UNIVERSITA POLITECNICA DELLE MARCHE

FACILITY OF ENGINEERING

Department of Civil and Environmental Engineering

Master of Environmental Engineering Thesis

INFLUENCE OF COOL PAVEMENT ON URBAN HEAT ISLAND (UHI) MITIGATION

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Contents

NOTEWORTHY POINTS

……. Facts? ………

Roofs and pavements cover about 60 percent of urban surfaces and absorb more than 80 percent of the sunlight that contacts them. This energy is converted to heat, which results in hotter, more polluted cities, and higher energy costs **[1,2].**

About 20 to 25 percent are roofs and 30 to 45 percent are pavements in an urban Land.

World temperatures are rising at an unprecedented rate [2,3,4]**.**

within 50 years an estimated 80 percent of the world's population will live in an urban area

Based on cool pavement development sources, how they investigate a way of mitigation on Surface and Atmospheric Heat Islands is important.

Cool pavements and roofs can help cool down Micro & Macro Climate and cities UHI.

Yes!

Definitely

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BACKGROUND

Pavement is the purpose of movement on land. The main form of land transport facilities can be considered as Road Transport.

The Carthaginians are generally credited with being the first to construct and maintain a road system (about 600 B.C.) according to Tillson [1900]. The first road construction was Romans took up the practice of a military road system from the Carthaginians. It is estimated that the Romans built about 87,000 km of roads within their empire (about equal to the length of the U.S. Interstate system). **[5]**

Like, in recent observation they are **64,285,009** kms of paved roads in the world, and there are on average 40 traffic signs on each km of paved roads for a total of 2,571,400,360 traffic signs in the world, more signs than drivers and observe the future usages with Pavement systems. **[7]**
Source: CIA World Factbook (2020-06-28) Generally, Roadways also belongs to the priority in the volume of passenger transportation utility - 82% of the world volume. It means, now a day's Conventional dark pavements contribute to urban heat islands as they absorb 80–95% of sunlight and warms the local air. It impacts the atmosphere conditions.

In cities the pavements are the major role to develop the heat engines in the presence of sunlight, such as concrete, asphalt and bitumen pavements are good absorbers and store more heat than natural vegetation, leading to the Urban Heat Island (UHI) effect. Typical pavements have a lower solar reflectance (albedo) and a higher thermal diffusivity as compared to natural surfaces. This, in turn, heats the surrounding air. Annually,
Among the world. the global surface Temperature Index (C)

In **1880** average earth temperatures are -0.08 and now **2019** 0.99(C) LATEST ANNUAL AVERAGE ANOMALY: 2019 **0.99 °C 1.78 °F. [4,6]**

the change in global surface temperature relative to 1951-1980 average temperatures. Nineteen of the 20 warmest years all have occurred since 2001, apart from 1998. The year 2016 ranks as the warmest on record. Easily we can identify every year summer temperatures. In the end these all effects show a drastic change in the global micro and macro climate to increases global warming.

As several research studies in pavement designs have developed 'cool reflective surfaces' this approach gives higher albedo to mitigates the pavements surface temperature.

Conventional paving materials can reach peak summertime temperatures of 50 to 65 degrees Celsius (120 to 150 degrees Fahrenheit), heating the air above them. [1]

There are many kinds of paving options that are lighter in color and create more reflective paved surfaces.

Additionally, many kinds of permeable pavements, including reinforced grass pavements, can also cool a pavement surface through the evaporation of moisture stored in the pavement. If pavements are too bright, they can cause undesirable glare, but there are many shades of gray that are reflective that do not cause too much glare. There are several additional benefits to light colored pavements beyond cooling.

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ACKNOWLEDGEMENTS

I intend to improve my learning efforts with a dedication to this dissertation project...

Any attention does not come without Inspiration. Gratitude for this great opportunity given by my institution.

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First, I would like to express my profound greetings to my supervisor, Prof. Gilda Ferroti,

providing me a thought to do my study on

INFLUENCE OF COOL PAVEMENT ON URBAN HEAT ISLAND (UHI) MITIGATION and her continued assistance

and guidance throughout the research, which led me to the right way.

This literature review corresponding to a global live climatic condition that is suitable for a group of Environmental sources.

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ABSTRACT

An extensive literature review was performed to identify potential technologies and strategies for cool pavements, key questions and what research has addressed them, and gaps in research and knowledge. This detailed literature reviews are presented in the corresponding in lessons for each area investigated in this dissertation. Instead, this review provides a comprehensive assessment of the strengths, weaknesses and influences of the cool pavement types of literature from each scope and comparison between each cool pavement type. To illuminate this study to understand for future global environmental stresses and potential mitigative solutions…

Heating pavement or the accumulation of heat in the pavement contributes significantly to the average temperature increases in modern urban environments. Because the portion of traffic areas in city centers are significant, the application of pavement structures that reduce the effect of warming is one of the strategies that can help mitigate the urban heat island effect.

The aim of this review is to present temperature trends of the covering surfaces in the urban areas and roofs compared to the same surfaces of the surrounding area and the observing air

temperatures during the summer. Here, temperature measurements which is studied by various associates and executed surfaces of different types of pavements (such as asphalt, concrete, stone ...) which is carried and compared in several different locations. where the use of cool pavements and cool roofs. to reduce urban heat island effect and improve the quality-of-life standard with a surveillance in different associates.

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INTRODUCTION

This research extends the thoughts on improving a right decision on influenced global climate and pavements infrastructure. Every decade the technology is modernizing with all infrastructural facilities like more built areas, darker surfaces and less vegetation than their surroundings. These differences affect the climate, energy use and habitability of the cities. Since the built environment absorbs and stores solar energy, the temperature in cities can be several degrees higher than in the surrounding suburban and rural areas. This is called urban heat island effect (UHI)

Pavements typically comprise 30 to 45 percent of the land area in major cities and contribute significantly to the UHI through low reflection of solar radiation and high levels of thermal storage. One potential tool that has been workout to lower cooling demand in air-conditioned surroundings and buildings through mitigation of the (UHI) effect is the use of reflective or cool paving. Pavement surface temperatures exceed 60°C on some days in summer and does not evapotranspiration water, unlike soil and other forms of natural land cover in these days **[5,6]**

When we look in the recent technologies there are three strategies 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, promote pavement cooling through evaporation.

Coming to the urban infrastructure which is occupied with specific ratios based on urban population.

As per our study. **Pavement performed up to 1/3rd of the average city of that third, about [8]**

1. **45% are streets (usually asphalt concrete)**
2. **15% are sidewalks (usually cement concrete)**
3. **40% is exposed parking (usually asphalt concrete)**

Related Problems:

1. **URBAN HEAT ISLAND**	**Increased needs for cooling**
2. **ENERGY CONSUMPTION**	**Increased need for energy**
3. **AIR POLLUTION**	**Decreased thermal comfort.**
4. **GLOBAL WARMING**	**Increased smog production**

Because of smog is a photochemical phenomenon, it is also related to temperature. Extensive scientific reports demonstrate that **per 1 degree rise of temperature** a 5% Smog increase is taking place.

The external factors affecting the structural performance of pavements are traffic, the environment, and the interaction of the two. The most significant environmental factors affecting pavement performance are pavement temperature and moisture content. Various climatic conditions to which the pavements are exposed influence pavement distress mechanisms and performance. Also investigates and discusses current cool pavement strategies; determines their applicability for existing and new pavements, including both streets and parking areas; workout on feasibility of using these strategies; identifies current and ongoing costs and benefits in comparison with existing paving methods programs.

On average, U.S. summer temperatures have increased nearly 2 degrees since 1970, the National Climate Assessment reported earlier this year.

"Thanks to the dual action of urbanization and climate change, cities are not just hotter, they are getting hotter faster: 45 of 60 cities we analyzed were warming at a faster rate than the surrounding rural land," Kenward reported. About 80% of Americans live in metropolitan areas.

Based on data from 2004-13, the top 10 U.S. cities with the most intense urban heat islands -- measured as the greatest difference in average temperatures between urban and rural areas over the entire summer -- were: s [9]

1. Las Vegas 22.778° C
2. Albuquerque 15 ° C
3. Denver 9.44 ° C
4. Louisville 8.88 ° C
5. Washington, D.C. 8.33 ° C
6. Kansas City 7.778 ° C
7. Columbus 6.66 ° C
8. Minneapolis 6.11 ° C
9. Seattle 5 ° C
10. Portland 8.88 ° C

FUNDAMENTALS OF UBI TERMONOLOGY - I

1.1 URBAN HEAT ISLAND

The occurrence of higher air and surface ambient temperatures are obtaining in medium and large sized urban centers due to the retention and emittance of mainly solar heat from roads, buildings and other structures, than in surrounding rural areas [10]

Figure – 1 Urban Heat Island Effect [1]

There are classified into two types: Urban Heat Island-1 & Urban Heat Island – 2

UHI-**1**: When a city is built, changes are made to the natural environment that affect the temperature. The changes affect energy transfers and the storage of energy. City centers in comparison to suburban areas demonstrate higher level of temperatures, which in some cases can be even 10 ° C higher.

UHI-**2:** One of the factors that play decisive role in the growth of phenomenon of urban heat island they are the thermal attributes of **materials** that are used in the urban environment:

- Construction materials generally have a lower albedo and higher heat capacities than soil and vegetation. The result is that buildings, streets, parking lots, etc. absorb more solar radiation than soil and vegetation. The increased absorption of solar radiation makes the city warmer than the surrounding rural area on sunny days and also this heat tends to retain internal energy longer and stay warmer than surrounding rural areas especially at night.

