usually require periodic vacuuming to remove fines and no seals may be placed in order to maintain their functionality. Vegetated pavers may need mowing or watering. Conventional concrete pavements may require periodic joint sealing. Therefore, the City will need to ensure that these capabilities are in place as part of adopting these strategies.

Finally, in order to monitor the performance of any new strategies adopted, it is recommended that the City implement a program to monitor and measure the performance of these cool pavement strategies. Measurements should be performed at least once a year, and preferably twice a year to measure any changes. Standard test methods have been defined by ASTM International that will assist in determining the appropriate tests and measurements.

1. INTRODUCTION & BACKGROUND

The City of Chula Vista is expending great efforts to promote innovative energy efficiency opportunities at municipal facilities and throughout the community. One potential tool that has been identified to lower cooling demand in air conditioned buildings through mitigation of the Urban Heat Island (UHI) effect is the use of reflective or cool paving. Based on current pavement technology, there are three strategies available to reduce the pavement's contribution to the urban heat island effect: a surface that reflects a greater amount of solar radiation, the ability of the pavement to cool at night, and/or promote pavement cooling through evaporation. A fourth option, which is not directly a pavement property, is to prevent solar radiation from reaching the pavement surfaces (e.g., use of shade trees).

This study investigates and discusses current cool pavement strategies; determines their applicability for existing and new pavements, including both streets and parking areas; discusses the feasibility of using these strategies; identifies current and ongoing costs and benefits in comparison with existing paving methods; and discusses programs that are in place by other agencies.

1.1 Initiatives

Recently, local and statewide initiatives have been started to help mitigate the urban heat island effect. As part of this effort, both the City of Chula Vista and the State of California are actively incorporating cool pavement strategies and the use of shade trees into design guidelines and recommendations.

1.1.1 Local Initiatives

The City of Chula Vista recognized the importance of climate change and has been working to develop strategies to reduce greenhouse gas emissions and to lower future risk from local climate change impacts. A Climate Change Working Group was formed to create climate adaptation strategies to help the community find viable ways to combat climate change. The strategy and implementation plans were created in May 2011. Cool pavements and shade trees are two of the eleven strategies put forth with specific implementation plans.

The strategy for cool pavements outlined a two year project of development, study, and testing of types of cool pavements. The ultimate goal of the strategy was an ordinance to incorporate reflective or cool pavements into all municipal projects, parking lots and streets, and new private parking lots over a specific size. To accomplish this goal, a comprehensive study was required to evaluate and test multiple reflective paving technologies. The costs, benefits, drawbacks, performance, and incentive opportunities required research and consideration for each technology (City of Chula Vista, May 2011).

As of May 2012, the Municipal Code of the City of Chula Vista requires the installation of trees in parking lots and new subdivisions. Shade trees in all new parking lots (public, private, and Capital Improvement projects) are required to achieve 50% canopy cover over the parking stall areas within 5 to 15 years after planting given good growing conditions. Cool paving and/or shade structures may be used to achieve 50% coverage in areas where the use of shade trees is limited due to space requirements for utilities, site lines, accessibility or parking lot design features. Street trees in all new public and private streets (excluding alleyways) need to be appropriate for the space available to plant them, as determined by the City of Chula Vista Arborist, in order to maximize shade coverage. Healthy existing trees that can be integrated in the proposed design will be credited 150% of the anticipated shade coverage of a new tree in the same location.

1.1.2 State Initiatives

The State of California has been on the forefront of creating regulations and policies aimed at lowering greenhouse gas emissions to help mitigate climate change. Assembly Bill 296 is currently in the Senate and would require Caltrans, with coordination of local and state agencies, to create a cool pavements handbook. The current green building standards included a voluntary provision for cool pavements in non-residential areas. AB 296 will adopt existing standards where available and provide an added set of guidelines. The handbook will have construction standards, best practices, and testing relating to cool pavement (Skinner, April 2011).

1.1.3 Other City Plans

Houston and Dallas are two cities that have created their own sustainability and climate change plans. The Houston Advanced Research Center (HARC) created the CoolHouston plan in 2004 for clean air and quality of life benefits. Within the plan, there is a section on cool paving which defined proposed actions and strategies to integrate cool paving options into the region. The plan looks at a ten year time frame and ways to achieve maximum change. The main target areas are parking lot resurfacing, new parking lots, and new streets in residential and commercial areas. Older parking areas were typically resurfaced every five to ten years and this provided the opportunity to use new cool paving methods and techniques to update existing facilities. Some cool paving techniques outlined in the plan are white topping, porous paving, interlocking concrete pavers, cool asphalt, and resurfacing to change the albedo effect (HARC, 2004).

HARC also developed the Dallas Sustainable Skylines Initiative, for the City of Dallas and the Environmental Protection Agency (EPA), which described voluntary programs for air quality improvements. The plan incorporated Leadership in Energy and Environmental Design (LEED®) standards and a comprehensive plan called forwardDallas!. The cool pavements strategy is outlined in three areas: increasing awareness through demonstration and outreach, policies for parking, medians, and freeways, and incentives and regulations. For parking (also for storm water management), the plan suggested reducing impervious surfaces, and incorporating reflective and porous pavement types and shade trees in parking lots (HARC, 2004).

1.2 Urban Heat Island Effect

High air temperatures throughout the day are a concern for many urban areas. Excess summer heat occurring in a city has multiple negative impacts, affecting the health, comfort, and lifestyle of the inhabitants, and also increasing the consumption of energy for air conditioning. The dense concentration of structures in an urban environment, such as buildings, parking lots, and roadways, contributes to the elevated air temperatures. In rural areas, such structures are less congested with more natural vegetation and open land to be found. Vegetation cools the surrounding air through evapotranspiration; a process by which heat is utilized to convert water absorbed from the ground into water vapor, thus dissipating heat and cooling the surrounding air. Evapotranspiration combined with shade provided by vegetation helps to keep the air cooler. The dry impermeable surfaces of most infrastructures are susceptible to absorbing and retaining heat from solar radiation, thus warming the surrounding air. When night falls, the stored heat dissipates slowly and continues to heat the air even after the sun has set. This phenomenon where air temperatures in urban areas are measurably higher than temperatures in the surrounding rural areas is known as the UHI effect (EPA, October 2008).

The severity of the UHI effect varies from city to city. Although even small cities can produce urban heat islands, the UHI effect grows more severe as the city size increases. The annual air temperature in a city with one million or more people can be 1.8° to 5.4°F warmer than the surrounding area, and as high as 22°F on a calm clear night (EPA, October 2008).

1.2.1 Surface and Atmospheric Urban Heat Islands

Heat islands occur both on the surface and in the atmosphere. On a hot, sunny summer day, the sun heats dry, exposed urban surfaces, such as roofs and pavement, to temperatures 50–90°F hotter than the air, while shaded or moist surfaces—often in more rural surroundings—remain close to air temperatures. Surface urban heat islands are typically present day and night, but tend to be strongest during the day when the sun is shining. In contrast, atmospheric urban heat islands are often weak during the late morning and throughout the day and become more pronounced after sunset due to the slow release of heat from urban infrastructure (EPA, 2012). Table 1 categorizes the key differences between these two heat islands.

TABLE 1. DIFFERENTIATING CHARACTERISTICS OF SURFACE AND ATMOSPHERIC URBAN HEAT ISLANDS (EPA, OCTOBER 2008)

Feature	Surface UHIs	Atmospheric UHIs
Temporal Development	• Present at all times of the day and night • Most intense during the day and in the summer	• May be small or non-existent during the day • Most intense at night or predawn and in the winter
Peak Intensity (most intense UHI conditions)	More spatial and temporal variation: • Day: 18 to 27°F • Night: 9 to 18°F	Less variation: • Day: 1.8 to 5.4°F • Night: 12.6 to 21.6°F
Typical Identification Methods	Indirect measurement: • Remote sensing	Direct measurement: • Fixed weather stations • Mobile traverses
Typical Depiction Methods	• Thermal image	• Isotherm map • Temperature graph

Surface Urban Heat Islands

Surface UHIs are defined by an increase in the surface temperatures of exposed urban surfaces compared to the air temperature. Surface UHIs are present at all times of the day and night but are most intense in the day and in summer. During the day, temperature variation is approximately 18° to 27°F compared to a night variation of 9° to 18°F.

Figure 1 shows how temperatures can vary over different land use areas. The pond shown has an almost consistent temperature during the day and night due to the high heat capacity of water. Weather can also influence the amount of temperature rise. The most intense surface UHIs are when the sky is clear and the winds are calm, whereas heavy cloud cover can reduce the warming.

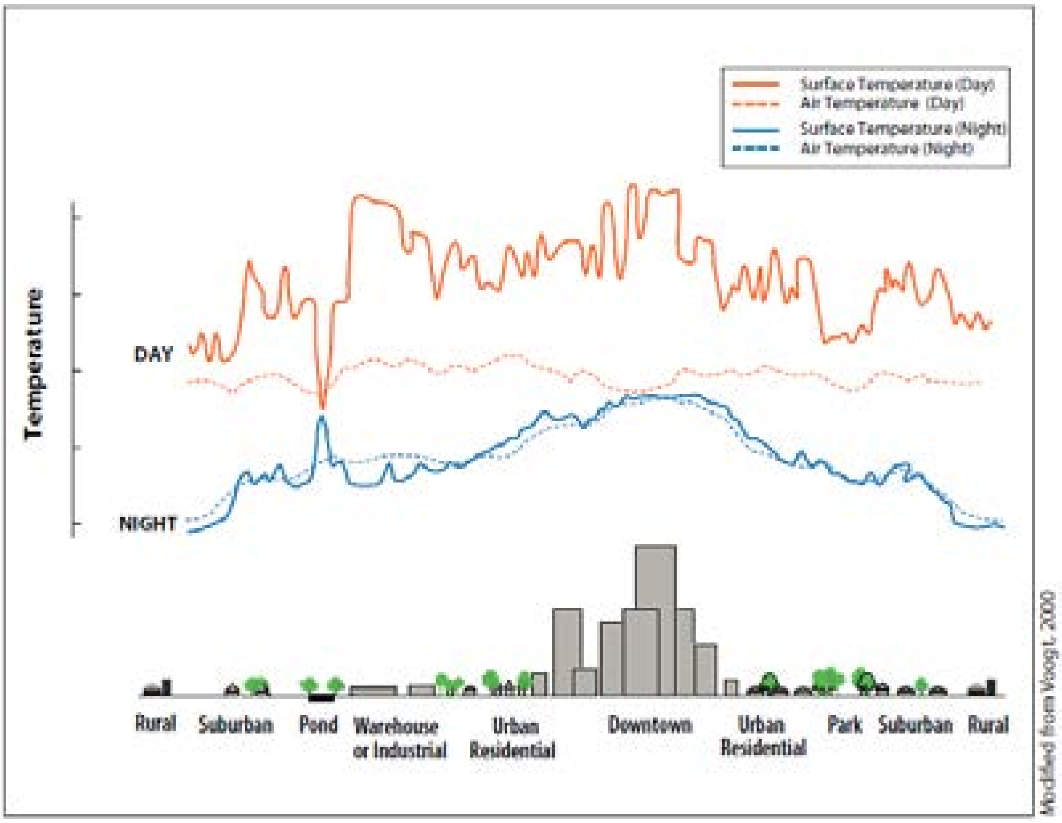


FIGURE 1. VARIATIONS OF SURFACE AND ATMOSPHERIC TEMPERATURES (EPA, OCTOBER 2008).

Remote sensing and thermal imaging are used to identify and depict surface UHIs. Figure 2 shows a thermal image of surface UHIs. The image was taken of Salt Lake City on July 13, 1998. The white areas are around 160°F and the dark blue is around 85°F. The left side of the image with the warmer temperatures is the downtown, urban area, whereas the cooler temperatures are in the surrounding foothills (EPA, October 2008).

Atmospheric Urban Heat Islands

Atmospheric UHIs are defined by warmer air temperatures in urban areas as compared to rural surroundings. There are two types of atmospheric UHIs: canopy layer and boundary layer. The canopy layer is the layer of air where people live, from the ground to below the tops of roofs and trees. The boundary layer starts from rooftop and treetop level and extends up to where urban landscapes no longer influence the atmosphere, typically no more than one mile. The boundary layer UHIs are less common and generally atmospheric UHIs refer to canopy layer UHIs. The atmospheric UHIs are typically small or non-existent during the day and most intense at night or predawn in the winter. There is less variation in the temperatures, ranging from 1.8° to 5.4°F during the day and 12.6° to 21.6°F during the night, than surface UHIs. Atmospheric UHIs can be measured directly using fixed weather stations and mobile traverses, and are depicted with isotherm maps and temperature graphs.

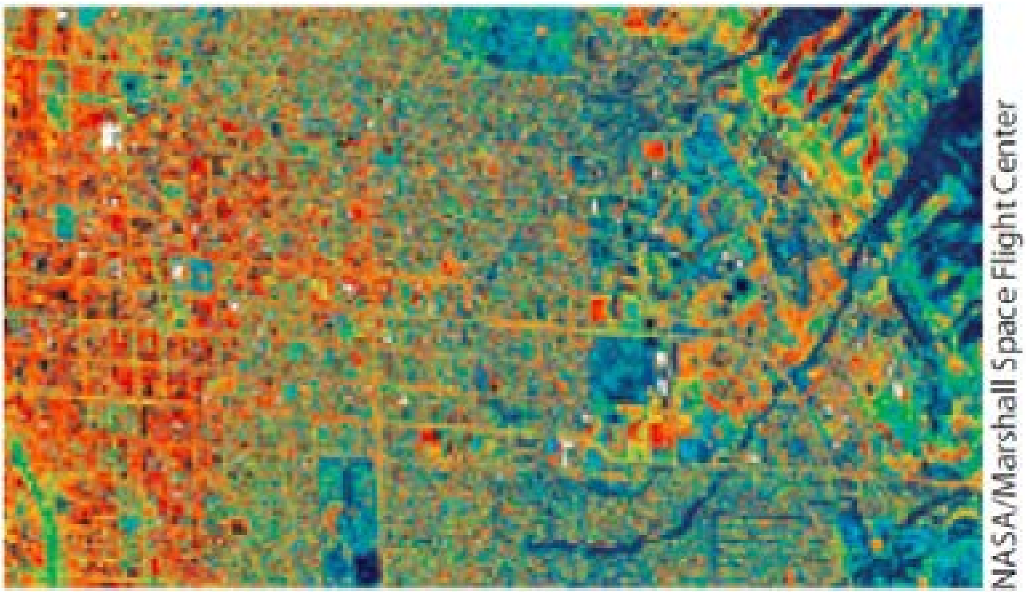


FIGURE 2. THERMAL IMAGE DEPICTING A SURFACE UHI (EPA, OCTOBER 2008).