The heat island effect results in daytime temperatures in urban areas about -17.2 to -13.8°C higher than temperatures in outlying areas and nighttime temperatures about -16.6 to -15 °C higher. Humid regions and cities with larger and denser populations experience the greatest temperature differences. Research predicts that the heat island effect will strengthen in the future as the structure, spatial extent, and population density of urban areas change and grow [11]**.**

Heat islands measures by the temperature difference between cities relative to the surrounding areas. Temperature can also vary inside a city. Some areas are hotter than others due to the uneven distribution of heat-absorbing buildings and pavements, while other spaces remain cooler as a result of trees and greenery. These temperature differences constitute intra-urban heat islands. In the heat island effect diagram, urban parks, ponds, and residential areas are cooler than downtown areas.[8]

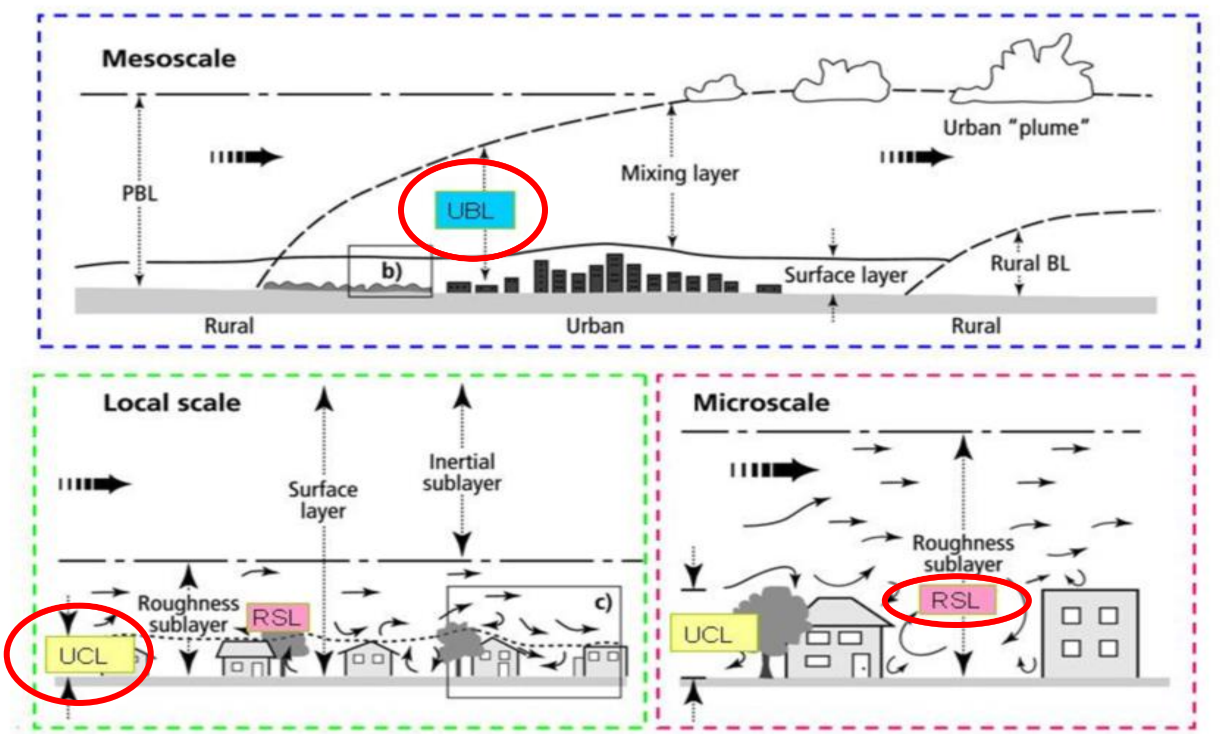


Figure – 2 the Urban Canopy Layer, and UBL is the Urban Boundary Layer [23]

In general, temperatures are different at the surface of the earth and in the atmospheric air, higher above the city. For this reason, there are two types of heat islands: **surface** heat islands and **atmospheric** heat islands. These differ in the ways they are formed, the techniques used to identify and measure them, their impacts, and to some degree the methods available to cool them.

Surface Heat Islands: These heat islands form because urban surfaces such as roadways and rooftops absorb and emit heat to a greater extent than most natural surfaces. On a warm day with a temperature of 32.77°, conventional roofing materials may reach as high as 15.5°C [12] warmer than air temperatures. Surface heat islands tend to be most intense during the day when the sun is shining.

Atmospheric Heat Islands: These heat islands form as a result of warmer air in urban areas compared to cooler air in outlying areas. Atmospheric heat islands vary much less in intensity than surface heat islands.

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

Figure – 3 Differentiating Surface and Atmospheric Urban Heat Islands EPA [12]

Urban materials play a fundamental role in the UHI development. Their thermal performance influences the formation and the intensity of the phenomenon. The main factors in this case are the solar reflectance, the thermal emissivity and the heat capacity. Sunlight reaches the Earth with a specific band of wavelength, the solar spectrum. It is composed of ultraviolet (UV) rays, visible (Vis) light, infrared energy (IR), and they reach the Earth respectively in 5% (including the part responsible for sunburns), 40% (with the visible colors wavelengths) and 55% (responsible for the heat sensation) of the total amount [12].

1.3 SOLAR REFLECTANCE OR ALBEDO (SR)

The fraction of sunlight (0 to 1, or 0 percent to 100 percent) that is reflected from a surface. SR typically ranges from about 0.04 (or 4 percent) for charcoal to 0.9 (or 90 percent) for fresh snow. High solar reflectance is the most important property of a cool surface.[1,10,11,13,12]

1.4 SOLAR ABSORPTANCE (SA)

The fraction of sunlight (0 to 1, or 0 percent to 100 percent) that is absorbed by a surface. Surfaces with high solar absorptance tend to get hot in the sun. If the surface is opaque, solar absorptance equals 1 minus solar reflectance.

1.5 THERMAL EMITTANCE (TE)

The efficiency (0 to 1) with which a surface emits thermal radiation. High thermal emittance helps a surface cool by radiating heat to its surroundings. Nearly all nonmetallic surfaces have high thermal emittance, usually between 0.80 and 0.95. Uncoated metal has low thermal emittance, which means it will stay warm. An uncoated metal surface that reflects as much sunlight as a white surface will stay warmer in the sun because it emits less thermal radiation. TE is the second most important property of a cool surface.

1.6 SOLAR REFLECTIVE INDEX (SRI)

A coolness indicator that compares the surface temperature of a roof on a sunny summer afternoon to those of a clean black roof (SRI=0) and a clean white roof (SRI=100). SRI is computed from solar reflectance and thermal emittance and can be less than 0 for an exceptionally hot surface (e.g.,a solar collector) or greater than 100 for an exceptionally cool material (e.g., a very bright white pavement surface). [1,10,11,13,12]

1.7 THERMAL RESISTANCE (R-value)

A measure of a material or system's ability to prevent heat from flowing through it. The thermal resistance of a roof can be improved by adding insulation, a radiant barrier, or both. [1,13,14]

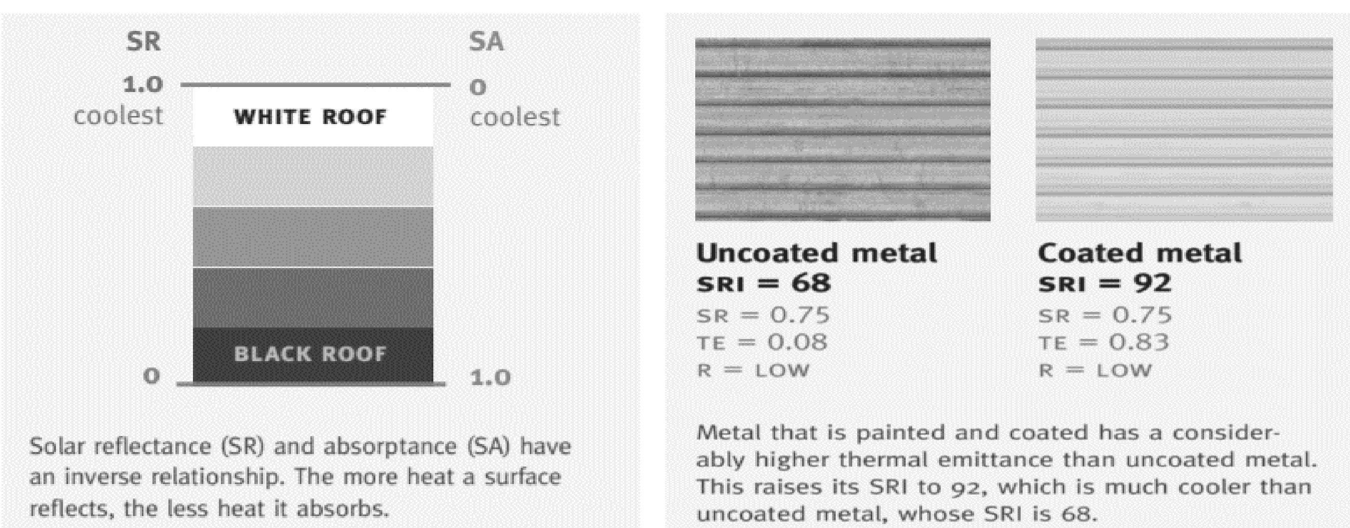


Figure – 4 Cooling Terminology [1]

1.8 THERMAL HEAT CAPACITY

Thermal capacity is a physical property of matter, defined as the amount of heat to be supplied to a given mass of a material to produce a unit change in its temperature. It is an ability to capture and store heat. materials (asphalt, concrete, brick) have higher values of heat capacity respect to natural materials (soil, sand), so the urban environment works as a big heat-storage, increasing the UHI. Despite urban materials generally have high emissivity values (so they dissipate heat quickly), they also have high heat capacity and low reflectivity, resulting in an overall bad thermal behavior.[15]

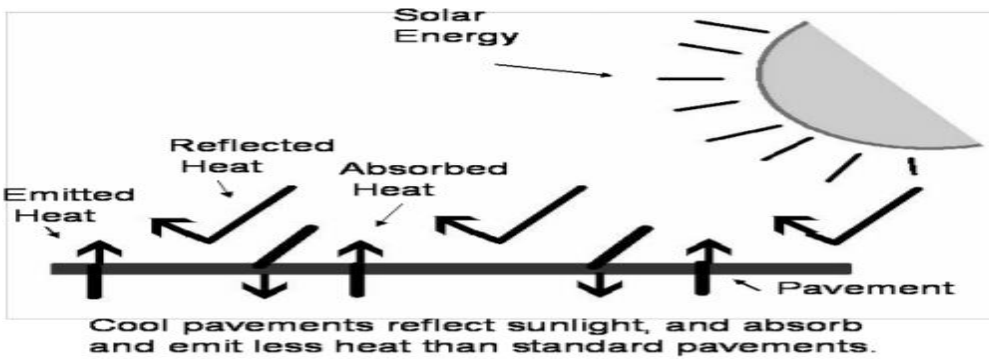


Figure – 5 example: Cool pavements [16]

1.9 CAUSES OF HEAT ISLAND

Reduced Natural Landscapes in Urban Areas: Trees, vegetation, and water bodies tend to cool the air by providing shade, transpiring water from plant leaves, and evaporating surface water, respectively. Hard, dry surfaces in urban areas – such as roofs, sidewalks, roads, buildings, and parking lots – provide less shade and moisture than natural landscapes and therefore contribute to higher temperatures**.** [15,10,11,13,1]

Urban Material Properties: Conventional human-made materials used in urban environments such as pavements or roofing tend to reflect less solar energy and absorb and emit more of the sun's heat compared to trees, vegetation, and other natural surfaces. Often, heat islands build throughout the day and become more pronounced after sunset due to the slow release of heat from urban materials.

Urban Geometry: The dimensions and spacing of buildings within a city influence wind flow and urban materials' ability to absorb and release solar energy. In heavily developed areas, surfaces and structures obstructed by neighboring buildings become large thermal masses that cannot release-their heat readily. Cities with many narrow streets and tall buildings become urban canyons, which can block natural wind flow that would bring cooling effects. The effects of urban geometry on UHI are often described through the "sky view factor" (SVF), which is the visible area of the sky from a given point on a surface.

Heat Generated from Human Activities: Vehicles, air-conditioning units, buildings, and industrial facilities all emit heat into the urban environment. These sources of human-generated, or anthropogenic, waste heat can contribute to heat island effects.[16]

Weather and Geography: Calm and clear weather conditions result in more severe heat islands by maximizing the amount of solar energy reaching urban surfaces and minimizing the amount of heat that can be carried away. Conversely, strong winds and cloud cover suppress heat island formation. Geographic features can also impact the heat island effect. For example, nearby mountains can block wind from reaching a city, or create wind patterns that pass through a city.

1.10 POTENTIAL IMPACTS OF HEAT ISLANDS

As we observe the colder cities at higher latitudes and/or elevations, the wintertime warming effects of the heat island are beneficial. In some urban areas during the summer, shade around high-rise buildings can create cooler areas for parts of the day.

Compromised human health and comfort.

Heat islands contribute to higher daytime temperatures, reduced nighttime cooling, and higher air-pollution levels. These, in turn, contribute to **heat-related deaths** and **heat-related illnesses** such as general discomfort, respiratory difficulties, heat cramps, heat exhaustion, and non-fatal heat stroke. Sensitive populations, such as children, older adults, and those with existing health conditions, are at particular risk from these events. Excessive heat abrupt and dramatic temperature increases are particularly dangerous and can result in above-average rates of mortality. From 2004 to 2018 the Centers for Disease Control and Prevention recorded 10,527 heat-related deaths in the United States, an average of 702 per year. the heat stress on the pavement will probably discourage people from walking or biking. [15,16,17,18]

Increased energy use: Heat islands increase demand for air conditioning to cool buildings. In an assessment of case studies spanning locations in several countries, electricity demand for air.

conditioning increased approximately 1–9% for each 2°F increase in temperature. Countries where most buildings have air conditioning, such as the United States, had the highest increase in electricity demand. This increase demand contributes to higher electricity expenses. Peak demand generally occurs on hot summer weekday afternoons, when offices and homes are running air-conditioning systems, lights, and appliances. During extreme heat events, which are exacerbated by heat islands, the increased demand for air conditioning can overload systems and require a utility to institute controlled, rolling brownouts or blackouts to avoid power outages. [16,17,18]

Elevated emissions of air pollutants and greenhouse gases:

Industries that supply electricity typically rely primarily on fossil fuel power plants in the U.S. and even more so in China and India to meet much of this demand, which in turn leads to an increase in air pollutant and greenhouse gas emissions. The primary pollutants from fossil-fuel-power plants include SO2, NOx, PM, CO, and Hg. These pollutants are harmful and formation of ground-level ozone (smog), fine particulate matter, and acid rain. Increased use of fossil-fuel-powered plants also increases emissions of GHG, such as CO2, which contribute to global climate change.

It develops ground-level ozone formation. Formed by NOx and VOCs react in the presence of sunlight and hot weather. If all other variables are equal, such as the level of precursor emissions in the air and wind speed and direction, more ground-level ozone will form as the environment becomes hotter.

Impaired water quality:

High pavement surface temperatures can heat stormwater runoff. Tests have shown that pavements that are at (38°C) can elevate initial rainwater temperature from roughly 21°C to over 35°C. This heated stormwater generally becomes runoff, which raises waterbody temperatures if it drains into streams, rivers, ponds, and lakes. this effect occurs primarily where there is rainfall at the same time as hot temperatures, which is common east of the Rocky Mountains, but uncommon in California. Water temperature affects all aspects of aquatic life, especially the metabolism and reproduction of many aquatic species. Rapid temperature changes in aquatic ecosystems resulting from warm stormwater runoff can be particularly stressful, and even fatal, to aquatic life. [16,17,18, 15,19]

1.11 POTENTIAL MITIGATION MEASURES FOR HEAT ISLANDS

The Environmental Protection Agency (EPA) has developed three approaches.

(1) **Cool Pavements**,

(2) urban forestry and vegetation, and

(3) cool roofs and green roofs to mitigate the UHI.[12]

These approaches developed by EPA communities can take several potentials steps to reduce the local and/or atmospheric heat island effect, such as the strategies listed below based directly on the causes of the heat island effect.

1. Increasing tree and vegetative cover.
2. Creating green roofs (aka. "rooftop gardens" or "eco-roofs").
3. Installing cool—mainly reflective—roofs.
4. Using cool pavements.
5. Introducing water bodies to the urban area.
6. Reducing anthropogenic heat (released waste heat from heating/cooling, etc.) and
7. Improving urban geometry to improve air flow and enhance the natural ventilation.

1.12 OVERVIEW OF AN OPEN SYSTEM FOR EVALUATING PAVEMENT-ENVI-INTERACTION

OUTDOOR THERMAL ENVI-DESIGN/MODELING/EVALUATION SYSTEM (STREET)					
PAVEMENT PARAMETERS	**Strategies**			**On-site Surroundings**	**INPUT**
Road cross section	Reflective pavement			Climate conditions	
Paved Area	Permeable Pavement			Building size	
Pavement Structure	Shading			Land cover	
Material Thermal Properties	Ventilation				
HUMAN THERMAL COMFORT	Energy use	Air Quality	Water quality	**Pavement Life**	**OUTPUT**
Near-surface Air Temperature	Building	Ozone	temperature	Rutting	
Humidity	Vehicle		pollution	cracking	
Wind Speed					
Thermal Radiation					

Table - 1 Outdoor Thermal Envi-Design/Modeling/Evaluation System (Street)

1.13PAVEMENT LIFE

Pavement temperatures can have significant influence on pavement durability. [19,21,22,20]

1. For asphalt pavements in hot climates conditions significantly increase the risk of rutting (permanent deformation) and aging and cracking if not specifically designed well. **[16]**
2. For concrete pavements, high temperature and temperature gradient can significantly increase the probability of cracking caused by thermal stress. However, for different pavement types, the effects of temperature on their durability are different. Moreover, the exact effects on some pavements such as permeable pavements are still not very clear.

Cool pavements and the related cooling technologies would potentially reduce the pavement temperature and temperature gradient, and thus could potentially improve the pavement durability due to mitigating the thermal-related deteriorations such as rutting and/or cracking. In general, this could reduce the pavement maintenance costs and also bring other associated benefits such as reduced material use and user traffic delay. [12,18]

LONGER PAVEMENT LIFE

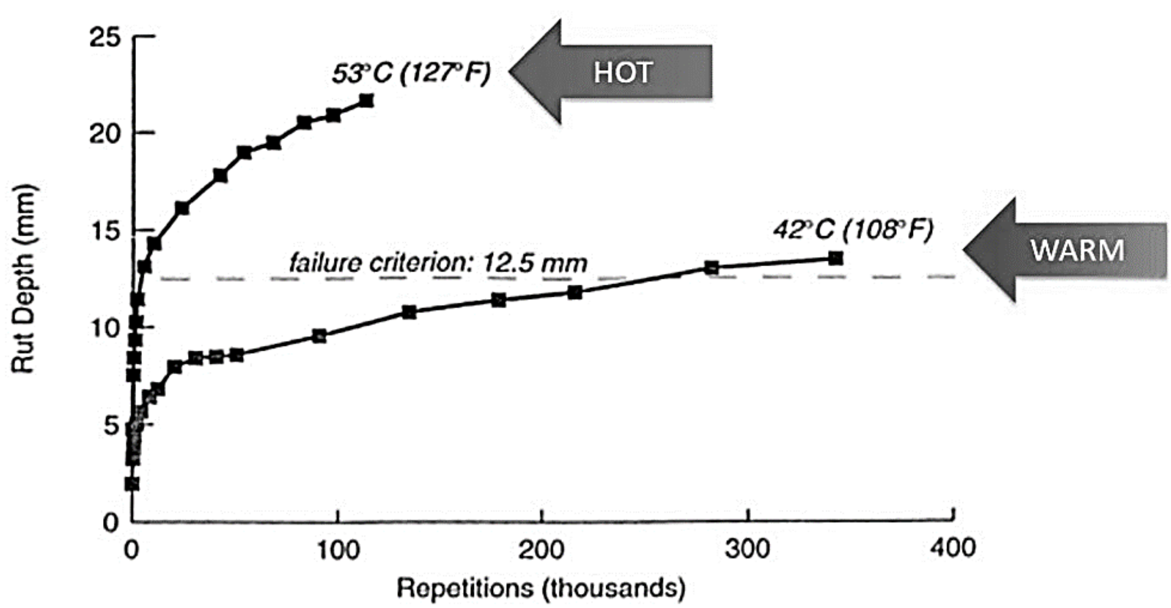


Figure – 6 Depth of rutting Vs Number of repetitions of standard Axle load, Wide Base single tire, at Pavement Surface Temperature 42°C and 53°C **[12]**

COOL PAVEMENTS - II

Solar reflective "cool" pavements stay cooler in the sun than traditional pavements. Pavement reflectance can be enhanced by using reflective aggregate, a reflective or clear binder, or a reflective surface coating. It means materials and construction techniques that are used in roads, driveways, parking lots, sidewalks, pedestrian ways and other hard surfaces, which act to reduce the absorption, retention and emittance of solar heat, a factor contributing to the urban heat island.

Typically, these pavements are impervious concrete and asphalt that reach summertime peak temperatures from 50°C to 65°C. With temperatures expected to rise with climate change, a need for cooler pavements has been advocated in EPA 2008 [12,24].

Cool pavements utilize coloration, materials, porosity and processes that increase solar reflectivity to reduce surface heating and to promote cooling through increased air filtration and evaporation.