Figure 3 is a conceptual isotherm map of an atmospheric UHI. The dotted red line indicates a traverse along which the measurements were taken. The measurements become lower with greater distance from the center (EPA, October 2008).

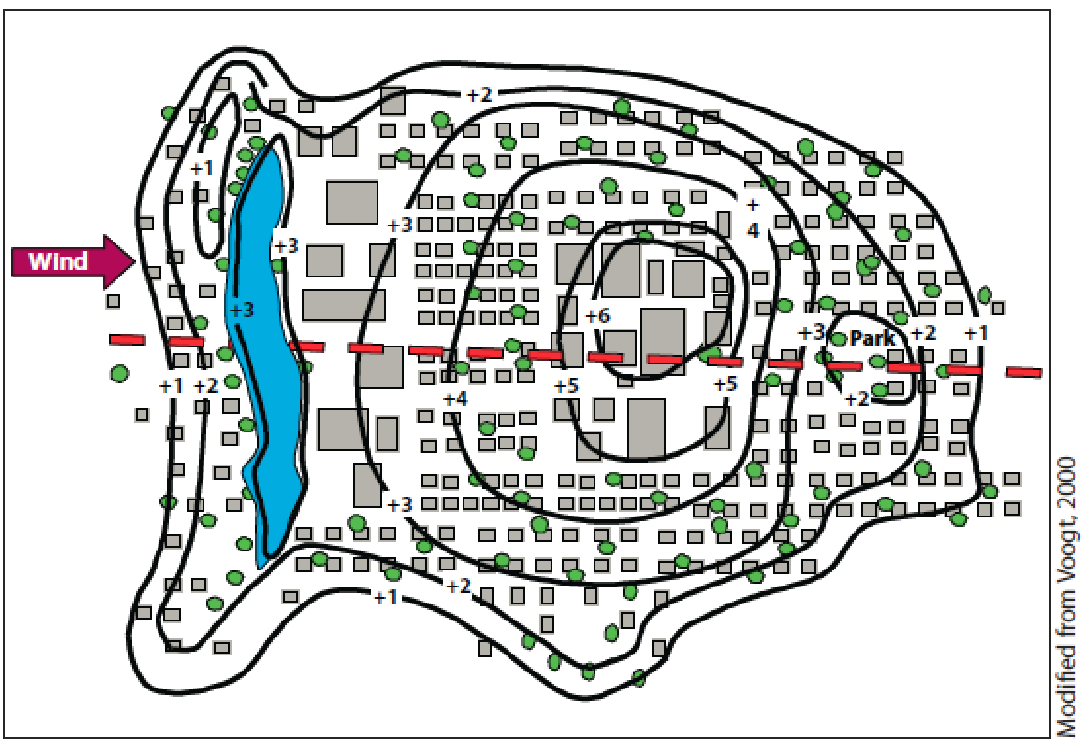


FIGURE 3. ISOTHERM MAP DEPICTING AN ATMOSPHERIC NIGHTTIME URBAN HEAT ISLAND (EPA, OCTOBER 2008).

1.2.2 Formation of Urban Heat Islands

There are several factors which contribute to the formation of UHIs. Two key factors that are given the most attention are the reduction of vegetation in urban areas and the solar reflectivity of urban materials. These are given more attention by the community because unlike other UHI factors, the technology to mitigate them is available via cool roofs and cool pavements. Other factors to consider in the formation of UHIs are urban geometry, anthropogenic heat emissions, weather, and geographical location (EPA, October 2008).

Vegetation and surface cover play an important role in creating UHIs. Vegetated areas and open land dominate the landscape in rural areas. Trees reduce air temperatures through evapotranspiration and provide shade, which helps lower the surface temperature. Urban areas are covered with roofs, sidewalks, parking lots, and roads. Vegetation is slowly lost and the ground cover provides less shade and moisture. Figure 4 shows the differences in urban and rural surfaces (EPA, October 2008).

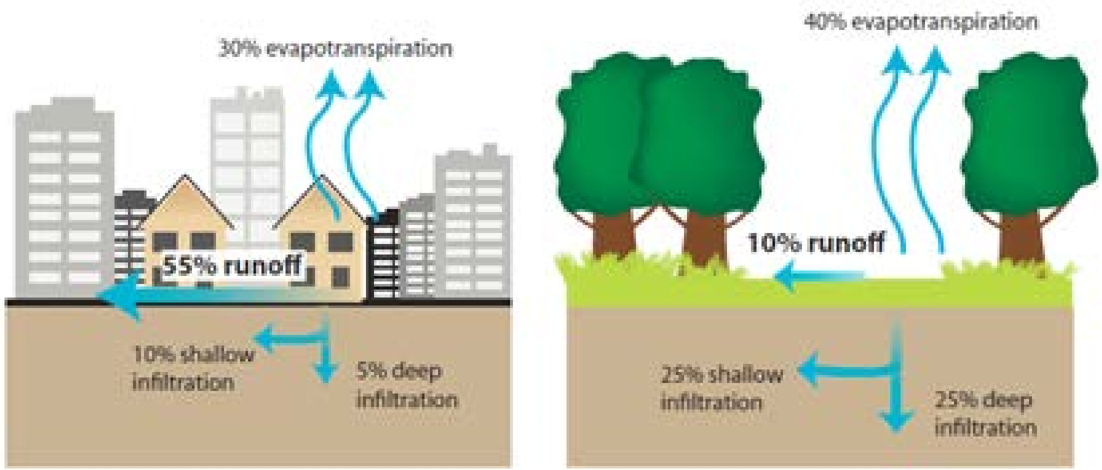


FIGURE 4. IMPERVIOUS SURFACES AND REDUCED EVAPOTRANSPIRATION (EPA, OCTOBER 2008).

In addition to vegetation loss, there are other factors that can create UHIs. The properties of many materials (e.g., asphalt on roofs and roads) used in urban environments can contribute to a higher absorption of solar energy. Urban geometry is also a factor due to the height and spacing of buildings, which can affect the amount of radiation received and emitted. The location of urban environments can also lead to the UHI effect based on wind patterns influenced by the proximity to large bodies of water or mountainous terrain (EPA, October 2008).

1.2.3 Consequences of the Urban Heat Island Effect

Warmer temperatures are the most apparent effect of UHIs. There is also an increase in energy consumption, reduced air quality, impaired water quality, and compromised health and comfort that come from these issues.

The increase in energy consumption is chiefly due to the increased use of air conditioning in buildings and vehicles. The increase in air temperature in a UHI is responsible for 5 to 10% of the urban peak electrical demand for air conditioning and as much as 20% of the population-weighted smog concentrations in the urban area. On a clear summer day, air temperatures can reach as high as 4.5°F higher than the surrounding rural areas, and the peak urban electrical demand can rise by 2 to 4% for each 1.8°F rise in the daily maximum temperature above a threshold of 59° to 68°F. A positive correlation between smog and air temperature can also be inferred based on a study that shows the incidence of smog in Los Angeles increases by 5% for every 1.8°F rise in air temperature when temperatures are higher than 72°F (Akbari, 2005).

Another consequence of UHI is the reduced performance of the pavement over it service life. At early ages, high temperatures make asphalt softer, increasing the risk for permanent deformation (rutting) (McPherson, 2005). Over time, the increase in pavement temperature causes volatilization of the asphalt binder and oxidization, which results in hardening of the binder, making it more susceptible to raveling and weathering as well as fatigue cracking.

1.2.4 UHI Background

Rising air temperatures have been a concern for many large cities throughout the world. However mitigation strategies are still not at the stage of widespread implementation. Japan, for example, has developed cool pavement strategies, but does not practice it due to the limited effect on the urban thermal environment (Kinouchi, 2004). Although cool pavements are a reasonable approach to mitigating UHI, the technology has not materialized much beyond research and speculation. A few reasons for this, as outlined by the EPA, include the complexity of factors affecting reflectivity and heat retention in pavements, the effect of radiative and thermal properties particular to pavement, and the variety of functions associated with design specifications and materials. Such constraints are the reason for the lack of demonstration projects and hard figures needed to promote cool pavements (Levine, 2011).

Despite this, the concern is still warranted as many U.S. cities can have air temperatures 9° to 16°F warmer than the surrounding rural areas (Cool Roofs Toolkit, 2012). During a period of industrialization from 1965 to 1989, loss of vegetation in urban areas contributed to increases in air temperatures of about 1.8°F (Akbari, 2005). Figure 5 shows examples of four U.S. cities where the percent of coverage by paved surfaces ranged from 30 to 45% of the land cover.

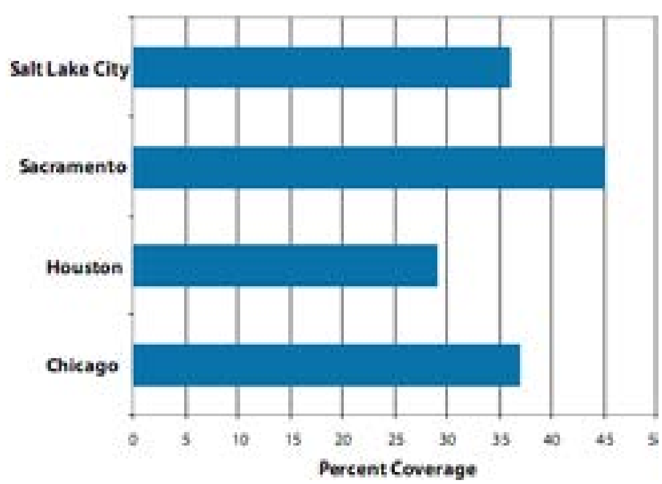


FIGURE 5. PAVED SURFACE STATISTICS FOR FOUR U.S. CITIES (EPA, OCTOBER 2008).

For every 10 to 25% increase in surface reflectance, measured as albedo, surface temperatures could decrease by as much as 1°F. A comprehensive approach to mitigating urban heat islands, through cool roofs, vegetation and cool pavements, can lower temperature by 1.5°F. In 1998, the Heat Island Group projected that Los Angeles could save $90 million per year if they improved the albedo of the city's pavements (Levine, 2011). (Note: the Lawrence Berkeley National Laboratory (LBNL) Heat Island Group is an organization that works to cool buildings, cities, and the planet using cool roof, cool pavement, and cool car technologies. The Heat Island Group's website (heatisland.lbl.gov) is a valuable resource for information on these technologies, current projects, and additional documentation.)

2. COOL PAVEMENTS

As shown in Figure 5, paved areas account for 30 to 45% of land cover in most cities. Typically these pavements are impervious concrete and asphalt that reach summertime peak temperatures of 120°F to 150°F. With temperatures expected to rise with climate change, a need for cooler pavements has been advocated (EPA, October 2008).

2.1 Types of Cool Pavements

There is no single definition of what constitutes a cool pavement. Historically, it is generally defined as a reflective pavement which will help lower surface temperatures and reduce the amount of heat absorbed (EPA, October 2008). Recently there has been a push for permeable pavements to improve storm water management with the added benefit that they lower temperatures as well through evapotranspiration. Pavements with low thermal conductivity like rubberized asphalt may get hot at the surface, but resist the transfer of heat into the substructure. There is also new research in photocatalytic materials, such as some types of titanium dioxide, that will clean the air of certain pollutants while maintaining a highly reflective white surface. All of these types of cool pavements are discussed in more detail below. Research projects and actual applications on successes and failures are also described.

2.2 Changing the Albedo

Albedo, or solar reflectance, is the percentage of solar energy reflected by a surface. The albedo affects the maximum surface temperature of a material as well as the subsurface temperatures. A paving material with a low albedo will absorb more energy, creating a hotter surface temperature and warmer subsurface temperatures because more heat will be transferred into the pavement structure. Table 2 provides some common albedo values for various surfaces.

Table 2. Common Albedo Values (Emerald Cities)

Fresh Asphalt	0.05	Fresh Grey Portland Cement	0.35
Black Soil	0.13	Desert Sand	0.40
Bare Soil (land)	0.17	Cool Pavement Coatings	+0.50
Aged Asphalt	0.20	Arctic Region	0.77
Green Grass	0.25	White Portland Cement	0.80
Aged Portland Cement	0.29	White Roof Coatings	0.88

Conventional concrete and asphalt pavements have an albedo of 0.05 to 0.40, which means they are absorbing 95% to 60% of the solar energy which reaches them instead of reflecting it away. Further, the albedo of these surfaces changes with time due to aging and wear. Figure 6 shows typical albedo over time for concrete and asphalt.