2.1 TYPES OF PAVEMENT SURFACES

Pavements are on-ground structures for riding, walking, and parking. Different materials are used in pavement construction; these are generally classified by the **type of surface**, also called the **wearing course**: [25]

1. “Flexible” pavements are built with Asphalt Concrete Pavement or Hot-mix asphalt (HMA)
2. “Rigid” pavements are built with Portland cement concrete (PCC)
3. Other types of conventional pavement in use include bituminous surface treatments, road mixes, and macadam construction.

The examples above all produce hard or bound surfaces. It also is possible to build traffic-bearing surfaces with unbound or “unpaved” materials. Gravel roads are one example but are used mainly in rural areas.

As pavements wear, they require resurfacing to correct distress, restore surface **smoothness** and **skid resistance**, and restore or add strength to handle future traffic loads. Both asphalt and concrete materials are used in resurfacing. Asphalt, Composite and concrete pavements, ultra-thin white topping or UTW.

Resurfacing is considered to restore or add pavement structural strength. Both new construction and resurfacing provide opportunities for installing materials consistent with cool pavements.

As we studied before pavements are viewed as an important factor that contributes to heat islands. However, pavements also could be part of the solution, not just part of the problem.

EPA Definition: "cool pavements refer to a range of established and emerging materials and technologies. These pavement materials and technologies could potentially make pavements have lower surface temperature and tend to release less heat into atmosphere compared with conventional pavements." [26,12,25,28]

There are several potential strategies to make pavements cooler with different **cooling mechanisms**, which can be performing into **four** categories as follows: [25]

- Modification of thermal properties of pavement materials
- Enhancement of evaporation from pavements.
- Enhancement of convection; and
- Reducing heat energy on/in pavements.

2.2.1 MODIFICATION OF THERMAL PROPERTIES OF PAVEMENT MATERIALS

The thermal behavior of pavements is largely dependent on the thermal properties of pavement materials, including thermal conductivity, specific heat capacity, density, solar reflectivity (i.e., albedo), and thermal emissivity. Appropriate modification of these properties could help keep pavements and near-surface air cooler.

Reduce pavement thermal conductivity:

The ability of materials to conduct or transmit heat. It determines how fast and readily the heat would be conducted from a high-temperature object/part to a low temperature object/part. Pavements with low thermal conductivity may heat up at the surface but will not transfer that heat throughout the other pavement layers as quickly as pavements with higher thermal conductivity.

Increase pavement heat capacity:

The amount of heat required to raise the temperature of one unit weight of a substance by one degree Celsius without change of phase. it determines pavement how much energy is absorbed and stored in the pavement at a certain temperature.

the specific heat capacity as well as density and thicknesses of pavement layers could increase the effective heat capacity of the whole pavements and help reduce the daytime high temperature and increase the nighttime low temperature. This is just similar to the moderating effect of large water bodies as heat sinks (e.g., pool, pond, lake, sea)

Increase pavement surface reflectance:

More studies focused on Solar reflectance, or albedo, is the percentage of solar energy reflected by a surface. the primary determinant of maximum pavement surface temperature. High albedo also could help to reduce. pavement subsurface temperatures, because less heat is available at the surface to then be transferred into the pavement layers below the surface. Many opportunities exist to improve this property of materials, due to the simplicity and convenience of reflectivity improvement for both new and existing surfaces of both asphalt and concrete pavements.

Increase pavement thermal emissivity:

A material's thermal emissivity determines how much heat it will radiate per unit area at a given temperature, that is, how readily a surface emits heat. Thermal emissivity plays a role in determining a material's contribution to heat islands. Research suggests **albedo** and **emissivity** have the greatest influence on determining how a conventional pavement cools down or heats up, with albedo having a large impact on maximum surface temperatures, and emissivity affecting minimum temperatures. it might not effectively help reduce heat islands in the urban canopy.[25]

2.2.2 ENHANCEMENT OF EVAPORATION FROM PAVEMENTS

Evaporation of water requires heat energy to achieve a phase change of water from liquid to gas. This process absorbs heat energy from surroundings and cools them down. The use of evaporative cooling could reduce pavement temperature and consequently air temperature through latent heat lost by the phase change of water (from liquid to gas) when moisture exists in the pavements or in the underlying soils or is sprinkled on hot pavement surfaces.

Permeable pavements: The majority of pollutants discharged to receiving water bodies are now associated with non-point sources. Runoff generated from impermeable streets, roads and highways are among these non-point sources that contain large amounts of inorganic and organic pollutants.

Water-retentive pavements: Some cities in Japan, such as Tokyo and Osaka,[26,12,25,28] are testing the effectiveness of water retentive pavements as part of using permeable pavements to reduce the heat island effect. These pavements can be asphalt or concrete-based and have a sublayer that consists of water retentive materials that absorb moisture and then evaporate. it through capillary action when the pavement heats up. Some of the systems involve underground water piping or surface water sprinkling to enhance the evaporation from the pavement. this pavement can effectively reduce the temperature of a road surface by up to 25 °C in mid-summer, when the surface temperature can be as high as 60°C. The resulting reduction in the air temperature is 2 to 3 °C.

2.2.3 ENHANCEMENT OF CONVECTION BETWEEN PAVEMENT AND AIR

Pavement transfers heat to the near-surface air through convection as air moves over the warmer pavement surface. The rate of convection depends on the velocity and temperature of the air passing over the surface, pavement roughness, and the total surface area of the pavement exposed to air. Some permeable pavements (e.g., permeable asphalt pavement, pervious concrete pavement, pervious cast pavement, and pervious brick or block pavers, etc.) have rougher surfaces and contain more air-voids than conventional pavements, which increases their effective surface area exposed to air and creates air turbulence/circulation over/within the pavement.

2.2.4 REDUCING HEAT ENERGY IN PAVEMENTS

shading pavement surfaces from solar radiation using shading trees/buildings and canopy covers (e.g., regular or solar panels) installed over the pavement. Another cooling option is the use of active mechanical cooling associated with harvesting and converting the heat energy stored in pavement. The active mechanical cooling strategies include cooling of fluid (e.g., water) circulating through pipes embedded in pavements as one kind of heat exchangers and cooling through thermoelectric devices embedded in pavements.[26,12,25,28,1]

The advantage of the active mechanical cooling is that it can be used for both cooling in hot seasons and heating (deicing, melting snow, etc.) in cold seasons as well as harvesting energy for local use.

Beyond shading pavement surfaces from incoming solar radiation to reduce the pavement temperature, these photovoltaic canopies also could generate electricity that can be used to power nearby buildings or provide energy for electric vehicles.

2.3 COOL PAVEMENTS TERMINOLOGY

Cool pavements can be made from traditional paving materials, such as cement concrete. New cement concrete has a solar reflectance (SR) of 30–50%. There are also novel cool-colored coatings for asphalt concrete pavements that reflect about 50% of sunlight. Another approach is to use a clear binder that reveals highly reflective (light-colored) aggregate. [12]

As with all materials exposed to the atmosphere and use, the solar reflectance of pavement can change over time.

For example, as cement concrete pavement ages it tends to get darker with tire and grease stains (new SR 30-50%; aged SR 20-35%), but asphalt concrete lightens (new SR 5%; aged SR 10-20%) as it ages because the asphalt binder oxidizes and more aggregate is exposed through wear.

2.4 CHANGING THE ALBEDO

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. This table provides some common albedo values for various surfaces.

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

Table - 2 Common Albedo Values [12]

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.

This image shows typical albedo over time for concrete and asphalt.

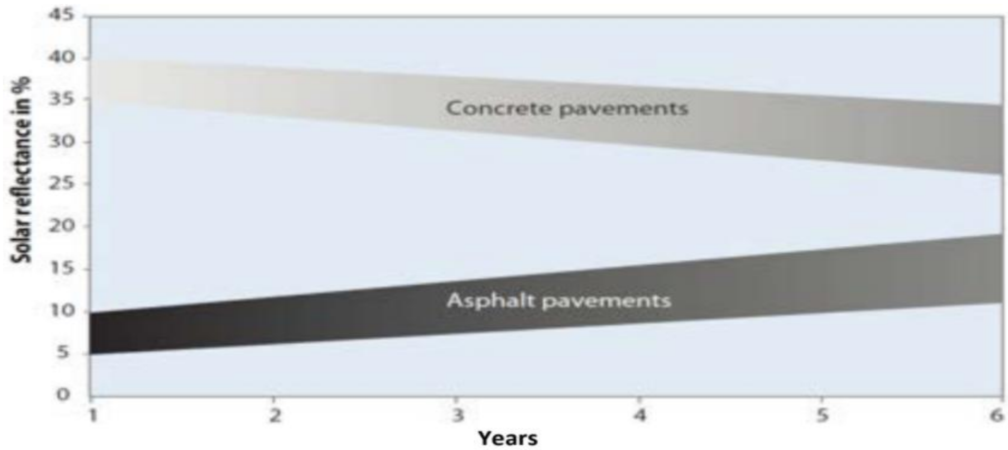


Figure – 7 TYPICAL SOLAR REFLECTANCE OF CONVENTIONAL ASPHALT AND CONCRETE PAVEMENTS OVER TIME [13]

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. [12]

2.5 MEASUREMENT METHODOLOGY FOR ALBEDO

Measurement method and equipment

There are two ASTM standard testing methods for determining solar reflectance of a surface:

(1) ASTM C1549 Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer.

(2) ASTM E1918, Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field

2.5.1 INFLUENCE OF CLOUDINESS ON ALBEDO

Here, cloudiness has an important influence on the incident solar radiation, reducing the amount of solar radiation incident to the pavement or other ground surfaces. influence of clouds on the albedo of pavements, the albedo of asphalt pavement on days with different cloud levels were measured for comparison. This tells us the cloudy days and resultant low incident solar radiation is much lower than those (0.08) on days with few clouds or clear days. This implies that the albedo should be measured on a clear day. Otherwise, a lower albedo will be given, even measured at mid-day.

2.5.2 INFLUENCE OF WIND SPEED AND AIR TEMPERATURE ON ALBEDO

Albedo is expected to be constant regardless of wind speed or air temperature. To verify this concept, the albedo of asphalt pavement on some days with different wind speeds and air temperatures were measured for comparison. The albedos around noon are all around 0.08 on these three days. No significant variation in mid-day albedo is observed on this period with quite different wind speeds or air temperatures [25]

2.6 PAVEMENT HEAT STORAGE

The primary factors in thermal performance of Asphalt pavements are low solar reflectance and moderate heat conduction. This study 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.

Finally, the lower thermal conductivity can produce higher surface temperature during day and lower temperatures at night, while high conductivity does the opposite.

HEAT-RELATED CHARACTERISTICS AND PROCESSES IN A PAVEMENT

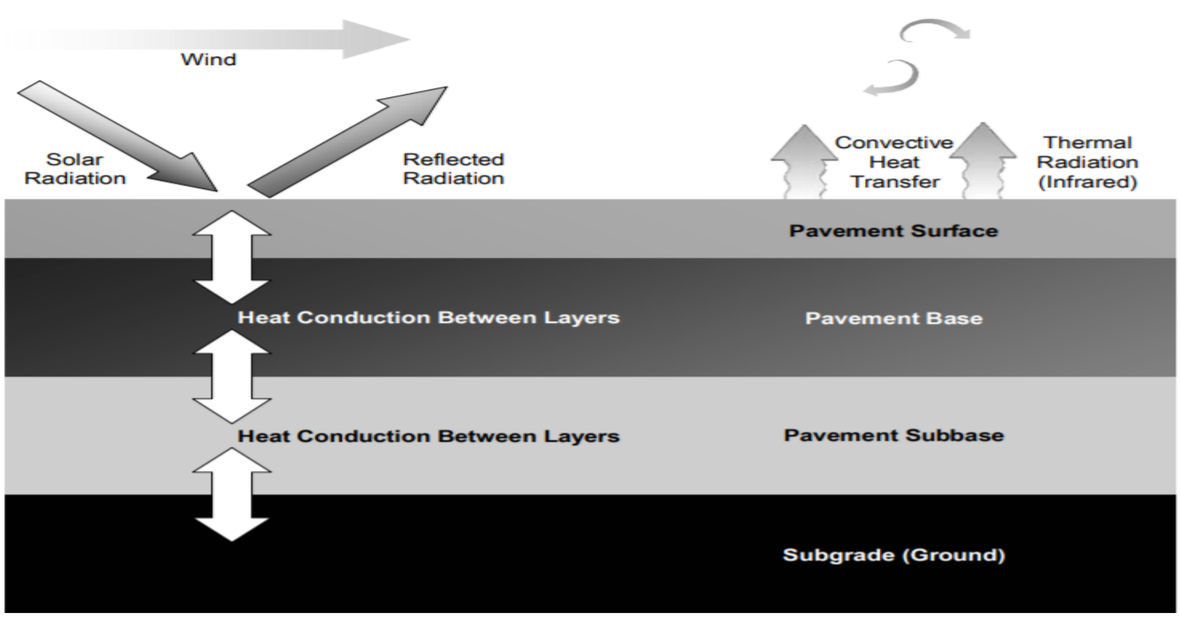


Figure – 8 Heat-Related Characteristics and Processes in a Pavement [16]

COOL PAVEMENT WORKS AND PERFORMANCE - III

3.1 WORKING:

1. Cool surfaces are measured by how much light they reflect (solar reflectance or SR) and how efficiently they radiate heat (thermal emittance or TE) [1].
2. Solar reflectance is the most important factor in determining whether a surface is cool. A cool roofing surface is both highly reflective and highly emissive to minimize the amount of light converted into heat and to maximize the amount of heat that is radiated away.
3. Every opaque surface reflects some incoming sunlight and absorbs the rest, turning it into heat. The fraction of sunlight that a surface reflects is called solar reflectance or albedo.

   For Ex: White roofs reflect more sunlight than dark roofs, turning less of the sun's energy into heat. Increasing the reflectance of our buildings and paved surfaces whether through white surfaces or reflective colored surfaces can reduce the temperature of buildings, cities, and even the entire planet.

   Albedo Effect: Comparison of a black and a white flat roof on a summer afternoon with an air temperature of 37 degrees Celsius (98 degrees Fahrenheit).[1]

   When sun light hits Black surface 38% heats the atmosphere

Black Flat surface	White Flat surface
38 % Heats the atmosphere	10 % Heats the atmosphere
52% Heats the city Air	8 % Heats the city Air
5% is Reflected	80 % is Reflected
4.5% Heats the building	1.5% Heats the building
Black surface 80 Degrees	Black surface 44 Degrees
Air temperature 37 Degrees	Air temperature 37 Degrees

Table – 3 Albedo Effect [1]

- Most roofs are dark and reflect no more than 20 percent of incoming sunlight (i.e., these surfaces have a reflectance of 0.2 or less); while a new white roof reflects about 70 to 80 percent of sunlight (i.e., these surfaces have a reflectance of 0.7 to 0.8).
- New white roofs are typically 28 to 36 degrees Celsius (50 to 65 degrees Fahrenheit) cooler than dark roofs in afternoon sunshine while aged white roofs are typically 20 to 28 degrees Celsius (35 to 50 degrees Fahrenheit) cooler.

3.2 BENEFITS OF COOL PAVEMENTS

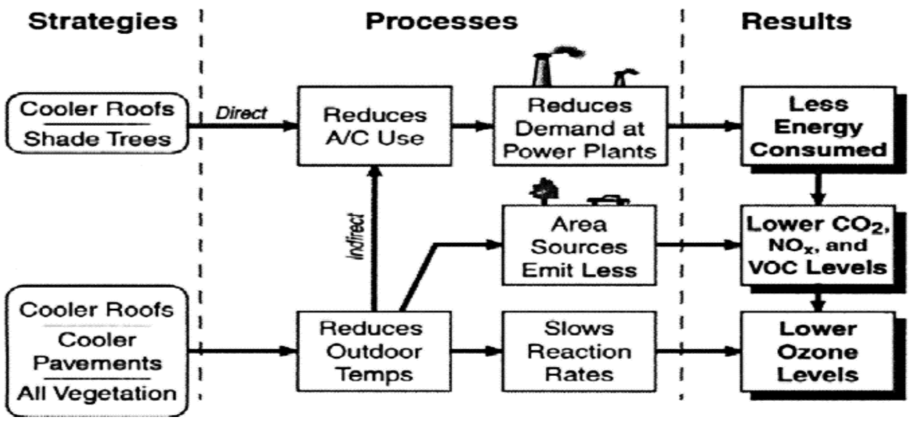


Figure – 9 Proposed Solution [11]

What 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).

Direct impacts of increasing albedo provide immediate benefits, altering the energy balance and cooling requirements of buildings that take advantage of using highly reflective surfaces.

Indirect impacts achieve benefits only with widespread deployment at Akbari, 2005.[11]

Case Study

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.

1. The Heat Island Group projected in 1998 that Los Angeles could save $90 million per year if the city improved albedo of its pavements at Levine, 2011. downtown Los Angeles recorded a growth.

2. of 1°F per decade. Every degree increase adds about 500 megawatts to the air conditioning load in the Los Angeles Basin at Akbari, 2005.

Energy savings and emission reductions.

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.

Which can be estimated in US $5 billion per year about $100 per air-conditioned house Akbari, 2005. 12.2 °C reduction of temperatures in Los Angles reduces power demands by 1.6 gigawatts which results in savings of about $175 million per year.

Cool pavements lower the outside air temperature, allowing air conditioners to cool buildings with less energy. Cool pavements also save energy by reducing the need for electric street lighting at night.

Pavement Durability

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.

Ex: Asphalt pavements are less likely to rut at low temperatures and oxidative aging of asphalt binder is reduced and curling stresses would be reduced in concrete pavements.

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%.

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. 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.

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 according to the EPA.

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.**

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.

Improved comfort and health. Cool pavements cool the city air, reducing heat-related illnesses, slowing the formation of smog, and making it more comfortable to be outside. Pedestrians also benefit from cooler air and cooler pavements.

Increased driver safety

- Light-colored pavements better reflect streetlights and vehicle headlights at night, increasing visibility for drivers.
- Improved air quality. By decreasing urban air temperatures, cool pavements can slow atmospheric chemical reactions that create smog.

Reduced street lighting cost.

- Cool pavements can increase the solar reflectance of roads, reducing the electricity required for street lighting at night.

Reduced power plant emissions.

By saving energy on street lighting and A/C use in surrounding buildings, cool pavements reduce the emission of greenhouse gases and other air pollutants at power plants.

Improved water quality.

Cool pavements lower surface temperatures, thereby cooling storm water and lessening the damage to local watersheds.

Slowed climate change.

Cool pavements decrease heat absorbed at the Earth's surface and thus can lower surface temperatures. This decrease in surface temperatures can temporarily offset warming caused by greenhouse gases.

3.3 CHOOSING COOL SURFACES

- A range of materials are available for standard paving needs. Pavement criteria can vary greatly depending on the use. Highways, highway shoulders, municipal streets, parking lots, sidewalks, playgrounds, driveways, bridge decks, and plazas all have specific functionality requirements that can be met by a range of cool pavement options.

- Many kinds of permeable pavements, including pervious concrete, porous asphalt, and reinforced grass pavements, are also considered cool because they can cool a pavement surface through the evaporation of moisture stored in the pavement.
- Permeable pavements have the added benefit of providing storm-water management. Some common pavement types are described in the table on the facing page.

COOL PAVEMENT MATERIALS

Pavement type	Solar Reflectance (SR)	Uses	Pavement surface life
Clear Resin Binders	Depends on aggregate	New construction & maintenance for streets, sidewalks, parking lots, etc.	20 years
Coatings (e.g., cementitious coating, elastomeric coating)	New: 35–55%	Coatings for preventive maintenance for streets, driveways, parking lots, etc.	1 to 5
Light-Colored Aggregates (e.g., chip seal)	Depends on aggregate	Overlay for preventive maintenance for highways, streets, parking lots	2 to 5 years
Light-Colored Cement (e.g., slag, white cement)	New: 70–80%	New construction & maintenance for highways, streets, sidewalks, parking lots, etc.	40 years
Porous Asphalt Cement (AC), Pervious Portland Cement Concrete (PCC), & Reinforced Grass Pavements	Depends on pavement type	New construction, to aid with stormwater management	varies
Portland Cement Concrete (PCC)	New (gray cement): 35–50% Aged (gray cement): 20–35%	New construction & maintenance for highways, streets, sidewalks, parking lots, etc.	40 years

Table – 4 Cool Pavement Materials [1]

STUDY OF COOL PAVEMENTS STRATEGIES - IV

This Section deals with the potential pavement technologies and strategies for reducing the UHI. Strategies for cool pavements follows into two categories:

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

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.

4.1 STRATEGIES FOR NEW CONSTRUCTION

This cool pavement construction can apply by new or existing which has specific list of analyzing. These 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.

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.
    - Asphalt pavement is also easily recyclable and reprocessed into new pavement when needed and more durability. (EPA, June 2005).[36]

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. It can absorb more heat up to 48.9 to 65.6 °C especially in summer.