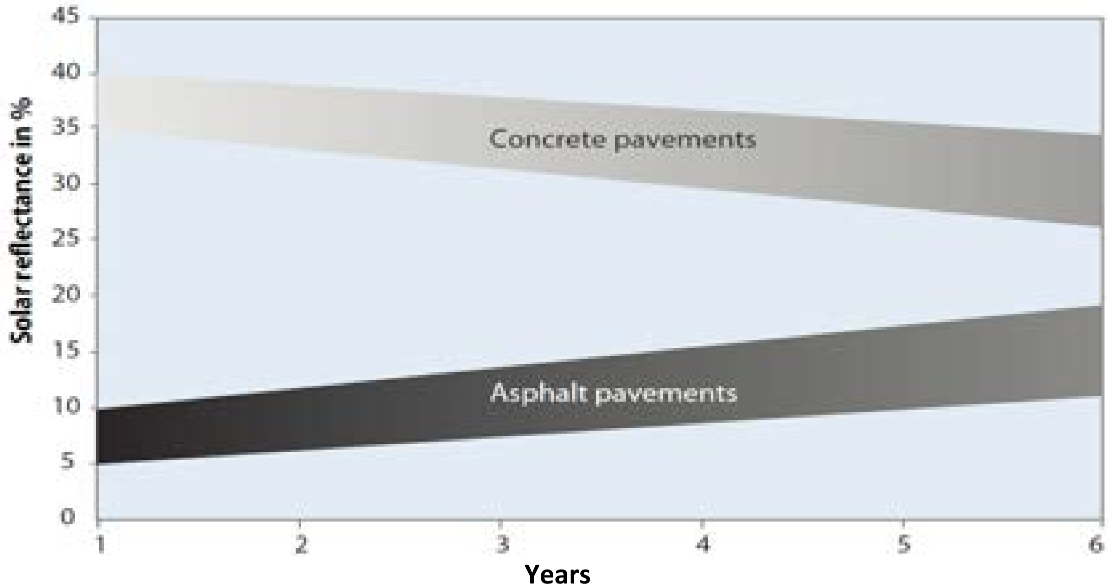


FIGURE 6. TYPICAL SOLAR REFLECTANCE OF CONVENTIONAL ASPHALT AND CONCRETE PAVEMENTS OVER TIME (EPA, OCTOBER 2008).

The albedo of concrete pavements decreases over time due to accumulation of dirt and traffic. In contrast, the albedo of asphalt increases as it ages and becomes more weathered as the binder oxidizes and wears away, exposing the aggregate (EPA, October 2008). The reflectivity of asphalt and concrete pavements approach one another, with one study concluding they become basically equivalent after about seven years in service if left unmaintained (Tran, 2009).

2.3 PAVEMENT HEAT STORAGE

Both low solar reflectance and moderate heat conduction are primary factors in the thermal performance of asphalt pavements. A study (Asaeda, 1996) shows that due to high thermal conductivity, asphalt overlaid portland cement concrete pavement not only stores a large amount of heat during the day, but also releases a large amount of heat at night. The high heat conduction of overlaid pavement allows the pavement to have lower surface temperatures than conventional asphalt pavement at noon. However, at night, the amount of heat released by the overlaid concrete was significantly higher than conventional asphalt due to the larger reservoir of heat stored in the subsurface. In essence, lower thermal conductivity can produce higher surface temperature during day and lower temperatures at night, while high conductivity does the opposite (Asaeda, 1996).

2.4 SOLAR REFLECTIVITY INDEX

The solar reflectivity index (SRI) is a common measurement for albedo in many projects. The SRI of a surface represents the steady-state surface temperature relative to the standard white (SRI=100) and the standard black (SRI=0) surfaces. An iterative approach to determining SRI is present in ASTM E1980 and the albedo of a pavement surface can be measured in the field using a pyrometer according to ASTM E1918 or a portable solar reflectometer in accordance with ASTM C1549. Both a mesoscale and microscale evaluation can be conducted to determine the impact of pavement surface temperatures on the UHI using satellite remote sensing for the mesoscale and handheld infrared thermography for the microscale (Golden, 2006).

2.5 Benefits of Cool Pavements

Figure 7 illustrates how cool pavements and shade trees can benefit energy use and air quality. As can be seen, the impacts are both direct (reduces outdoor temperatures) and indirect (reduces use of air conditioning, which reduces power demand, which results in lower energy consumption).

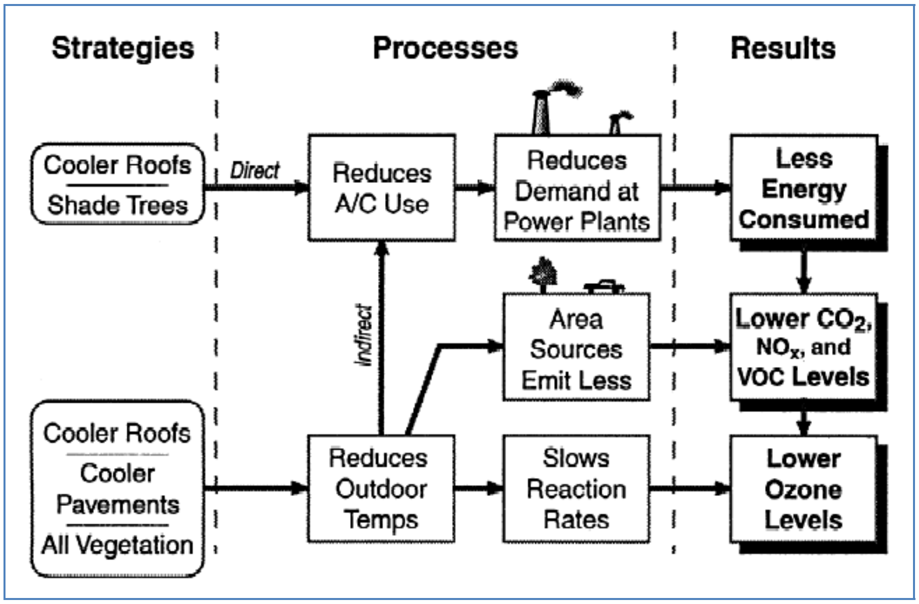


Figure 7. Impact of shade trees, cool roofs, and cool pavements on energy use and air quality (Akabari, Pomerantz, & Taha, 2001).

Direct impacts of increasing albedo provide immediate benefits, altering the energy balance and cooling requirements of particular buildings that take advantage of using highly reflective surfaces. Indirect impacts achieve benefits only with widespread deployment (Akbari, 2005). However, these impacts can be sizable. For example in Los Angeles, it has been estimated that increasing the albedo of 480 sq. miles of pavement by 0.25 would save cooling energy worth $15 million per year and reduce smog-related medical and lost-work expenses by $76 million per year (Levinson, 2001). In a similar study, the Heat Island Group projected in 1998 that Los Angeles could save $90 million per year if the city improved albedo of its pavements (Levine, 2011). From 1930 to 1990, downtown Los Angeles recorded a growth of 1°F per decade. Every degree increase adds about 500 megawatts to the air conditioning load in the Los Angeles Basin (Akbari, 2005).

2.5.1 Energy Conservation

Reflective coatings on building roofs and pavements, and tree-planting schemes, have been tested to demonstrate reductions of energy use between 10 to 40%. Cool (light-colored) pavements also increase nighttime visibility and pavement durability. Heat island mitigation is also an effective air pollution control strategy, more than paying for itself in cooling energy cost savings. It was estimated that the energy savings in the U.S. from cool surfaces and shade trees, when fully implemented, is about $5 billion per year (about $100 per air-conditioned house) (Akbari, 2005). On a smaller scale, a 5.4°F reduction of temperatures in Los Angles reduces power demands by 1.6 gigawatts which results in savings of about $175 million per year (based on electricity prices in 1996), of which $15 million is contributed by cool pavements (Cool Roofs Toolkit, 2012).

2.5.2 Pavement Durability

As stated previously, a consequence of UHI is the reduced performance of the pavement over its service life. Testing and research is underway to determine if using cool pavement materials can improve a pavement's durability and longevity. As a common example, asphalt pavements are less likely to rut at low temperatures (Cool Roof Toolkit, 2012) and oxidative aging of asphalt binder is reduced and curling stresses would be reduced in concrete pavements.

2.5.3 Air Quality

City-wide reduction in temperature can also result in improved air quality because smog (ozone) forms more easily on hot days. Ozone pollution is a major contributing factor in respiratory illness, which is predicted to be the third leading cause of death by 2030. Simulations in Los Angles indicated that light colored surfaces and shade trees could cool air temperatures and thereby reduce smog (in excess of safe concentrations as defined by the EPA) by 10%. The energy and air quality saving that result from increasing the reflectivity of urban surface are estimated to be as high as $10 billion (Cool Roof Toolkit, 2012).

2.5.4 Storm water Management

Heat in storm water runoff can affect the metabolism and reproduction of aquatic life. Accordingly, the Environmental Protection Agency has classified elevated water temperatures as a pollutant in the Clean Water Act (Cool Roofs Toolkit, 2012).

Impervious surfaces increase the volume of storm water runoff, increasing the volume directed into nearby surface waters and/or combined sewers than pervious surfaces. Using permeable pavements, either vegetated or non-vegetated, will allow storm water to pass through the surface and be absorbed directly into the ground. This lowers the amount of storm water flowing directly into nearby surface water (reducing flooding and minimizing warming and into sewer pipes, potentially keeping untreated sewage from entering local water sources.

2.5.5 Noise Reduction

Permeable pavements create an open surface which can reduce tire-pavement noise by two to eight decibels, keeping the noise levels below 75 decibels (EPA, October 2008).

2.5.6 Safety

Permeable pavements have added safety characteristics compared to conventional pavements. Water is allowed to drain through the permeable pavements and does not create puddles that cause hydroplaning. Permeable pavements also reduce water spray, increases traction, and improve visibility by draining away water that may create glare (EPA, October 2008).

Safety in parking lots can also be enhanced by using paving materials that address the UHI effect. For example, it takes about 30% more lighting fixtures to have the same amount of lighting on low albedo pavements than high albedo pavements (Riley). The lighter pavement creates a brighter area and a safer environment.

2.5.7 Health and Outdoor Recreation

Parking lots are normally large areas that would be ideal for outdoor gatherings. Cool pavements would allow events to take place on the lots during hot summer months at reasonable temperatures. Figure 8 shows Reliant Stadium's, 317,000 ft² parking lot of Grasspave² (to be discussed later) in Houston, TX. The Grasspave² creates a cool parking lot that is able to park cars as well as allow other outdoor events to take place on the "grass".

From a practical sense, high albedo cool pavements provide a cooler sensation for urban inhabitants than conventional low albedo pavements, reducing heat conduction through the feet of pedestrians as well as upward long-wave radiation (Kinouchi, 2004). Citywide implementation of cool roofs, cool pavements, and shade trees will, on average, reduce a city's ambient air temperature by 4° to 9°F in the summer months. Lowering air temperatures in a city provides a more comfortable environment for the populace to live in and promotes a healthier lifestyle. Also, cool roofs and cool pavements can reduce the risk of death from heat waves. For example, Chicago incurred 739 deaths in the heat wave of 1995, in which virtually all deaths occurred on the top floors of buildings with dark roofs (Cool Roofs Toolkit, 2012).

FIGURE 8. RELIANT STADIUM'S PARKING LOT AND OUTDOOR EVENT SPACE.

2.5.8 Leadership in Energy and Environmental Design

The Leadership in Energy and Environmental Design (LEED®) certification system, according to some programs, can award up to three points for construction projects that provide any combination of the following cool pavement strategies for up to 75 percent of the site landscape (Tran, 2009):

1. Shading hard surfaces on the site with landscape features,
2. Using high-reflectance materials with a minimum Solar Reflectance Index (SRI) of 29, and
3. Utilizing an open grid pavement system.

The rating system helps to identify and implements projects that use green construction techniques and operation. Various LEED® initiative and incentive programs may also be available at the federal, state, and local level.

2.6 LIMITATIONS OF COOL PAVEMENTS

One study found that the widespread use of high albedo pavements may cause the surrounding buildings to absorb part of the reflected solar radiation and thereby increasing the wall temperatures. A simple urban energy balance model for mesoscale simulations (SUMM) was employed to calculate the energy balance and surface temperature at each face of the urban canopy (i.e., roof, floor, and four vertical walls). It was determined from the model that total sensible heat flux, temperature of urban canopy facets, and the overall canopy albedo was dependent on the pavement albedo and urban geometry (Kinouchi, 2004).

The visible reflectance of pavement is also of interest to transportation engineers concerned with lane marking and artificial illumination of roads (Levinson, 2001). Although highly reflective pavements might make lighting more efficient, it may not provide the same lane demarcation as less reflective pavement surfaces.

It is inevitable in the case of most high albedo pavements that they will naturally darken over their lifetime due to soiling. Therefore, a strategy to clean/renew the surface albedo should be a consideration as part of a cool pavement strategy. The exceptions are permeable pavements and rubberized pavements which do not rely entirely on surface albedo for cooling. Also, concrete pavements with titanium oxide can reduce pollutants from vehicle emissions.

In contrast, it is known that conventional asphalt surfaces lighten as they age and weather. If it were possible to extend the age at which the surface is maintained, this would help keep the albedo higher for a longer period of time. Alternatively, if high albedo surface treatments are used to maintain the surface, this would help increase the albedo.

It is noted that some light colored surface treatments are not durable enough to be applicable to roads with heavy or even moderate traffic or roads with moderate distresses. Surface treatments such as chip seals, fog seals, sand seals, and slurry seals, for example, are typically used as preventive measures in low traffic conditions on pavements in good condition. However, outside these areas of application, there are valid concerns of durability and safety. The City of Chula Vista customarily uses chip seals covered by fog and sand seals as a preventive maintenance on arterial and collector streets. The use of the fog and sand seals will decrease the surface's albedo and contribute to the UHI effect.

3. COOL PAVEMENT STRATEGIES

This chapter lists and discusses potential pavement technologies and strategies for reducing UHI. Strategies for cool pavements fall into two broad categories:

1. Use of high-reflective, porous paving materials and/or thinner pavements to reduce absorption and retention of heat (Tran, 2009).
2. Use of urban landscape and vegetation to reduce direct sunlight on pavement surfaces;

This chapter of the report focuses on methods for reflective or porous pavements. The next chapter discusses the use of urban landscape and vegetation.

Most strategies that rely on high albedo to keep the pavement cool will lessen in effectiveness over time. This is due to exposure to environmental factors such as soiling that naturally darken the pavement. However, conventional asphalt which is black to begin with, will lighten over time as long as it is not maintained with a treatment that again darkens the surface.

Another important consideration is the effect urban geometry has on the strategy. Since high albedo pavements reflect a higher percentage of solar radiation, it means a larger amount of reflected radiation will be directed at surrounding buildings and other upright structures.

In the case of permeable pavements, the effectiveness of evaporative cooling is dependent on the availability of moisture in the pavement. Supplemental moisture (e.g., watering the pavement) may be a consideration in such cases. Regardless of climate, the void structure of permeable pavements may also help insulate the subsurface from heat absorption (EPA, October 2008).

3.1 STRATEGIES FOR NEW CONSTRUCTION

Cool pavement strategies can be applied to new pavements or existing pavements. The cool pavement strategies listed in the following subsections are applied through reconstruction or major rehabilitation activities, such as removing and replacing of the pavement surface or overlaying the existing surface with a thick new surface.

3.1.1 Conventional Asphalt Pavements

Conventional asphalt is the most common type of pavement surface. It is quickly and easily placed, and has a wide range of applications, from low volume parking lots to roadways under high traffic conditions to airport runways. It offers drivers a smooth driving surface with good skid resistance and white line visibility. With proper design and maintenance asphalt pavements can last for many years. Asphalt pavement is also easily recyclable and reprocessed into new pavement when needed.

However, conventional asphalt pavements normally have low albedo due to their dark and impervious surface, which makes them prone to absorbing and storing heat from solar radiation. Because of this, peak summertime asphalt surface temperatures can reach as high as 120° to 150°F (Cool Roofs Toolkit, 2012). The albedo of conventional asphalt pavements can be increased by using light colored aggregates, which become exposed as the asphalt weathers. Limestone for example, is a light colored aggregate that is naturally available throughout many parts of the country (EPA, June 2005). These light colored aggregates are often used in decorative pavements and are available locally, according to contractors. However, local quarries should be consulted to check the availability of specific aggregates or to obtain aggregates in sufficient quantities for paving projects.

Conventional asphalt pavement will normally lighten in color as it ages due to oxidization of the binder. The albedo of asphalt concrete at initial construction is approximately 0.05 to 0.10 and increases as it ages, to about 0.12 to 0.18 at 6 years (EPA, October 2008). Asphalt pavements can be constructed with high albedo materials or can be constructed conventionally and subsequently modified using a surface treatment or coating to improve its surface reflectivity. High albedo materials that can be used in the initial construction include light colored aggregate, color pigments, sealants, etc. The use of light colored aggregates can improve albedo by 0.15 to 0.20 in a freshly laid pavement (Levine, 2011). Treatments that can be applied after installation as a preventive maintenance activity and concurrently improve solar reflectance include chip seals and sand seals with light colored aggregates, surface coating, and grinding (if light colored aggregates are used).

3.1.2 Resin-based Pavements

Resin-based pavements use a clear tree resin in place of the typical black petroleum-derived asphalt binder. This allows the pavement to take the natural appearance of the aggregates used in the mix. Because the pavement takes on the color of the aggregates, resin-based pavements can be lighter in color and have better solar reflectivity than conventional asphalt pavements if light colored aggregates are used. Resin-based pavements have typically been used for hiking and biking trials.

Aside from resin-based pavement, a variety of colorless and reflective synthetic binders are available for use with light colored aggregates. These are typically used in surface courses for sports and leisure areas (Tran, 2009).

3.1.3 Porous Asphalt Pavements

Porous asphalt is similar to conventional asphalt, except the percent of smaller fine aggregate particles in the mix is significantly reduced or removed. By reducing this fine material, the percent voids is increased, and the pavement becomes permeable. This allows storm water to drain through the pavement into to the underlying storm water recharge bed (a stone bed, typically 18 to 36 inches in depth). The stone bed allows storm water to slowly infiltrate into the soil. Soils should have field verified permeability rates of 0.5 inches per hour and a minimum 4 foot clearance from the bottom of the system to bedrock or the water table. Two common modifications to the design porous asphalt systems are (1) the amount of storage in the stone reservoir and (2) the addition of perforated pipes near the top of the reservoir in case of overflow (EPA, September 1999).

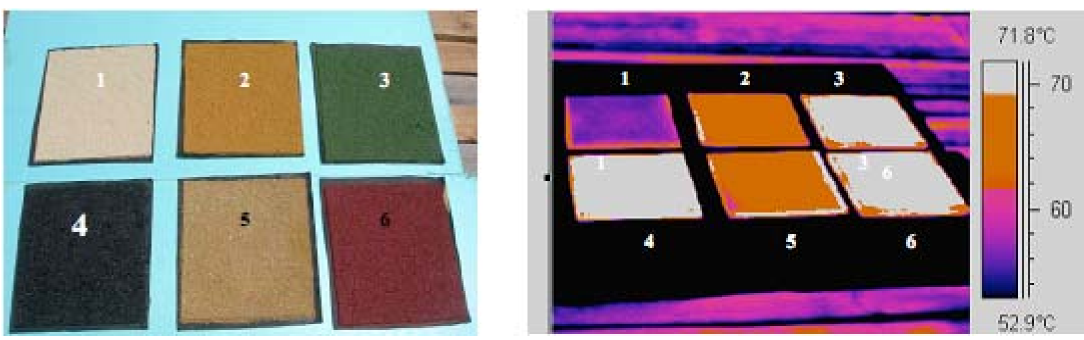
Porous asphalts have been used as a means to control surface runoff and meet storm water regulations. They also have the added benefit of filtering some pollutants from runoff if properly maintained. However, a risk of ground water contamination does exist and so it is not advisable to construct porous pavements near ground water drinking supplies (EPA, September 1999). Storm water stored in the pavement can help cool the pavement by means of evaporative cooling, where heat stored in pavement is used up by converting water into water vapor. The porous surface also increases heat conductivity by being more exposed to air. The underlying stone bed causes porous asphalt pavements to be more expensive than conventional asphalt pavement construction. However, they have cost advantages when considering the value of the land used as a retention basin or other storm water management features (NAPA).

Regular maintenance is needed for open graded surfaces to prevent dust and other particle matter from clogging the surface (Levine, 2011). Maintenance consists of vacuum sweeping at least four times a year followed by high pressure hosing to unclog pores in the surface layer. Inspection of pavement surface is advisable during the first few months and after construction and after major storm events. Pothole patching and crack sealing may be performed on no more than 10% of the pavement surface area. Spot clogging may be fixed by drilling half inch holes through the porous pavement layer every few feet. Surface treatments should not be used since they will seal the pores on the pavement surface. Rehabilitation of deteriorated asphalt surface entails removal and repaving of the deteriorated porous asphalt layer or layers. Porous pavements are applicable to low volume parking areas, access roads, and residential streets. Areas with moderate to high traffic or significant truck traffic should be avoided. As with all open graded surfaces, noise reduction and improved surface friction are added benefits (EPA, September 1999).

3.1.4 Color Pigments and Seals

Color pigments and seals are additives that can be mixed into asphalt and emulsion sealers. The pigments and seals change the color of an asphalt binder to make the surface appear lighter, thus enhancing its reflectivity. Iron oxide is the most common pigment application, which results in asphalt with a red tone, but there are a variety of pigments that offer many colors. Color pigments and seals are typically used for decorative purposes on driveways, walkways, and bike paths.

Figure 9 shows colored samples of thin layered asphalt (0.2 inches). These have higher solar reflectance and cooler surface temperatures than conventional asphalt (shown in No. 4) mainly due their high near infrared reflectance. The greatest difference in surface temperature was 27°F, which was recorded in an off-white sample (Synnefa, 2009).



(A) (B)

FIGURE 9. VISIBLE (A) AND INFRARED (B) IMAGES OF THE FIVE COLOR THIN LAYER ASPHALT SAMPLES AND BLACK CONVENTIONAL ASPHALT SAMPLE (SYNNEFA, 2009).

3.1.5 Rubberized Asphalt Pavements

Rubberized asphalt is made by blending recycled crumb tire rubber with asphalt, creating a binder that can be used with conventional and recycled aggregates. The primary benefits of rubberized asphalt include being cost effective, durable, safe, quiet, and more environmentally friendly than traditional materials (Gauff, 2012). Pavements constructed with rubberized asphalt have low thermal conductivity and therefore, less heat storage capacity. Since less heat is stored in the substructure, a rubberized asphalt pavement cools more quickly at night than compared to conventional asphalt pavements of the same thickness. While there is a difference in heat storage capacity, surface temperatures during the day should be similar between rubberized and conventional asphalt pavements. Similar to porous pavements, rubberized asphalt has better thermal insulation. However, further investigation is needed to determine the effectiveness of rubberized pavement as a cool pavement as only limited studies have been conducted on pavements of widely varying characteristics.

3.1.6 Texturing/Grouting of Open-Graded Course with Cementitious Materials

Texturing is a process that consists of first laying the asphalt, compacting it into a patterned form, and then finishing it with a polymerized cement coating. Salviacim® and Densiphalt®+D99 are a proprietary semi-rigid surfacing process consisting of an open-graded asphalt concrete with 20 to 25 percent voids filled with a high-strength cementitious grout. The reflectivity of the grouted surface is expected to be similar to that of concrete materials. Densiphalt can also be used to protect against fuel spillage and to increase resistance to abrasion and rutting (Tran, 2009).

3.1.7 Gritting with Light-Colored Aggregate

Surface gritting involves spreading light colored aggregate over newly placed HMA and pressing it in with a roller. Surface gritting can lighten the color of asphalt as well and provide improved surface friction (skid resistance). Gritting of an existing asphalt pavement may result in vehicle traffic kicking grit up off the road and may pose a hazard. While surface gritting may be a viable strategy, further investigation is needed to determine if the construction process will result in uncoated lightly-colored aggregate sufficiently adhering to the asphalt surface (Tran, 2009).

3.1.8 Conventional Concrete Pavements

Conventional concrete is a very common pavement structure, but traditionally has not been used in Chula Vista and surrounding cities aside from alleys and high traffic loading areas such as parking lots or bus pads. Less than 1% of the total pavement area in the City has a concrete surface. Concrete pavements typically take longer to place than asphalt pavements, and in the past were more expensive although this is no longer a given in many markets. Concrete pavements have higher albedo than asphalt due to the lighter color of the portland cement binder. Like asphalt, conventional concrete pavements have an impervious surface which prevents the expenditure of heat by means of evapotranspiration.

There are three major types of concrete pavements, jointed plain concrete pavement (JPCP), jointed reinforced concrete pavements (JRCP), and continuously reinforced concrete pavement (CRCP), JPCP is the most common and JRCP is rarely constructed today. CRCP is restricted to a few markets and is primarily only used for heavily trafficked pavements. Jointed concrete pavements (JPCP and JRCP) have transverse contraction joints across the pavement that allows the pavement to shrink and crack at designed intervals. Steel dowel bars are often placed across these joints to assist in load transfer from one slab to the next. CRCP is not transversely jointed, but is designed to have closely spaced, hairline transverse cracking. The cracks are held tightly together by continuous steel reinforcement embedded within the concrete. Concrete pavement surfaces are textured to provide a skid resistant, quiet surface.

Concrete pavements are more commonly found on state highways that are exposed to high volumes of truck traffic. Unlike asphalt which increases in albedo as it ages, concrete pavements will darken over time due to soiling from traffic and its albedo may drop from 0.35 to 0.40 at initial construction to 0.27 to 0.35 after 6 years (EPA, October 2008).

Like asphalt, the albedo of concrete can be further improved by using lighter colored materials in the initial mix, including slag cement, light colored aggregates, white cement, titanium dioxide, and/or other additives. Studies have correlated concrete albedo with the albedo of the cement and fine aggregate (sand), and after abrasion, with the albedo of the coarse aggregate (rock). The albedo of the cement has a disproportionately strong influence on the reflectance of concrete (Levinson, 2001). This makes the use of lighter colored cement more attractive. Figure 10 and Figure 11 show examples of light colored aggregate material that could be used in concrete. Table 3 shows the albedo of concrete mixes using the aggregates described in Figure 10 and Figure 11.

(1) (2) (3) (4)

Figure 10. Light colored sand aggregate: (1) dark gray riverbed sand (quartz, clay minerals, mica) (albedo 0.20), (2) dark red volcanic sand (basalt) (albedo 0.22), (3) brown sand (quartz, clay minerals) (albedo 0.27), and (4) beach sand (quartz, clay minerals) (albedo 0.45) (Levinson, 2001).

(1) (2) (3) (4)

Figure 11. Light colored rock aggregate: (1) dark red volcanic rock (basalt) (albedo 0.17), (2) black and red rock (granite) (albedo 0.19), (3) white rock (plagioclase) (albedo 0.49), and (4) gold and white rock (chert, iron impurities) (albedo 0.55) (Levinson, 2001).

3.1.9 White Cement

While conventional concrete uses gray cement, white cement is similar except that, as shown in Figure 12, it is lighter in color. This is largely achieved by reducing the iron content in the raw materials from which the cement is produced. As the iron is a fluxing material, this change raises the temperature to which the cement must be processed, consequently raising the cost of manufacturing as well as the emissions associated with production. This is the only real difference as the strength and behavior of the cement and the time it takes for the cement to set and gain strength is the similar. White cement is more expensive that gray cement. White-cement concretes are on average significantly more reflective than gray-cement concretes. The albedo of the most-reflective white-cement concrete was 0.18 to 0.39 higher than that of the most-reflective gray-cement concrete, depending on the state of exposure (Levinson, 2001).

TABLE 3. ALBEDO OF CONCRETE SURFACES USING LIGHT COLORED AGGREGATES (LEVINSON, 2001).