Conventional asphalt pavement will normally lighten in color as it ages due to oxidization of the binder. (Levine, 2011).

Proposed solution:

Increasing Albedo in conventional asphalt pavements by using light colored aggregates, which become exposed as the asphalt weathers. 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.

- 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. [36]
- 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).

Resin-based Pavements:

Resin-based pavements use a clear tree resin in place of the typical black petroleum-derive 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. [36]

Proposed solution:

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.

Porous Asphalt Pavements

Porous asphalt is similar to conventional asphalt, 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. (EPA, September 1999). [36]

Two common modifications to the design porous asphalt systems are.

1. the amount of storage in the stone reservoir
2. the addition of perforated pipes near the top of the reservoir in case of overflow.

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.

Proposed solution and uses:

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.

Maintenance: Regular maintenance is needed for open graded surfaces to prevent dust and other particle matter from clogging the surface. vacuum sweeping at least four times a year followed by high pressure hosing to unclog pores in the surface layer. [36]

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.

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. (Synnefa, 2009). [36]

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. These colored samples have mailnly thin layered asphalt about 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.

Rubberized Asphalt Pavements

This 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. This has low thermal conductivity and therefore, less heat storage capacity. (Gauff, 2012). [38]

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. Similar to porous pavements, rubberized asphalt has better thermal insulation.

Texturing/Grouting of Open-Graded Course with Cementitious Materials

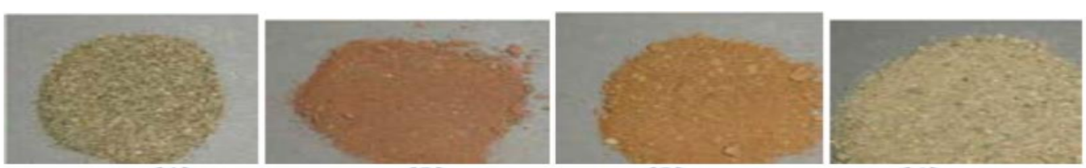
Texturing is a process that consists of first laying the asphalt, compacting it into a patterned form, and then finishing it with a polymerized cement coating. Salviacim® and Densiphalt®+D99 are a proprietary semi-rigid surfacing process consisting of an open-graded asphalt concrete with 20 to 25 percent 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). [36]

Gritting with Light-Colored Aggregate 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.

The gritting with light-colored aggregate construction process will result in uncoated lightly colored aggregate sufficiently adhering to the asphalt surface. (Tran, 2009).

Conventional Concrete Pavements have been utilized for all types of pavement applications including roadways, highways, parking facilities, industrial facilities and airfields. Concrete pavements offer a long-life, low-maintenance alternative for all pavement applications. These pavements have been refined into three primary structural types: 1. Jointed plain concrete pavement (JPCP), 2.Jointed reinforced concrete pavement (JRCP) 3. Continuously reinforced concrete pavement (CRCP) (EPA, October 2008). [33,34,35]

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. 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



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

Figure 1. 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 2. 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).

Figure – 10 Light colored sand and Rock Aggregate [12] the cement has a disproportionately strong influence on the reflectance of concrete. This makes the use of lighter colored cement more attractive.[32,33,34,35]

White Cement: (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

Table – 5 ALBEDO OF CONCRETE SURFACES USING LIGHT COLORED AGGREGATES (LEVINSON, 2001). [12]

On average Gray type Portland cement albedo is 0.32 and white type Portland cement albedo is 0.87.

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. SCMs are lighter in color, slag cement is normally very light in color and will produce a very light-colored concrete 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) [12]

Roller-Compacted Concrete Pavements 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.

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).

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. 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. [33,34,35]

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 coated with a titanium dioxide coating will oxidize air pollutants from vehicle emissions such as NOx and Sox as well as break down VOCs. (Burton, December 2011) [29,30,31]

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.

Solution**:** Kaiser, 2010. this study shows that concrete pavements containing titanium dioxide will reduce airborne NOx by 25 to 45%. 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.

Concrete Pavers Concrete pavers come in many different forms. This includes permeable concrete no vegetated 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. Block pavers are typically used on driveways, walkways, patios, and other recreational outdoor areas. Mitigating of the UHI effect.

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, October2008)

4.2 STRATEGIES FOR EXISTING PAVEMENTS

Reconstruction and rehabilitation are 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. [33,34,35]

- Chip Seals with Light-Colored Aggregate
- Sand and Scrub Seals with Light-Colored Sand
- Conventional and Rubberized Slurry Seals
- Micro surfacing with Light-Colored Materials (Tran, 2009)
- Painting/Colored Surface Coating (Kinouchi, 2004) (Levinson, 2001)
- White topping [Pavement Interactive, 2008]
- Diamond Grinding[IGGA]
- Shot/Abrasive Blasting [Tran, 2009][36]

4.3 OVERVIEW OF EACH STRATEGIES COOLING PERFORMANCE AND LIFE SPAN TABLES

Hot pavements aggravate urban heat islands by warming the local air and contribute to global warming by radiating heat into the atmosphere - pavements can aggravate urban heat islands because they comprise about one third of urban surfaces. Hot pavements can also raise the temperature of storm water runoff. While facing these issues we proposed cooling strategies that reduce the rise of temperature and various factors in the urban geometry.

From this tables, we can understand the workability and performance of each type of pavement study.

In new Road Construction:

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

Technology	Albedo		Service Life (years)	UHI Impact
	Initial	Over Time		
Arterial & Collector				
Conventional Asphalt	0.05 – 0.10[4]	0.10 – 0.15[4]	15 – 20	Low
Rubberized Asphalt	0.05 – 0.10	0.10 – 0.15	15 – 25	Low
Conventional Concrete	0.35 – 0.40[4]	0.20 – 0.30[4]	20 – 35	Medium
White Cement Concrete	0.70 – 0.80[4]	0.40 – 0.60[4]	20 – 35	High
Concrete Pavers	0.10 – 0.80	0.10 – 0.80	15 – 20	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	20 – 35	High
Residential				
Conventional Asphalt	0.05 – 0.10[4]	0.10 – 0.15[4]	20 – 30	Low
Rubberized Asphalt	0.05 – 0.10	0.10 – 0.15	20 – 30	Low
Porous Asphalt*	0.05 – 0.10	0.10 – 0.15	15 – 20	Medium
Conventional Concrete	0.35 – 0.40[4]	0.20 – 0.30[4]	20 – 40	Medium
Pervious Concrete*	0.35 – 0.40	0.35 – 0.40	15 – 25	Medium
White Cement Concrete	0.70 – 0.80[4]	0.40 – 0.60[4]	20 – 40	High
Concrete Pavers	0.10 – 0.80	0.10 – 0.80	15 – 30	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	20 – 40	High

Table – 6. New Road Construction [12]

Existing Road Construction

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

Technology	Albedo		Service Life (years)	UHI Impact
	Initial	Over Time		
Arterial & Collector				
Conventional Asphalt Overlay	0.05 – 0.10[4]	0.10 – 0.15[4]	15 – 20	Low
Rubberized Asphalt Overlay	0.05 – 0.10	0.10 – 0.15	15 – 25	Low
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	3 – 7	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Medium
Whitetopping	0.40[1]	0.25[1]	10 – 15	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	20 – 35	High
Residential				
Conventional Asphalt Overlay	0.05 – 0.10[4]	0.10 – 0.15[4]	15 – 20	Low
Rubberized Asphalt Overlay	0.05 – 0.10	0.10 – 0.15	15 – 25	Low
Chip Seals (Light Colored Aggregate)	~ 0.20[1]	declines	5 – 10	Medium
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	5 – 10	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Medium
Whitetopping	0.40[1]	0.25[1]	20 – 30	Medium

Table – 7 Existing cool pavement Construction [12]

Parking lots and bike lots construction

All new construction can be sealed with the exception of porous asphalt, pervious concrete, grass pave, and gravel pave pavements.

Technology	Albedo		Service Life (years)	UHI Impact
	Initial	Over Time		
New Construction				
Conventional Asphalt	0.05 – 0.10[4]	0.10 – 0.15[4]	20 – 30	Low
Rubberized Asphalt	0.05 – 0.10	0.10 – 0.15	20 – 30	Low
Chip Seals (Light Colored Aggregate)	0.20[1]	declines	5 – 10	Medium
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	3 – 7	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Medium
Porous Asphalt*	0.05 – 0.10	0.10 – 0.15	20 – 30	Medium
Conventional Concrete	0.35 – 0.40[4]	0.20 – 0.30[4]	15 – 35	Medium
Whitetopping	0.40[1]	0.25[1]	10 – 15	Medium
Pervious Concrete*	0.35 – 0.40	0.35 – 0.40	15 – 25	Medium
White Cement Concrete	0.70 – 0.80[4]	0.40 – 0.60[4]	15 – 35	High
Concrete Pavers	0.10 – 0.80	0.10 – 0.80	15 – 30	Medium
Color Pigments and Seals	0.10 – 0.80	0.10 – 0.80	3 – 7	Medium
Titanium Dioxide Cement	0.35 – 0.40	0.35 – 0.40	20 – 40	High
Resin Based	0.33 – 0.55[5]	declines	Unknown	Medium
Grasspave[2] and Gravelpave[2] *	0.26 & 0.60[8]	0.26 & 0.60[8]	10 – 15	Medium
Emerald Cities™	0.45 – 0.55[3]	declines	Unknown	Medium
Existing Construction				
Chip Seals (Light Colored Aggregate)	0.20[1]	declines	5 – 10	Medium
Conventional Scrub / Slurry / Cape Seals	0.05 – 0.10	0.10 – 0.15	3 – 5	Low
Light Colored Binder†	0.10 – 0.80	0.10 – 0.80	Unknown	Medium
Whitetopping	0.40[1]	0.25[1]	10 – 15	Medium
Color Pigments and Seals	0.10 – 0.80	0.10 – 0.80	5 – 10	Medium
Emerald Cities™	0.45 – 0.55[3]	declines	Unknown	Medium

Table – 8 Detail view cool pavement Construction [12]

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
Grasspave[2] and Gravelpave[2]	3	3	5	4	2	3.4	Medium
Emerald Cities™	2	1	3	3	3	2.2	Low

Table – 9 Other factors cool pavement Construction [12]

Any surface exposed to radiant energy will heat up until it reaches thermal equilibrium (i.e., gives off as much heat as it receives). When exposed to sunlight, a surface with high emittance will reach thermal equilibrium at a lower temperature than a surface with low emittance, because the high-emittance surface gives off its heat more readily.