GRAY CEMENT

	Basalt Rock	Granite Rock	Plagioclase Rock	Chert Rock
Riverbed Sand	0.34	0.44	0.41	0.43
Basalt Sand	0.27	0.33	0.38	0.22
Brown Sand	0.24	0.29	0.25	0.19
Beach Sand	0.41	0.44	0.52	0.48

WHITE CEMENT

	Basalt Rock	Granite Rock	Plagioclase Rock	Chert Rock
Riverbed Sand	0.54	0.68	0.69	0.38
Basalt Sand	0.32	0.47	0.57	0.33
Brown Sand	0.54	0.48	0.54	0.39
Beach Sand	0.59	0.77	0.77	0.60

FIGURE 12. GRAY TYPE I-II PORTLAND CEMENT (LEFT) (ALBEDO 0.32) AND WHITE TYPE I PORTLAND CEMENT (RIGHT) (ALBEDO 0.87) (LEVINSON, 2001).

3.1.10 Concrete Additives

Additives are routinely used in concrete to enhance its workability (mixing, placing, consolidation, and finishing during construction), strength, and durability. Supplementary cementitious materials (SCMs), such as slag cement and fly ash, are additives that can also result in lighter colored concrete if the SCMs are lighter in color. Slag cement is normally very light in color and will produce a very light colored concrete. SCMs, such as slag cement and fly ash, are not only economically and ecologically beneficial, but also improve workability, reduce segregation, bleeding, heat evolution and permeability, inhibit alkali-aggregate reaction, and enhance sulfate resistance (FHWA).

3.1.11 Roller-Compacted Concrete Pavements

Roller-compacted concrete (RCC) is not actually a new concept, but is receiving more attention recently due to more refined mix designs and better placing equipment. RCC is defined by the Portland Cement Association (PCA) as a no-slump concrete compacted by vibratory rollers. The initial cost of RCC is lower than that of conventional concrete and is competitive with asphalt concrete in many markets. RCC creates a pavement with a natural appearance, taking on the color of the added aggregate or sand. As with conventional concrete, a lighter colored RCC equates to a high albedo (Nasvik, 2012).

3.1.12 Pervious Concrete Pavements

A pervious concrete pavement allows storm water to pass directly through, thereby reducing the runoff from the site and allowing groundwater recharge. Similar to porous asphalt, pervious concrete is made by greatly reducing or removing the finer aggregate particles in the mix in order to increase the percent of voids. Water stored below the pervious concrete surface reduces pavement temperature by means of evapotranspiration, where heat in the pavement is released as water vapor forms. Pervious concrete naturally has a rougher surface than traditional concrete and is typically used to meet storm water regulations by reducing runoff. The porous surface also increases reflectivity by being more exposed to air. Pervious concrete pavements are applicable to low volume parking areas, access roads, and residential streets. Areas with moderate to high traffic or significant truck traffic should be avoided. As with all open graded surfaces, noise reduction and improved surface friction are added benefits

3.1.13 Titanium Dioxide

Certain forms of titanium dioxide are a photocatalyst, which is a substance that uses solar energy to accelerate a chemical reaction without being consumed in the process. In the presence of sunlight, concrete pavements either containing titanium dioxide cement or coated with a titanium dioxide coatings will oxidize air pollutants from vehicle emissions such as NOx (nitrogen oxides) and SOx (sulfur oxides) as well as break down VOCs (volatile organic compounds). Organic materials such as components of dirt (soot, grime, oil, and particulates), biological organisms (mold, algae, bacteria, and allergens), airborne pollutants (VOCs, tobacco smoke, NOx and SOx), and chemicals that cause odors are all decomposed by the photocatalytic effect (Burton, December 2011).

One study shows that concrete pavements containing titanium dioxide will reduce airborne NOx by 25 to 45% (Kaiser, 2010). Not only does titanium dioxide help to reduce air pollution, but by removing NOx that typically darkens the concrete surface, the pavement better maintains its lighter color, thus enhancing reflectivity over time. The cost of using titanium dioxide cement costs about 50% more than traditional concrete, but the increase in total construction costs is only 10% (Kaiser, 2010). Investigations into the run-off from photocatalytic surfaces are currently underway.

3.1.14 Concrete Pavers

Concrete pavers come in many different forms. This includes permeable concrete nonvegetated block pavers and segmented concrete pavers as well as vegetated concrete grid pavers, which use a concrete lattice to allow vegetation to grow between the lattices. Figure 13 below is an example of vegetated concrete grid pavers.

Block pavers are typically used on driveways, walkways, patios, and other recreational outdoor areas. These pavers are available in a variety of colors and are typically used for decorative purposes. Segmented concrete pavers can be found in industrial or warehouse operations since the interlocking design allow the pavers to withstand higher load conditions. Block pavers and segmented concrete pavers are considered nonvegetated permeable pavement because space between blocks allows water to infiltrate, but is too small for significant vegetation.


FIGURE 13. VEGETATED CONCRETE GRID PAVERS

Interlocking concrete pavers represent the majority of pavers currently in use, including those for both impermeable and permeable pavement applications. The following website provides a good reference on the basic use of concrete pavers in a sustainable pavement system:

http://www.icpi.org/sustainable

Of particular interest in mitigating of the UHI effect, concrete pavers can be precast to form a highly reflective surface, whether through the choice of lighter concrete-making materials throughout, or by integrating a highly reflective thin layer on the paver surface. The latter is especially attractive if titanium dioxide cement is being considered, as its high expense can be offset by minimizing the use of the material. And as described, permeable pavements can reduce surface temperatures through evapotranspiration.

3.1.15 Non-Concrete Permeable Pavers

Grass pavers using a plastic or metal lattice are examples of vegetated permeable pavements. The space between lattices allows for growth of vegetation such as grass. While these pavements are comparable to conventional pavements in their ability to support vehicle weight, they typically are used in low traffic conditions such as alleys, parking lots, and trails in order to minimize damage to the vegetation. Also, they are best suited to climates with adequate summer moisture (EPA, October 2008).

3.2 STRATEGIES FOR EXISTING PAVEMENTS

Reconstruction and rehabilitation is performed on an as needed basis; therefore for most existing pavements, applying strategies that require new construction is unreasonable. In cases where the existing pavement is in relatively good condition, the effective strategy is to apply a surface treatment to change the reflectivity of the pavement surface. Doing this can also extend the life and improve the performance of the pavement due to reduced thermal and environmental stresses (Levine, 2011). Some surface treatments, which are considered preventive measures, can also help extend service life by reducing the rate of deterioration.

3.2.1 Chip Seals with Light-Colored Aggregate

A "chip seal" is a common preventive maintenance activity performed on asphalt-surfaced roads with low traffic volumes. It is typically applied to pavements in good structural condition in order to prolong the pavement's service life and/or enhance surface characteristics. A chip seal is constructed by first placing a thin layer of asphalt emulsion on the existing pavement surface and then broadcasting and embedding graded aggregates using a pneumatic roller. This results in a surface that initially takes on the appearance of the aggregate used in the seal. The use of light colored aggregates in the chip seal would result in surface with much greater reflectivity than a typical existing asphalt pavement, although this reflectivity will diminish with time as the aggregates continue to be embedded into the asphalt under the action of traffic.

Chip seals add little to no structural capacity to the existing pavement. At most a chip seal may be used to repair minor cracks. The primary purpose the chip seal is to seal the surface and prevent further oxidization (aging) of the existing asphalt binder and to prevent water intrusion. Chip sealing results in an impervious surface with increased surface friction.

In Chula Vista, chip seals followed by fog or sand seals have been successfully used as a preventive maintenance activity. Covering the natural color of the aggregate in the chip seal with a fog seal will result in the creation of a dark surface with low albedo. However, there are reasons uncovered chip seals may not be appropriate for city streets. The surface is rough and noise from the pavement is increased. There is also a hazard that comes with loose aggregates being kicked up by vehicles. For these reasons, chip seals are more ideal for low volume, rural roads, slow speed residential streets, and private residential driveways. Also, the use of chips in parking lots needs careful consideration as they may not be durable enough to withstand parking lot conditions (Tran, 2009).

3.2.2 Sand and Scrub Seals with Light-Colored Sand

Sand seals and scrub seals are similar surface treatments, except fine aggregates (sand) are used, and the construction methods differ slightly. A typical sand seal is constructed in a similar manner as a chip seal. Asphalt emulsion is sprayed on to the existing pavement surface and is then followed by application of fine aggregate. The fine aggregate is then compacted into the emulsion and excess aggregate is removed. In the case of a scrub seal, the emulsion and aggregate are separately broomed into cracks and voids in the pavement before being rolled in place by pneumatic tires. The difference between construction methods causes scrub seals to be more expensive but last longer that sand seals.

The expense and performance of a scrub seal is comparable to a chip seal. Like chip seals, sand and scrub seals are often used for preventive maintenance in order to fill low severity cracking and delay pavement deterioration. The use of light-colored sand can be used to enhance the reflectivity of the pavement surface (Tran, 2009) although this enhancement would likely be short-lived as the sand will be quickly embedded fully into the asphalt binder under the action of traffic.

3.2.3 Conventional and Rubberized Slurry Seals

A slurry seal is a mixture of asphalt emulsion, water, well-graded fine aggregates (rocks of special, even sizes), and mineral fillers. Slurry seals are a preventive maintenance activity used to repair minor distress and improves skid resistance. Slurry seals are expected to last 3 to 5 years. Slurry seals are usually black but can be made gray or tan by adding zinc oxide (Gartland, 2001). Rubberized slurry seals are not only more durable, but their thermal properties resist conduction of heat into the substructure.

3.2.4 Microsurfacing with Light-Colored Materials

Microsurfacing refers to an emulsion-based paving system that uses a dense-graded aggregate blend, emulsion, water, and mineral fillers. It is an enhancement of a slurry seal, often using high-quality aggregates and a polymer-modified emulsion. The resulting surface provides good riding quality, skid resistance, and reduced water infiltration. Microsurfacing can also be used to correct bleeding and minor cracking and minor rutting. The use of light colored materials in microsurfacing can increase solar reflectance of the surface. An example of such a microsurfacing material is E-Krete® from PolyCon Manufacturing, Inc. The E-Krete micro-surfacing and StreetBond coating can be used for general-purpose parking lot pavements. A very thin layer (1/8 to 1/4 inch) of these materials is applied on the pavement surface. In general, these do not improve the pavement structure capacity (Tran, 2009).

3.2.5 Painting/Colored Surface Coating

Painting the pavement surface with light colored paint is a basic way to improve surface reflectivity. An example of this technology is the StreetBond™ coating system, which offers seven colors with SRI values of 29 or greater. The coating material used is a combination of cement fortified acrylic resins, epoxy-based polymers and a blend of aggregates to provide a durable color and texture to the pavement surface (Tran, 2009). Figure 14 below is an example of an asphalt concrete pavement where the bicycle lane has been painted green.

FIGURE 14. PAINTED BICYCLE LANE

Brightly colored painting is typically used in parking lots for decorative purposes, but can also be applied to road and building surfaces to help mitigate the UHI effect. However, a concern for driving safety arises when considering white line visibility on a brightly colored pavement.

A study in Japan concluded that certain types of pigments and paint structures are effective in achieving high reflectivity for the near infrared and low reflectivity for the visible light spectrum. In other words, the paint could achieve both low brightness and high albedo by exclusively reflecting the near infrared spectrum of sunlight (Kinouchi, 2004). Solar reflectance can differ from its visible reflectance because visible light (wavelengths 400-700 nm) accounts for only 43% of the energy in the solar spectrum (300-2,500 nm). Another 52% lies in the near-infrared (700-2,500 nm), and 5% in the ultraviolet (300-400 nm) (Levinson, 2001). Figure 15 shows reflectivity with respect to wavelength of trial paint coatings which met the desired criteria. Fine hollow ceramic particles were added to reduce thermal conduction. Ultra-violet radiation exposure testing concluded that changes to albedo from prolonged exposure are very limited yet controlled testing found that the paint coated pavement surface temperature were about 27°F less than surface temperatures of conventional asphalt pavements. Surface temperature of paint coat pavement is slightly lower even at nighttime or in winter (Kinouchi, 2004).

Photocatalytic coatings made with titanium dioxide are under development for treating both asphalt and concrete pavements. These coating are spray-applied and can be used to treat emissions including NOx and SOx. More research is needed prior to implementation (Hassan).

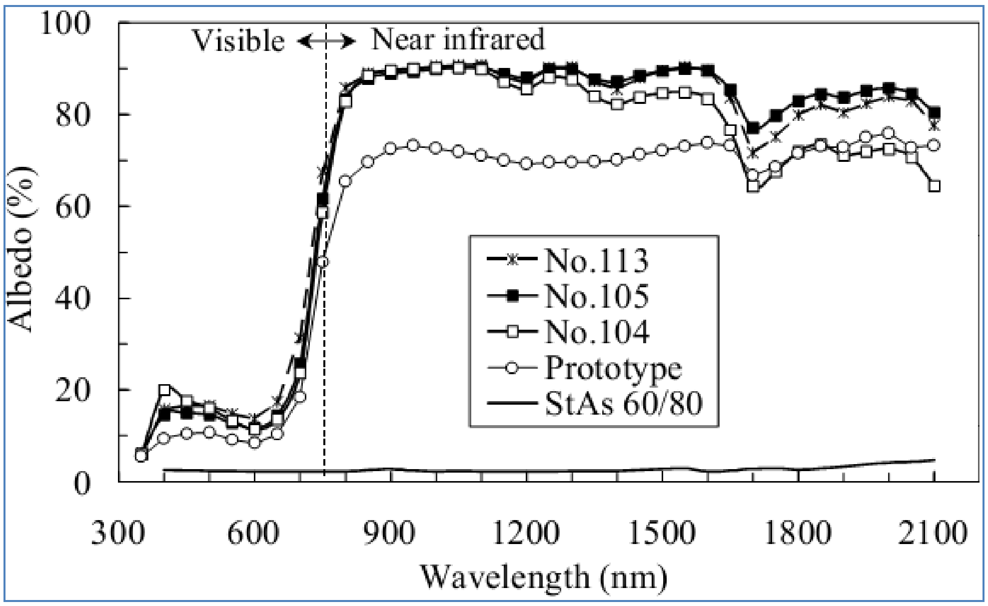


FIGURE 15. REFLECTIVITY WITH WAVELENGTH OF TRAIL PAINT COATINGS (KINOUCHI, 2004).