Thermal emittance plays a role in determining a material's contribution to urban heat islands. [37] Research from 2007 suggests albedo and emittance have the greatest influence on determining how a conventional pavement cools down or heats up, with albedo having a large impact on maximum surface temperatures, and emittance affecting minimum temperatures. Although thermal emittance is an important property, there are only limited options to adopt cool pavement practices that modify it because most pavement materials inherently have high emittance values.

5.1 STANDARDS FOR MEASURING SOLAR REFLECTANCE AND THERMAL EMITTANCE

ASTM International has validated laboratory and field tests and calculations to measure solar reflectance, thermal emittance, and the solar reflectance index, which was developed to try to capture the effects of both reflectance and emittance in one number. Laboratory measurements are typically used to examine the properties of new material samples, while field measurements evaluate how well a material has withstood the test of time, weather, and dirt.

To calculate the "solar reflectance index" a specific method is introduced in below. The SRI is a value that incorporates both solar reflectance and thermal emittance in a single value to represent a material's temperature in the sun.

This index measures how hot a surface would get compared to a standard black and a standard white surface. In physical terms, this scenario is like laying a pavement material next to a black surface and a white surface and measuring the temperatures of all three surfaces in the sun. The SRI is a value between zero (as hot as a black surface) and 100 (as cool as a white surface).

Solar Reflectance and Emittance Test Methods

Property	Test Method	Equipment Used	Test Location
Solar reflectance	ASTM E 903 - Standard Test Method for Solar Absorbance, Reflectance, and Transmittance of Materials Using Integrating Spheres.	Integrating sphere spectro-photometer	Laboratory
Solar reflectance	ASTM C 1549 - Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer	Portable solar reflectometer	Laboratory or field
Solar reflectance	ASTM E 1918 - Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field	Pyranometer	Field
Total emittance	ASTM E408-71 - Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques	Portable, inspection-meter instruments	Laboratory or field
Solar reflectance index	ASTM E 1980 - Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces	None (calculation)	—

Table – 10 Solar Reflectance and Emittance Test Methods [24]

5.2 PROPERTIES THAT INFLUENCE PAVEMENT TEMPERATURES—IMPACTS AND APPLICATIONS

Reflective Pavement Options: (Asphalt pavement)

1. **Properties to Consider.** Solar reflectance, which initially may be 5%, can increase to 15–20% as conventional asphalt ages.

   Using light-colored aggregate, color pigments, or sealants, the reflectance of conventional asphalt can be increased. [24]

2. Maintenance applications such as chip seals also can increase solar reflectance.
3. Urban geometry can influence the effect of high albedo pavements.

Issues and Considerations:

Solar reflectance increases over time, and conventional asphalt may reach a reflectance of 20% after seven years.

Urban geometry, in particular urban canyons, influences the impact reflective pavements have on the urban climate.

: (Conventional, Modified Concrete):

1. **Properties to Consider.** Initial solar reflectance ca be 40%
2. This can be raised to more than 70% using white cement instead of gray cement mixtures.
3. Urban geometry can influence the effect of high-albedo pavements.

Issues and Considerations:

1. Solar reflectance decreases over time, as soiling from traffic darkens the surface.
2. Conventional concrete may reach a reflectance of 25% after 5 years.
3. Urban geometry [24]

:(Resin Based, Colored Asphalt, Colored concrete):

1. **Properties to Consider.** These alternative pavements will have varying solar reflectance based on the materials used to contract them.
2. Urban geometry can influence the effect high-albedo pavements have.

Issues and Considerations:

As with concrete, solar reflectance may decrease over time as soiling from traffic makes the pavement darker and the surface wears away.

1. Urban geometry[24]

Pavement temperature impacts:

1. Lowers pavement temperature because more of the sun energy is reflected away, and there is less heat at the surface to absorb into the pavement.

Urban climate impacts:

1. Can contribute to lower air temperatures day and night, although air temperatures are not directly related to surface temperatures and many complicating factors are involved.
2. Reflected heat can be absorbed by the sides of surrounding buildings warming the interior of the building and contributing to the nighttime urban heat island effect, due to the additional heat that needs to be released from urban infrastructure.

Permeable Pavement Options (Non vegetated permeable pavements)

2. **Properties to Consider.** Provides cooling through evaporation.
3. Solar reflectance of these materials depends on individual materials (e.g., gravel may be white and very reflective). In general, permeable pavements may be less reflective than their nonpermeable equivalent due to the increased surface area. [24]
4. Increased convention may help cool the pavement due to increased surface area.

Issues and Considerations

1. Cooling mechanisms depends on available moisture supplemental watering may keep them cooler.
2. Void structure may aid in insulating the subsurface from heat absorption.
3. More research needed to determine permeable pavement impacts on pavement and air temperatures.

Urban climate impacts

5. Wet moist, can contribute to lower air temperature day and night, through evaporative cooling, although air temperatures are not directly related to surface temperatures and many complicating factors are involved. [24]
1. When dry, can contribute to higher daytime surface temperatures, but may not affect or may even reduce nighttime air temperatures, although air temperatures are not directly related to surface temperatures and many complicating factors are involved.

(Vegetated permeable pavements) (Grass pavers, Concrete, grid pavers)

1. **Properties to Consider.** Provides cooling through evapotranspiration.
2. Sustainability of vegetation may vary with local conditions.

Pavement temperature impacts. Lowers pavement temperatures through evapotranspiration, particularly when moist. When dry may still be cooler than other pavement options due to the natural properties of vegetation.

Maintenance/ Rehabilitation (Reflective pavements**) Chip seals.**

6. **Properties to Consider.** Solar Reflectance of chip seals will correlate with the albedo of the aggregate used. In san Jose, CA researchers identified albedo of 20% for new chip seals, which then decline with age. Urban geometry can influence the effect high-albedo pavements. [24]

   White topping, Solar Reflectance of white topping material can be as high as concrete.

   Micro surfacing with high- albedo materials.

   Solar Reflectance of micro surfacing will correlate with the albedo of the materials used. Researchers recently measured solar reflectance of micro surfacing application over 35%.

COLLECTION OF COOLING MATERIALS RESEARCH OUTCOMES TO MITIGATE UHI - VI

6.1 STUDIES ON HIGH ALBEDO MATERIALS.

Study	Year	Purpose	Outcomes
Givoni and Hoffman	1968	white colored building facades compared with grey ones	3 K lower surface temperature
Berg and Quinn	1978	superficial temperature of surfaces with various albedo	a = 0.55: temperature close to ambient a = 0.15: temperature 11° C higher than ambient
Taha *et al*	1992	superficial temperature of surfaces with various albedo	white (a = 0.72) was 45° C cooler than black (a = 0.08)
Akbari *et al*	1998	impact of roof albedo in buildings' cooling demand	22° C lower temperature with 40% increase in roof's albedo
Akridge	1998	high-albedo acrylic coating vs. conventional roof	33° C decrease of roof peak temperature
Doulos *et al*	2004	thermal properties of 93 commonly used pavement materials	"cold" materials = smooth and light colored and/or made of marble/mosaic/stone
Synnefa *et al*	2004	reflective coatings vs. white tile	coatings were cooler up to 4° C under hot summer conditions
Santamouris *et al*	2008	low cost cool coating using lime vs. standard cool coating	15% increase in reflectance
Stathopoulou *et al*	2008	properties of various building and paving materials	white coating (a = 0.83) up to 40° C than black (a = 0.04)
Santamouris	2013	white pavement vs. black asphalt	white was up to 18° C cooler
Pisello and Cotana	2014	cool roof for traditional building	indoor temperature decreased up to 4.7° C

Table – 10 High Albedo Materials [39]

These all are Highly reflective materials which Mitigate Urban Heat Island Effect:

The first step towards the mitigation of UHI came off with the introduction of Cool Materials (CMs) which is given in above table. Cool materials main attribute is high solar reflectance (also referred to as 'albedo' together with high emittance in the infrared spectrum.

This reduces the solar energy gains of the surface, and increases the longwave radiative heat dissipation efficiency, and thus low surface temperatures can be achieved. [40,41]

6.2 MICROCLIMATIC STUDIES ON HIGH ALBEDO MATERIALS.

Study	Year	Purpose	Outcomes
Rosenfeld *et al*	1995	albedo modification in Los Angeles	peak summertime temperature reductions between 2-4° C with albedo increase of 0.13
Rosenzweig *et al*	2006	impact of cool surfaces on New York microclimate	light colored surfaces can decrease air tempppferature up to 1.6° C
Synnefa *et al*	2008	impacts of large-scale increases in surface albedo on ambient temperature	1.5° C and 2.2° temperature decrease with 0.63 and 0.85 albedo respectively
Taha	2008	multi-day episode in August 2000 Texas, USA region	0.2, 0.05 and 0.12 increase of roof, wall and pavement albedo can decrease Tair up to 3° C
Lynn *et al*	2009	surface modification in New York	0.35 increase of pervious surfaces albedo can decrease Tair up to 2° C
Zhou and Shepherd	2009	first-order effects of UHI mitigation strategies	0.3 increase of pervious surfaces albedo can decrease Tair up to 2.5° C
Zhang *et al*	2016	potential global climate impacts of cool roofs	global adoption of cool roof (a = 0.9) may reduce UHI from 1.6° C to 1.2° C
Morini *et al*	2016	surface modification in Terni, Italy	a = 0.8 for walls/roofs/roads may decrease UHI up to 2° C
Tsoka *et al*	2018	ground surface modification in Thessaloniki, Greece	a = 0.4 may decrease Tair up to 0.8° C
Tsoka *et al*	2018	evaluation of ENVI-met performance	synergistic UHI mitigation with cool/-greenery solutions may decrease Tair up to 2° C
Macintyre and Heaviside	2018	cool roof intervention in West Midlands, UK,	a = 0.7 may decrease Tair and heat-related mortality up to 3° C and 25%

Table – 11Micro climates High Albedo Materials [39]

In parallel, a large number of simulation studies have been carried out for evaluating the UHI mitigation potential of CMs which is given in above table. In one of the first approaches, Rosenfeld implemented the Colorado State University Mesoscale Model (CSUMM) and showed that the replacement of dark colored paving and building surfaces with high albedo counterparts could decrease peak summer temperature within Los Angeles area by 2-4◦ C. [42,43]

Similarly, Rosenzweig emphasized the significance of high albedo values concerning both roofs and pavements in New York City in terms of overall cooling potential.

In fact, they utilized the Penn State/NCAR MM5 regional climate model and showed a potentiality of lowering the 2-meters air temperature by up to 2.9◦C.