3.2.6 Whitetopping

Whitetopping is essentially a bonded concrete overlay of an existing asphalt pavement. In urban areas it is often constructed at street intersections and in bus lanes where rutting and shoving of asphalt surfaces is a predominant problem. However, whitetopping is not limited to these applications, as it may also be applied to any existing pavement type including interstate highways, urban arterials, low-volume rural roads, and parking areas. These are all areas where the pavement is being subjected to heavy trucks, particularly in accelerating/decelerating, turning movements, or slow traffic environments. For these areas, whitetopping of asphalt pavements provides for improved serviceability, longer service life, lower life-cycle cost, and better safety.

Conventional whitetopping is typically 4 to 7 inches thick, while ultra-thin whitetopping is 2 to 4 inches in thickness. The concrete surface also provides lighter color and higher albedo than an existing asphalt surface (Pavement Interactive, 2008).

3.2.7 Diamond Grinding

Diamond grinding is a commonly conducted pavement treatment used to restore ride quality and texture to a pavement surface. Most commonly conducted on concrete pavements, diamond grinding is often used to address joint faulting by removing a thin layer of concrete from the surface, typically less than 0.25 inches. The resulting surface has the appearance of corduroy, with the color being dominated by that of the coarse aggregate, as seen in Figure 16. In cases where these aggregates are light in color, diamond grinding can be used to significantly increase the albedo of the pavement. Diamond grinding is a chemical free process, virtually dust free, and has a low carbon footprint making it environmentally-friendly. It has high production rates and is cost effective compared to repaving, overlays, and chip seals (IGGA).

FIGURE 16. DIAMOND GRINDING (FELDMAN, 2009).

3.2.8 Shot/Abrasive Blasting

Shot/abrasive blasting is a process where streams of steel shot or abrasive material (such as sand) are propelled against the pavement surface at a high velocity and a specified angle. Shot blasting is considered a surface treatment which is typically used for surface preparation purposes in advance of coating or overlaying to facilitate bonding of the new material to the old. The steel shot abrades the pavement surface, removing the surface and exposing the underlying aggregates. The texture of abraded surface improves the ability of a coating or overlay to bond to the existing pavement surface. In respect to cool pavements, the natural color of the aggregate used in the pavement mixture is exposed after shot blasting and the pavement surface reflectivity is improved if light colored aggregates are present (Tran, 2009).

Other benefits to shot blasting include abrading polished aggregate to restore skid resistance, and improving drainage. Shot blasting is a water and chemical free process, virtually dust free, and has a low carbon footprint making it environmentally-friendly. It has high production rates and is cost effect compared to repaving, overlays, and chip seals (JDL Surface Innovations).

4. LANDSCAPING AND SHADE TREES

There are two ways—directly and indirectly—in which trees and vegetation will help to reduce accumulation of heat in pavement. Firstly, trees and vegetation provide shade which protects the pavement from direct exposure to sunlight. Secondly, plants can expend absorbed heat by means of evapotranspiration. Evapotranspiration is a process where plants move water from their roots to their leaves where this water evaporates through small pores called stomata. This evaporation into the air is the force that draws water upward against gravity. Heat held in the water molecules leaves the plant as the liquid water turns to vapor, cooling the plant and the air around it (Stabler, 2005).

As noted in Chapter 1, the City of Chula Vista has a shade tree policy that affects parking lots and streets.

4.1 SHADE TREES

The use of shade trees for cool pavements involves planting trees at intervals along the side of a road or along a traffic island. Spacing between the trees depends on the type of tree and its expected canopy size. Besides roadways, shade trees can also be planted adjacent to parking lots or any other paved areas. One study has shown that direct shading of the ground surface and evapotranspiration of water from the leaves results in an oasis effect (isolated reduction of temperature) of 9° to 12.6°F. Street trees benefits often exceed their management cost, but are often perceived as liabilities due to litter drop, root damage, and visibility and security problems (McPherson, 2005).

Shade trees both directly and indirectly reduce the amount atmospheric CO_2. Each tree directly uses carbon dioxide for photosynthesis and indirectly reduces carbon emissions from power plants by reducing demands for cooling energy. The amount of CO_2 avoided indirectly is actually greater than the amount sequestered directly (Akbari, 2005). The cost of planting and maintaining trees can vary from $10 (small trees 5 to 10 feet high) to $500 (large trees) per tree. However, each tree can provide up to $200 in energy savings over the life of the tree depending on the climatic region (Akbari, 2001). It is estimated that tree and vegetation shading can minimize a buildings cooling energy cost by up to 25% per year. When using trees to shade buildings, it is best to situate them along the east and west walls to maximize efficiency (Reyes, 2007).

A study (McPherson, 2005) concluded street trees have a moderating effect on climate conditions that affect pavement performance. This improvement in pavement performance could translate to less frequent repaving schedule and cost savings. The street superintendent in Modesto, California, U.S. estimated that repaving could be deferred 10 years on a well-shaded street and potentially up to 25 years on heavily shaded streets. In order to compare the effect of tree shade on pavement performance, one study developed a PCI and TSI (tree shade index) comparison analysis. Subsequent analyses did not find strong relationship between any one distress and tree shade. However, tests indicate that there is a significant, inverse relationship between shading and road damage (more shade correlated with less damage). Although the results are limited to a select group of pavements in a specific location, they are significant enough to establish a correlation between tree shade and pavement performance and to warrant further investigation (McPherson, 2005).

However, one study conducted in Phoenix, AZ to analyze the effect shade trees have on microclimate (i.e. a local atmospheric area with its own unique climate) suggests that while urban forest cover can modify the microclimate, urban forest cover and latent heat fluxes are not principal determinants of microclimate in the city. Instead, it is suggested that microclimates are a result of vegetation densities interacting with other factors of the urban geometry, such as parking lots and buildings (Stabler, 2005).

Trees provide other added benefits besides energy and air quality savings. They have a positive ecological impact, as trees provide an ecosystem for many animals such as birds. They can also reduce the amount of storm water runoff which may be useful in areas that experience floods (Akbari, 2001). They also have a social impact, improving the livability of communities.

4.2 Tree Selection Considerations

There are several hundred tree species to choose from when initiating a tree planting program. Choosing the best species is highly dependent on the climatic conditions of the region. For example, in dry climates with severe water shortages, it is recommended that drought-resistant trees are chosen to avoid trees that may have a high maintenance cost over their lifetime. Different tree species will grow at different rates and provide different canopy sizes and areas of shade. Large trees, while providing more shade, can be more expensive and smaller trees, while less expensive, provide less shade.

Selecting the correct tree species and strategic placement of trees highly influences the cost effectiveness of a shade tree policy. Proper design for planting trees on a large scale is also necessary in order to minimize damage to underground utilities and to minimize fire hazards. Typically deciduous trees are preferred since they work well to balance energy requirement over an annual period (Reyes, 2007). However, some trees will emit volatile organic compounds which can exacerbate the smog problem.

Studies have been conducted that extensively list and estimate the average VOC emission rates for specific trees. Such a list should be consulted before selecting species for a tree planting program (Akbari, 2001). It is best to consult with local certified urban foresters and landscape architects in order to develop a suitable and cost effective design (Reyes, 2007).

5. RECENT COOL PAVING AND LANDSCAPING PROJECTS

While cool pavements is still a developing technology, many cites have been involved in large scale cool pavement applications. Most apply to low traffic areas such as parking lots and alleyways. Examples of these pilot projects are discussed in this chapter.

5.1 EMERALD CITIES

Emerald Cities™ has developed "cool pavement coatings" and "cold slurry seal" technologies. It is claimed that the resurfacing can reduce the surface heat of asphalt by 20 to 40°F and save 30% on parking lot lighting, as well as providing UHI effect benefits. The coatings form a barrier for the asphalt from UV radiation and water penetration, which can slow the process of asphalt binder aging. It is claimed that this reduces pavement maintenance. The coatings come in a range of colors, from grey, earth tones and decorative tones, all of which will increase the albedo of the pavement surface. Figure 17 shows two projects which used decorative shades of green and blue to coat the parking lots (Emerald Cities).

FIGURE 17. SHERATON HOTEL (LEFT) AND DUFFY CHARTER SCHOOL (RIGHT), BOTH IN PHOENIX, AZ (EMERALD CITIES).

The Emerald Cities™ coating qualifies for the LEED® Credit through Sustainable Sites Credit 7.1: Heat Island Effect and according to the company's documentation, it also qualifies for carbon offset credits under the United Nations. Emerald Cities™ launched a "100 Cities" program to offer their coating installations at a reduced price. In order to qualify, cities have to define a high profile project and have funding to pay for discounted Emerald Cities™ coating and Emerald Cities™ will pay the cost of labor for installation. All cities are elible to participate in the 100 Ciites program. Cities seeking to apply are asked to send a letter of request to application@emeraldcitiesusa.com. Cities that qualify will be given a formal "Letter of Invitiation" for the mayor's written acceptance (Emerald Cities).

5.2 CHICAGO'S GREEN ALLEY PROGRAM

The City of Chicago implemented a Green Alleys Program in 2006 "to create a greener, environmentally sustainable Chicago" (CDOT). Chicago has approximately 1,900 miles of alleyways and most have poor drainage which leads to flooding and infiltration of runoff into the sanitary sewer system. The City designed the green alleys for multiple benefits including storm water management, heat reduction, material recycling, energy conservation, and glare reduction. Five techniques were investigated and used in various combinations to create green alleys: proper alley pitching and grading, permeable pavement, high albedo pavement, recycled materials, and dark sky compliant light fixtures. An example of an alley before and after being made into a "green alley" is shown in Figure 18 (CDOT).

FIGURE 18. ALLEY WITH IMPERMEABLE PAVEMENT AND POOR DRAINAGE (LEFT) AND ALLEY INCORPORATING GREEN ALLEY PRINCIPLES (RIGHT) (CDOT).

The Chicago Department of Transportation started with six pilot alleys and has constructed more than 100 as of 2010 (CDOT).

5.3 WAL-MART EXPERIMENTAL STORE

Wal-Mart created an experimental store in McKinney, Texas to better understand ways in which its company and others like it can improve its environmental sustainability. They looked to reduce the environmental impact from construction to operations and maintenance. Three general areas were studied: vegetation, materials, and energy savings (Wal-Mart Experimental Store).

To create a more environmentally-friendly store, vegetation bioswales were used to create an urban forest, a wildflower meadow, and xeriscaping, reducing runoff and the need for costly storm water piping. The plants also clean the runoff water in a process called phytoremediation, which works well in heavy clay soils where there is low permeability. An urban forest was created to provide shade and give back oxygen to the atmosphere. Trees also help reduce the ambient air temperature, erosion, and amount of runoff. Specific trees were chosen that were compact and required fewer nutrients, making them better suited for an urban environment. A wildflower meadow was built in the open areas of the site. Wildflowers do not require mowing or irrigation, reducing emissions and materials over the life-cycle. The wildflowers selected reseed themselves every year and provide color and interest. Xeriscaping is providing water conservation through creative landscaping. Native grasses were chosen over the traditional Bermuda grass because they do not require irrigation or mowing. Through the use of drought tolerant plants, the site hopes to reduce water use, mowing by eliminating turf grass, and the amount of fertilizers and chemicals needed. Different mulches, from rubber to decomposed granite, were also used to help hold water in the soil. Water conservation was a big criterion when designing the vegetation as Texas summers can have droughts and soaring temperatures (Wal-Mart Experimental Store).

The site also looked at pervious pavements and recycled materials to mitigate the UHI effect and conserve energy. Examples of pervious pavements considered were porous concrete, porous asphalt, open graded aggregate, and open joint pavers. Wal-Mart is testing the pavements to understand their effectiveness for paving an entire parking lot (Wal-Mart Experimental Store).

Another experimental store was opened in Aurora, CO around the same time and one in Sacramento, CA a few years later. Reports have been made on the energy conservation of the interior of the building, but the results and finding of the pavements and vegetation are still ongoing.

5.4 GRASSPAVE² AND GRAVELPAVE² IN CALIFORNIA

Grasspave² and Gravelpave² are two porous paving solutions from Invisible Structures, Inc. The two systems use a series of rings connected on a flexible grid system with 92% void space. Soil and grass or gravel is used to fill the void space creating a very porous surface. The grids can support 2,100 psi empty and 5,700 psi when properly filled. These values are well over the 120 psi truck tire pressure typical of trucks using public highways.

Both Grasspave² and Gravelpave² are made from recycled materials, and through bioremediation, are able to clean pollutants from the storm water. They also reduce erosion and can mitigate the temperature rise from urban heat island effect. Grasspave² has the added benefit of converting carbon dioxide to into oxygen. Figure 19 shows an example Grasspave² in various construction stages (Invisible Structures, Inc.).

FIGURE 19. GRASSPAVE² (INVISIBLE STRUCTURES, INC.).

Grasspave² and Gravelpave² have been used successfully in California, and some of the San Diego area pavement projects are described below. Many sites have used Grasspave² to create a permeable fire line: the Biogen-Idec research campus in San Diego is one example. Grasspave² allows the fire lane to have a natural landscape feel and not require concrete or asphalt. The Allen Airways Flying Museum in El Cajon used Grasspave² to create airplane access and transport. Grasspave² is able to provide enough strength to withstand the weight of the airplanes. In Rancho Santa Fe, Grasspave² and Gravelpave² were used to create guest and main parking lots covering over 15,000 ft^2 with the porous and permeable paving. Figure 20 shows the permeable fire lane and Gravelpave² parking lot (Invisible Structures, Inc.).

FIGURE 20. GRASSPAVE² FIRE LANE AND GRAVELPAVE² PARKING LOT (INVISIBLE STRUCTURES, INC.).

These are some of projects where Grasspave² and Gravelpave² have been able to help with the UHI effect. Other applications are utility access roads, on-street parking, helicopter landing pads, automobile storage yards, trails, and high-use pedestrian areas.

6. LOCAL AND REGIONAL SUPPLIERS AND CONTRACTORS

As part of this study, local and regional suppliers and contractors were contacted to determine if they had undertaken any cool pavements projects and if so, to determine the unit cost of various cool pavement strategies. The following 14 local contractors were contacted:

- TC Construction
- ATP General Engineering Contractors
- ABC Construction Co., Inc.
- Continental Western Transportation
- Bond Blacktop, Inc.
- International Surfacing Systems
- Manhole Adjusting, Inc.
- Pavement Coatings Co.
- Windsor Fuel
- Copp Contracting, Inc.
- Sealmaster
- Ramona Paving & Construction Corp.
- Hazard Construction
- SRM Contracting and Paving

Most either did not have any experience with the cool pavement strategies discussed in this report, or they did not respond to attempts to gather information. Two contractors (Pavement Coatings Co. and Windsor Fuel) only used conventional sealcoats but had light colored seal coats available. Four contractors (TC Construction, ABC Construction Co., Continental Western Transportation, and SRM Contracting and Paving) gave rough estimates on unit prices of various materials and commented on the practicality of using of some cool pavement technologies.

Most local contractors had little to no knowledge of what cool pavement strategies were. They were skeptical about the benefits of localized implementation and the practicality of widespread implementation. Therefore, it is anticipated that any new strategy will initially have a higher construction cost due to the unconventional nature of the job and the local contractors' lack of familiarity. Also, the unit price for most paving depends drastically on the quantity of materials needed and the extent of the project. For this reason, the cost estimates of cool pavement strategies are highly variable.

Contractors were asked by phone to estimate a range of unit prices for pavement strategies based on what they considered a large project and a small project. As the size of the project becomes smaller, the unit cost and the variability of the unit cost generally increases. Table 4 summarizes some of the unit costs that were obtained. Due to the lack of data for local contractors, other sources were used to determine unit costs in the next chapter, such as Caltrans and other suppliers from other parts of the country.

TABLE 4. COST ESTIMATES PROVIDED BY LOCAL CONTRACTORS

	Contractor 1		Contractor 2		Contractor 3		Contractor 4	
Cool Pavement Strategy	Unit	Unit Price	Unit	Unit Price	Unit	Unit Price	Unit	Unit Price
Conventional asphalt	TN	$100-150	TN	$100	SY	$9-12	SF	$1.20-1.50
Light colored asphalt	-	-	TN	$100	-	-	-	-
Rubberized asphalt	TN	$120	TN	$125	-	-	-	-
Resin based pavements	-	-	TN	$150-200	-	-	SF	$2.50
Porous asphalt	TN	$100	TN	$150-200	-	-	-	-
Color pigments and seals	-	-	SF	$0.30	-	-	-	-
Conventional concrete	TN	$200-300*	-	-	-	-	SF	$3†
Roller-compacted concrete	-	-	-	-	-	-	SF	$10
Scrub seals	-	-	-	-	SF	$0.65-0.75	-	-
Sand seals	-	-	SF	$0.20	SF	$0.25-0.30	-	-
Conventional slurry seals	-	-	SF	$0.30*	-	-	-	-
Emulsion sealcoats	-	-	SF	$0.02	-	-	-	-
Open graded friction course	TN	$120	TN	$125	-	-	-	-
Grinding	SF	$2	-	-	-	-	SF	$0.30

*Estimates for construction services not provided by the contractor
†Paving of sidewalks only

7. COSTS & BENEFITS OF COOL PAVEMENTS

As previously discussed, there are many benefits to cool pavements including energy savings, health benefits, increased livability, and in some cases, storm water management. With respect to the cost of the pavement, many techniques result in a higher cost compared to pavements constructed with conventional materials, and that these costs may be greater than the benefit. For resurfacing techniques typical values are under one dollar. An exception to this is the use of SCMs (supplementary cementitious materials) (such as slag cement or light colored fly ash) in concrete pavements, which are generally less expensive or cost neutral compared to Portland cement.

Given the wide range of materials, techniques, and application as discussed in Chapter 3, it was not possible to conduct a traditional quantitative cost benefit analysis. Rather, a qualitative assessment was developed to rate the impact on UHI effects, and this is included in Table 5.

Table 5 includes the following information:

- Technology – cool pavement strategy evaluated in this study
- Albedo – ratings at initial construction and over time, as light colored pavements will darken over time, and dark pavements will get lighter over time.
- Typical range in costs – sources for costs came from contractors, manufacturer's literature, City records and Caltrans. Wide ranges were noted due to low-high ranges in construction quantities and the lack of experience of most local contractors.
- Estimated service lives – a range is included because many expected service lives change as traffic patterns change, so that the actual traffic may be higher or lower than predicted at the time of design. Variations in construction quality, and impacts from utility trenching, construction traffic from development projects etc. are all factors that may affect the service life.
- UHI Impact - The UHI designations are based on how the technology will help address temperatures generated through the UHI effect. A rating of "low" indicates that the strategy has a low impact on mitigating the UHI effect. For example, white cement concrete pavements will have a high impact on mitigating UHI, while in contrast, conventional asphalt pavements will have a low impact.

The cool pavement strategies in Table 5 are further sorted by the type of facilities where they may be constructed, i.e. new road construction, existing road construction, and parking lots and bicycle lanes, respectively. This is to facilitate the selection of an appropriate strategy for a specific facility.

Although UHI is the primary focus of this study, there are other factors that should be considered by the City in any decisions on treatment selection. Table 6 was therefore developed to include these factors, which are:

- Longevity – this rating is based on the service life of the different techniques and is given a high weighting factor because a pavement that lasts longer without the need for serious repairs is considered more sustainable as less materials and energy are expended over the life cycle. A rating of 5 indicated the highest longevity.
- Ease of implementation – this rating is based on three criteria: 1) is the pavement technology currently used by Chula Vista? 2) does the City currently have specifications for construction? and 3) are the materials needed readily available in the area? This category

thus reflects the ease and confidence with which each technique can be implemented. A rating of 5 indicates a strategy that can be currently implemented with little to no changes to existing procedures or specifications, and local contractors are available to bid on these projects. Conversely, a rating of 1 indicates that the City will require significant time or effort to develop specifications and/or find contractors who can bid on the projects.

- Storm water management, Air Quality and Noise Reduction – for each of these categories, each pavement technique was ranked on whether they actively improve or hinder each category. A median value of "3" was given if the technique was neutral, having neither a positive nor negative impact.
- A qualitative rating of low, medium, and high was then assigned, using conventional asphalt and concrete pavements as the benchmarks.

These two different designations (UHI impact and other factors) were created to illustrate how certain technologies, such as conventional asphalt, can have a low UHI impact, but has a broader positive impact. On the other hand, a technique such as white cement concrete can have a high positive impact on UHI, but the overall impact is moderate due to difficulties in implementation.

The impact ratings do not have any direct correlation to cost. Comparison between technologies can be drawn by looking at both the cost and the impact ratings and deciding if the cost is worth the higher or lower impact. Further, some technologies are still emerging, such as resin-based binders and Emerald Cities™ technology, and thus long-term performance data are not available. This increases the risk of unexpected performance or behavior.

TABLE 5. COSTS & BENEFITS OF COOL PAVEMENTS

NEW ROAD CONSTRUCTION					
Technology	Albedo		Range in Cost ($)	Service Life (years)	UHI Impact
	Initial	Over Time			
Arterial & Collector					
Conventional Asphalt	0.05 – 0.10[4]	0.10 – 0.15[4]	$100 per ton	15 – 20	Low
Rubberized Asphalt	0.05 – 0.10	0.10 – 0.15	$125 per ton	15 – 25	Low
Conventional Concrete	0.35 – 0.40[4]	0.20 – 0.30[4]	$4 - $6 per ft^2 [2]	20 – 35	Medium
White Cement Concrete	0.70 – 0.80[4]	0.40 – 0.60[4]	$3.40 - $12 per ft^2 [10]	20 – 35	High
Concrete Pavers	0.10 – 0.80	0.10 – 0.80	$3 - $4 per ft^2 [9]	15 – 20	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	$3 - $9 per ft^2 [6]	20 – 35	High
Residential					
Conventional Asphalt	0.05 – 0.10[4]	0.10 – 0.15[4]	$100 per ton	20 – 30	Low
Rubberized Asphalt	0.05 – 0.10	0.10 – 0.15	$125 per ton	20 – 30	Low
Porous Asphalt*	0.05 – 0.10	0.10 – 0.15	$1 - $2 per ft^2 [2]	15 – 20	Medium
Conventional Concrete	0.35 – 0.40[4]	0.20 – 0.30[4]	$2 - $4 per ft^2 [2]	20 – 40	Medium
Pervious Concrete*	0.35 – 0.40	0.35 – 0.40	$2 - $6 per ft^2 [2]	15 – 25	Medium
White Cement Concrete	0.70 – 0.80[4]	0.40 – 0.60[4]	$3.40 - $12 per ft^2 [10]	20 – 40	High
Concrete Pavers	0.10 – 0.80	0.10 – 0.80	$3 - $4 per ft^2 [9]	15 – 30	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	$3 - $9 per ft^2 [6]	20 – 40	High

*All new construction can be sealed with the exception of porous asphalt and pervious concrete pavements.

TABLE 5. COSTS & BENEFITS OF COOL PAVEMENTS (CONTINUED)

EXISTING ROAD CONSTRUCTION					
Technology	Albedo		Range in Cost ($)	Service Life (years)	UHI Impact
	Initial	Over Time			
Arterial & Collector					
Conventional Asphalt Overlay	0.05 – 0.10[4]	0.10 – 0.15[4]	$100 per ton	15 – 20	Low
Rubberized Asphalt Overlay	0.05 – 0.10	0.10 – 0.15	$125 per ton	15 – 25	Low
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	$0.08 - $0.10 per ft²	3 – 7	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Unknown	Medium
Whitetopping	0.40[1]	0.25[1]	$1.50 - $3 per ft² [2]	10 – 15	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	$3 - $9 per ft² [6]	20 – 35	High
Residential					
Conventional Asphalt Overlay	0.05 – 0.10[4]	0.10 – 0.15[4]	$100 per ton	15 – 20	Low
Rubberized Asphalt Overlay	0.05 – 0.10	0.10 – 0.15	$125 per ton	15 – 25	Low
Chip Seals (Light Colored Aggregate)	~ 0.20[1]	declines	$0.09 - $0.14 per ft² [2]	5 – 10	Medium
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	$0.08 - $0.10 per ft²	5 – 10	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Unknown	Medium
Whitetopping	0.40[1]	0.25[1]	$1.50 - $3 per ft² [2]	20 – 30	Medium

†Technology refers to the use of light colored binder in scrub seals, slurry seals, or cape seals.

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Table 5. Costs & Benefits of Cool Pavements (Continued)

PARKING LOTS AND BICYCLE PATHS CONSTRUCTION					
Technology	Albedo		Range in Cost ($)	Service Life (years)	UHI Impact
	Initial	Over Time			
New Construction					
Conventional Asphalt	0.05 – 0.10[4]	0.10 – 0.15[4]	$100 per ton	20 – 30	Low
Rubberized Asphalt	0.05 – 0.10	0.10 – 0.15	$125 per ton	20 – 30	Low
Chip Seals (Light Colored Aggregate)	0.20[1]	declines	$0.09 - $0.14 per ft^2 [2]	5 – 10	Medium
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	$0.12 - $0.14 per ft^2	3 – 7	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Unknown	Medium
Porous Asphalt*	0.05 – 0.10	0.10 – 0.15	$1 - $2 per ft^2 [2]	20 – 30	Medium
Conventional Concrete	0.35 – 0.40[4]	0.20 – 0.30[4]	$2 - $6 per ft^2 [2]	15 – 35	Medium
Whitetopping	0.40[1]	0.25[1]	$1.50 - $3 per ft^2 [2]	10 – 15	Medium
Pervious Concrete*	0.35 – 0.40	0.35 – 0.40	$2 - $6 per ft^2 [2]	15 – 25	Medium
White Cement Concrete	0.70 – 0.80[4]	0.40 – 0.60[4]	$3.40 - $12 per ft^2 [10]	15 – 35	High
Concrete Pavers	0.10 – 0.80	0.10 – 0.80	$3 - $4 per ft^2 [9]	15 – 30	Medium
Color Pigments and Seals	0.10 – 0.80	0.10 – 0.80	$0.06 - $0.10 per ft^2 [2]	3 – 7	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	$3 - $9 per ft^2 [6]	20 – 40	High
Resin Based	0.33 – 0.55[5]	declines	$3 per ft^2 [2]	Unknown	Medium
Grasspave^2 and Gravelpave^2 *	0.26 & 0.60[8]	0.26 & 0.60[8]	$2.30 - $7 per ft^2 [8]	10 – 15	Medium
Emerald Cities™	0.45 – 0.55[3]	declines	$0.90 per ft^2 [3]	Unknown	Medium
Existing Construction					
Chip Seals (Light Colored Aggregate)	0.20[1]	declines	$0.09 - $0.14 per ft^2 [2]	5 – 10	Medium
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	$0.12 - $0.14 per ft^2	3 – 5	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Unknown	Medium
Whitetopping	0.40[1]	0.25[1]	$1.50 - $3 per ft^2 [2]	10 – 15	Medium
Color Pigments and Seals	0.10 – 0.80	0.10 – 0.80	$0.06 - $0.10 per ft^2 [2]	5 – 10	Medium
Emerald Cities™	0.45 – 0.55[3]	declines	$0.90 per ft^2 [3]	Unknown	Medium

*All new construction can be sealed with the exception of porous asphalt, pervious concrete, grasspave^2, and gravelpave^2 pavements.

†Technology refers to the use of light colored binder in scrub seals, slurry seals, or cape seals.

Table 6. Other Factors To Be Considered for Cool Pavements

Technology	Longevity	Ease of Implementation	Stormwater Management	Air Quality	Noise Reduction	Other Factors	Qualitative Impact of Other Factors
Weight	35%	25%	20%	10%	10%	**100%**	
Conventional Asphalt	**4**	**5**	**3**	**3**	**4**	**4.0**	**High**
Rubberized Asphalt	**4**	**5**	**3**	**3**	**5**	**4.1**	**High**
Chip Seals (Light Colored Aggregate)	2	5	3	2	2	3.0	Medium
Conventional Scrub / Slurry / Cape Seals	2	5	3	3	3	3.2	Medium
Light Colored Binder†	1	1	Unknown	3	3	Unknown	Unknown
Porous Asphalt	3	3	5	3	5	3.6	Medium
Conventional Concrete	**5**	**4**	**3**	**3**	**3**	**4.0**	**High**
Whitetopping	4	3	3	3	3	3.4	Medium
Pervious Concrete	**4**	**3**	**5**	**3**	**5**	**4.0**	**High**
White Cement Concrete	5	2	3	3	3	3.5	Medium
Concrete Pavers	3	3	4	3	2	3.1	Medium
Color Pigments and Seals	1	2	3	3	3	2.1	Low
Titanium Dioxide Cement	5	2	3	5	3	3.7	Medium
Resin Based Binder	2	1	3	3	3	2.2	Low
Grasspave² and Gravelpave²	3	3	5	4	2	3.4	Medium
Emerald Cities™	2	1	3	3	3	2.2	Low

†Technology refers to the use of light colored binder in scrub seals, slurry seals, or cape seals.

8. CONCLUSIONS & RECOMMENDATIONS

This study found that there is a wide variety of technologies that can be applied as cool pavement strategies for the City of Chula Vista. These technologies can be applied to new and existing pavements and can be summarized in the form of modifications to conventional paving, porous pavements, rubberized pavements, vegetated and non-vegetated pavers, various surface treatments, and shade trees. Each of these technologies varies in application, cost, sustainability, and impact on the UHI effect.

From Chapter 7, conclusions can be made on the technologies with the highest and lowest mitigation of the UHI effect. The technologies with the highest impact on UHI all increase the solar reflectance (as expressed in the SRI) of the pavement above that of in-service conventional concrete and include white cement pavement, whitetopping using concrete containing light colored fly ash or slag cement, resin-based pavements and Emerald Cities™ coating technology. These technologies range in cost and have applications in new and existing construction. A high impact on UHI effect does not necessarily signify a higher cost. There are less expensive options (e.g. concrete made with light colored fly ash and/or slag cement) that have a positive impact on reducing UHI as well as more expensive options (e.g. titanium dioxide, Emerald Cities™).

Technologies with a low impact on UHI are asphalt-based as these do not significantly increase the SRI although they have other benefits that should be considered. In between, rated as having a medium UHI impact, are technologies that are either colored (pigments, chip seals with light colored aggregates) or permeable (porous asphalt, pervious concrete, Grasspave[2] and Gravelpave[2]), which rely on evapotranspiration to cool the pavements. This latter category also can help with storm water management.

Finally, any consideration of these strategies should include other factors in the decision making process, such as those described in Table 6 (longevity, ease of implementation and impacts on storm water management, air quality, and noise reduction).

8.1 Potential Funding Sources

There is little or no information on new or additional funding sources apart from those that are already available for street/pavement projects i.e. gas tax, TransNET etc. The paragraphs below discuss some of our findings on potential funding sources.

8.1.1 MAP-21

The recently passed federal transportation bill (MAP-21) is still being analyzed and evaluated to determine what the impacts are for cities and counties, and it is expected that much of this will not be known until the end of 2012. The bill consolidated almost 100 separate funding programs and eliminates earmarks, a significant change from SAFETEA-LU. One distinctive feature is that MAP-21 requires the use of performance measures related to highway condition and performance, safety, congestion and air quality, and freight improvement in transportation planning and programming. However, the bill does not define what these performance measures are, and delegates the establishment of targets to track progress to MPOs (Metropolitan Planning Organization); in the case for Chula Vista, this will be the responsibility of SANDAG (San Diego Association of Governments). It is conceivable that UHI could be added as a performance measure in urban areas.

Currently, MPOs across California are discussing the merits of pursuing statutory changes to change raise the allocation formula for STP (Surface Transportation Program). This will affect the funding that goes to cities and counties. Also, since this is a two-year bill (unlike past transportation bills which have been covered six years), it is also unknown what the funding picture will be after FY 2014-15.

8.1.2 CalRecycle

The California Department of Resources Recycling and Recovery (CalRecycle) provides a Rubberized Pavement Grant Program to promote markets for recycled-content surfacing products derived from waste tires generated in California and decrease the adverse environmental impacts created by unlawful disposal and stockpiling of waste tires. One hundred percent (100%) California waste tires must be used in the rubber portion of the projects. The maximum grant amount available to an agency is $250,000 per year. Additional information is available at http://www.calrecycle.ca.gov/Tires/Grants/Pavement/default.htm.

Two types of projects are eligible for the grants:

1. Rubberized asphalt concrete (RAC) Projects - grant awards are based on the differential cost of using RAC versus conventional asphalt concrete and the tonnage of RAC used. Projects must use a minimum of 3,500 tons of RAC.

2. Chip Seal Projects - grant awards are based on a fixed dollar amount per square yard of material used. Projects must use a minimum area of 35,000 square yards of RAC chip seal material.

Eligible applicants include cities, counties, and qualifying Indian tribes that fund public works projects located in California. However, if an agency has received three total grants previously, they are no longer eligible to apply for RAC projects but may be eligible for Chip Seal projects. Agencies who have received four total grants under the RAC Chip Seal Grants are no longer eligible to apply for Chip Seal projects but may still be eligible for RAC projects. Finally, agencies who have received grants are not eligible to apply in the following fiscal year.

8.1.3 Emerald Cities™

Emerald Cities™ launched a “100 Cities” program to offer their coating installations at a reduced price. In order to qualify, cities have to define a high profile project and have funding to pay for discounted Emerald Cities™ coating and Emerald Cities™ will pay the cost of labor for installation. All cities are eligible to participate in the 100 Cities program. Cities seeking to apply are asked to send a letter of request to application@emeraldcitiesusa.com. Cities that qualify will be given a formal “Letter of Invitation” for the mayor’s written acceptance.

8.2 Public Outreach and Education Efforts

The City of Chula Vista has conducted public outreach and education efforts for other adopted policies or programs in the past. One relevant policy is the “Shade Tree Policy” which was adopted in

May 22, 2012. Today, most residents probably expect to obtain information from the City's website, with perhaps a modicum of printed materials available at City Hall or the public library.

Briefly, the materials on the website for cool pavements should contain information presented in a succinct manner for residents as well as reasons why the policy is being adopted in a question/answer format. The benefits need to be clearly explained so that the public can understand how this policy will benefits them and their families, at work and at home. This may be enhanced by adding a FAQ (frequently asked questions) as there are multiple pavement strategies which can be complex to explain.

Links to additional resources should be provided, such as this report, relevant city policy documents and ordinances, information from other cities or agencies and state climate initiatives. Examples of projects completed in the City may be included, together with photos. As more performance data are obtained, updates to the website will be required to show the City's progress.

Finally, prior to construction, informational flyers should be sent to affected residents, businesses, schools, hospitals, etc. This flyer should include information on the selected strategy, the reason for its selection, and its benefits. Where new techniques require an extended construction period (e.g. concrete pavements) and where parking and access may be affected, a public meeting may be warranted.

8.3 Recommendations

8.3.1 Maintenance and Rehabilitation Strategies

The City's pavement network (approximately 457 centerline miles), is composed of primarily AC pavements, with less than 1% of PCC pavements. The maintenance practices currently employed by the City include a range of seals (e.g. chip seals, slurry seals), AC overlays with rubber and reconstruction (e.g. full depth reclamation). The PCC pavements usually require individual slab replacements as needed, or reconstruction.

In reviewing the information presented in the preceding chapters, there are clearly some pavement strategies that may be implemented in the City of Chula Vista with minimal changes required to existing practices and procedures.

However, an immediate wholesale change to existing City strategies with the medium to high impact on UHI may not be reasonable for the following reasons:

1. Many strategies are still relatively new with little long-term performance data, such as color pigments and seals, resin-based pavements, or the Emerald Cities' products. While there are examples of these technologies cited in this study, little to no data are available from independent studies on their lifespan and effective performance.

2. Few public agencies have developed specifications for many of these products, and most rely on the manufacturer's specifications.

3. There are little to no contractors in the greater San Diego area or even Southern California who have experience or expertise in many of these technologies. Even with well-proven

technologies such as conventional concrete or pavers, the local contractors contacted had experience primarily with small projects such as driveways, crosswalks and little to no experience with large quantities as would be expected on a roadway paving project.

4. The newer technologies have relatively large ranges in costs as shown Table 5. As more agencies implement them, and as more contractors gain experience, we would expect the market to adjust and expect many of these costs to drop.

However, there are treatment strategies that can have a medium to low impact on UHI that may be immediately implemented. These include adopting the use of light colored aggregates in seals, or porous/pervious pavements in parking lots. This group of strategies may be viewed as treatments that are modifications of existing strategies, and therefore will require little change to existing processes.

Therefore, a two-tiered recommendation is proposed, with ease of implementation as the primary criterion (see Table 6):

Short Term (2 to 3 years)

In the short term (2 to 3 years), it is recommended that:

1. The City review current decision-making processes for selecting maintenance and rehabilitation strategies. Although the UHI impact is the primary focus of this study, a pavement strategy that has the highest mitigation of the UHI impact may not necessarily be the best overall strategy when we consider longevity, storm water, air quality, cost or noise issues. Therefore, a more comprehensive decision making process should be considered and then institutionalized.

2. Modify existing treatments to reduce UHI for those strategies with an "Ease of Implementation" rating of 3 to 5. For instance, the use of chip seals with light-colored aggregates and no fog seal will require relatively minor changes to the current specifications, and projects may be constructed within a year. When pavement reconstruction is necessary, consider the use of conventional concrete pavements as part of the decision making process. Current City specifications include conventional concrete and this is easily implemented. An additional benefit is that more projects with conventional concrete will also attract more contractors and perhaps also build the experience of local contractors with larger scale projects. Light colored aggregates are currently available according to local contractors, although they are only used for decorative construction.

For short term projects, there is no need to change the existing criteria for selecting pavements since the treatments are essentially the same. For instance, the criteria for chip seals currently include arterials and collectors with a Pavement Condition Index (PCI) between 70-100. This will not change. Similarly with microsurfacing and reconstruction street candidates, the PCI ranges used will not change.

Longer Term (3 to 5 Years)

For the longer term (3 to 5 years), it is recommended that:

3. The City implement a pilot program to construct pavements with the newer strategies e.g. coatings, pigments, pervious concrete, titanium dioxide cement, all of which are relatively new and few agencies in California have implemented them. These have an Ease of Implementation rating of 1 to 2 (see Table 5).The pilot program will allow the City to "work out the bugs" in developing specifications as well as during the construction and inspection process. It will also allow the City to attract contractors with experience in these products, or at least build up the experience of local contractors with larger scale projects.

4. New maintenance practices may be required for some of these strategies. For example, porous or pervious pavements will usually require periodic vacuuming to remove fines and no seals may be placed in order to maintain their functionality. Vegetated pavers may need mowing or watering. Conventional concrete pavements may require periodic joint sealing. Therefore, the City will need to ensure that these capabilities are in place as part of adopting these strategies.

8.3.2 Candidates for Pilot Program

Potential candidates for the pilot program should be low to medium volume facilities (parking lots, residential roadways or minor collectors). Small to medium sized projects again allow the City to refine the design and construction process before adopting them as "standard" strategies for more critical or higher volume facilities.

The specific pavement criteria will depend on the type of treatment. For example, seals will be most suitable for those pavements that have PCIs between 60 to 90. Table 5 indicates the type of strategies appropriate for new construction, maintenance and rehabilitation of existing streets, and those for parking lots and bicycle lanes.

8.3.3 Performance Monitoring of Cool Pavement Strategies

In order to monitor the performance of any new strategies adopted, it is recommended that the City implement a program to monitor and measure the performance of these cool pavement strategies. Measurements should be performed at least once a year, and preferably twice a year to measure any changes.

Standard test methods have been established by ASTM International (formerly known as the American Society of Testing and Materials). Generally speaking, testing to determine the SRI may be performed in the field or in a laboratory. In the case of the latter, cores are usually removed and sent to the lab for testing; for the former, specialized equipment is needed to perform the field tests.

As previously discussed, the SRI or Solar Reflectance Index is the measure of the surface's ability to reflect solar heat as measured by a small temperature rise. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100. To calculate the SRI, a measurement of the reflectance value and emittance value of the paved surface is required.

Reflectance is measured according to one of the following methods:

ASTM E 1918-06: Standard Test Method for Measuring Solar Reflectance of Horizontal and Low Sloped Surfaces in the Field

ASTM C 1549-09: Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer

Emittance is measured according to one of the following methods:

ASTM E 408-71(2008): Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection Meter Techniques

ASTM C 1371- 04a(2010)e1: Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers

Calculation of the SRI is described in:

ASTM E1980-11: Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low Sloped Opaque Surfaces

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