6.3 COOL MEMBRANES

A number of studies aiming to counteract UHI effect focused on the development of cool surface and roof membranes.

Study	Year	Purpose	Outcomes
Pisello *et al*	2016	in-lab/field analysis of waterproof cool roof membranes	85.4% solar reflectance
Pisello *et al*	2016	polyurethane cool roof waterproof membrane with PCMs	Spectral reflectance/thermal emittance not compromised by PCMs
Pisello *et al*	2017	optimize durability of polyurethane cool roof waterproof membrane with PCMs	durability optimization up to 25 wt%.
Pisello *et al*	2017	cool coatings on differently oriented building envelope surfaces	a = 0.51 may improve indoor thermal comfort by 4.4° C
Saffari *et al*	2018	impacts of large-scale increases in surface albedo on ambient temperature	an optimized melting temperature of PCMs in cool membranes can reduce energy need without compromising durability

Table – 12 cool members [39]

6.4 NATURAL COOL MATERIALS

Several more eco-friendly or sustainable solutions have been reported as alternative passive cooling techniques and hence, capable of mitigating UHI. [44,45]

Study	Year	Purpose	Outcomes
Pisello *et al*	2014	characterization of low-cost grave coverings for roofs/paving	finest grain size has the highest solar reflectance (62%), highly reflective stone decreased its temperature by 5.5° C compared to the commonly-used gravel
Castaldo *et al*	2015	experimental and numerical analysis of low-cost grave coverings for roofs/paving	depending on the grain size albedo can change up to 24%, global scale implementation: equivalent carbon emission offset of 4400 tCO_{2-eq}
Gonçalves *et al*	2015	experimental evaluation of natural stone and ceramic brick as building components	limestones' drying rate was lower than the evaporation rate from a free water surface

Table –13 Natural cooling Materials [39]

6.5 COOL COLOURED MATERIALS

Study	Year	Purpose	Outcomes
Levinson *et al*	2005	optical characterization of various pigments	colored materials that can reflect NIR (> 90%) remain cooler in sunlight than comparable NIR-absorbing colors
Levinson *et al*	2007	thermal performace roof tiles with NIR-reflective coatings	roof surface temperature decrease up to 14° C
Levinson *et al*	2007	methods for creating solar-reflective nonwhite surfaces	NIR reflectance's importance for UHI mitigation.
Syneffa *et al*	2011	thero-optical characterization of 5 color thin layer asphalt samples	surface temperature decrease up to 12° C
Doya *et al*	2012	application of cool selective paint on street facades	reduction of surface temperatures up to 1.5° C
Song *et al*	2014	effect of particle size distribution to NIR reflectance of TiO_2-based coatings	increasing the particles size leads to enhanced NIR reflection
Rosso *et al*	2017	cool colored cement-based materials for maintaining buildings' external heritage	decrease surface temperatures up to 8° C
Rosso *et al*	2017	cool-colored concrete materials for historical areas' facades/pavements	up to 10.6° C lower with respect to non-NIR samples
You *et a*	2019	cool black membrane for asphalt	decrease surface temperature by 12.62° C
Jin *et al*	2019	Asphalt with PCM	reduction of the surface temperature up to 8.11° C
Xie *et al*	2019	thermo-optical properties of cool pavement nano-coatings	NIR reflectance = 95%, solar reflectance = 60%

Table –14 cool-colored Materials [39]

In many cases, due to aesthetic or other reasons such as cultural heritage preservation, specific appearance should be preserved through colored materials and finishing's. For that reason, scientists, apart from white high albedo materials, also developed cool colored alternatives. The principal idea behind cool colored materials lies in their ability to highly reflect the **near infrared (NIR)** part of the solar energy spectrum. [45]

In fact, more than 50% of the incoming solar global radiation is included within the NIR wave-range. As a result, a cool material that (i) absorbs in the visible part for having its color, highly (ii) reflects in the NIR part and (iii) re-emits in the infrared part, can remain cooler than a conventional colored counterpart that absorbs also in the NIR part and overall stores more energy.

6.6 RETRO-REFLECTIVE MATERIALS

Study	Year	Purpose	Outcomes
Akbari and Touchaei	2014	development of a model for the hourly reflectance of directional reflective materials	Summer period: accurate estimation of mean hourly heat absorption and energy saving less than 40 W/m^2 error for peak heat absorption, Winter period:less than 20% error for energy saving estimation 22 kJ/m^2 and 9 W/m^2 error for mean hourly and peak heat absorptions
Rossi *et al*	2015	optic behaviour of RR materials in terms of angular reflectance for several inclination angles of solar radiation	higher cooling potential than traditional diffusive coatings
Han *et al*	2015	effect of bio-inspired RR on building envelopes	average temperature reductions up to 0.46 $^\circ$C
Yuan *et al*	2015	durability of novel RRM for a period of 485 days	maintenance of initial reflectance (0.81), retroreflectance (0.44) for over a year.
Rossi *et al*	2015	cool, white, diffusive material compared to white RR	during hot hours of the day the RR surfaces are 3–7 $^\circ$C cooler
Qin *et al*	2016	cool, white, diffusive material compared to white RR	when incident sunlight's angle exceeds 40° RR performance is deteriorated
Yuan *et al*	2016	optical behavior of glass bead RR for application to building walls	sharply decreased performance at incident angles above 70°
Rossi *et al*	2016	white/beige traditional cool diffusive materials compared to RR	net (downward/upward) signal of RR and beige diffusive is 27 mV and 73 mV
Sakai and Iota	2017	evaluation of novel high-reflective and ordinary RR materials	high-reflective RR: reflects light only during summer but is fragile Ordinary RR: weak retroreflectivity but it can withstand distortion
Manni *et al*	2018	application of optimized selective RR materials	up to 50% decrease of the incident to urban surfaces radiation

Table –15 Retro- reflective Materials [39]

One another passive cooling technique for counteracting UHI, are the Retroreflective (RR) materials. Unlike white and colored cool materials whose mechanism is based on diffuse reflection, RR are specifically designed to reflect the incident solar radiation directly back to its source.

Thus, they preserve their cooling potentiality even if high rise structures are located in the packed surrounded area.

6.7 PHOTOLUMINESCENT MATERIALS.

Photoluminescent materials have been suggested as an alternative cooling method for mitigating UHI due to their intrinsic property to reject incident radiation not only by reflection but also by photoluminescence. Photoluminescence is a subcategory of luminescence and refers to the light emission from a matter, owing to the precedent absorption of photons.

More analytically, when a molecule absorbs a photon in the visible region, it subsequently excites one of its electrons to a higher electronic excited state and then radiates a photon (i.e. releases energy), as the electron returns back to a lower energy state. [39]

Therefore, unlike conventional materials, photoluminescent materials, are characterized by a twofold rejection mechanism concerning incident radiation.

Study	Year	Purpose	Outcomes
Berdahl *et al*	2016	development and test of fluorescent cool-colored materials	6.5° C lower surface temperature than the conventional paint
Levinson *et al*	2017	Test methods for measuring ESR	developed a computer-controlled rotary apparatus that measures ESR with a repeatability of about 0.02
Kousis *et al*	2020	in-field monitoring of phosphorescent-based paving fields during summer period	up to 3.3° C lower surface temperature than cool concrete, phosphors delay peak surface temperature

Table –16 photoluminescent materials cooling Materials.

6.8 THERMOCHROMIC MATERIALS

Depending on the microclimatic characteristics of the implementation area cool materials could result to increased heating demand during the winter period.

Under this framework, academics launched the “Thermochromic" Materials. i.e. materials capable to alter their color and thus their optical properties when their temperature reaches a predefined transition temperature value. As a result, a decreased heating/cooling demand during the cold/hot periods can be ensured.

Study	Year	Purpose	Outcomes
Ma *et al*	2002	investigation of chameleon-type building coatings	Winter: higher temperature by up to 3.5° C than ordinary white building coating Summer: lower surface temperature by up to 4° C than ordinary colored building coating
Karlessi *et al*	2009	comparative analysis in-between thermochromic, highly reflective and common coating	Mean daily surface temperatures: 23.8-38.4° C - thermochromic 28.1-44.6° C - highly reflective 29.8-48.5° C - common
Karlessi *et al*	2013	optical filters for improving thermochromic durability	red filter, which cuts off wavelengths below 600 nm, protects most efficiently the reversible color change
Yu and Hu.	2017	investigation of polymeric thermochromic materials into asphalt binder	Winter period: higher surface temperature than regular asphalt - ideal for delaying ice formation Summer period: cooling effect
Perez *et al*	2018	smart mortar based on ordinary white Portland cement and organic microencapsulated thermochromic pigments	enhanced reflectance above transition temperature (31° C) fine mechanical properties for building application
Xu and Yu	2019	evaluation of thermochromic roof coating	decreased heating/cooling demand up to 40.9% and increased energy and cost savings up to 47.7%
Fabiani *et al*	2019	evaluation of thermochromic roof with an Urban Canopy Model	annual stabilization of heat flux and temperature gradients, enhanced thermal comfort of occupants

Table –17 photoluminescent materials cooling Materials. [39]

6.9 ADVANCED NANO-SCALE MATERIALS.

Advanced nanoscale thermochromic and radiative cooling materials Recently, nanoscale thermochromic solutions, based on Quantum Dots, Plasmonic, and Photonic structures were proposed as the next generation of cool urban materials in the study of Garshasbi and Santamouris.

Due to their non-bright nature, nanoscale materials can assert a pedestrian's visual comfort. In addition, since their properties are based on molecular rearrangement and nanoscale optical effects, they could counteract the photo-degradation issues apparent on intermediate-scale materials.

Study	Year	Purpose	Outcomes
Raman *et al*	2014	development of photonic solar reflector and a seven-layer thermal emitter	sub-ambient temperature by 4.9° C during the hot hours of the day
Zou *et al*	2017	radiative cooling design based on a dielectric resonator metasurface	7.4° C below the ambient temperature during day-time
Garshasbi *et al*	2019	QDs-based coating for UHI mitigation	10° C lower temperature than the reference

Table –18 Advanced nanoscale thermochromic cooling Materials.

6.10 SUSTAINABLE MATERIALS FOR MITIGATING UHI.

In parallel, apart from developing novel materials for mitigating the UHI, research efforts have been attempted for maintaining a more ecofriendly approach. [39]

In fact, urban environment has been found responsible for almost 55% of the world-wide emitted greenhouse gases.

Study	Year	Purpose	Outcomes
Zinzi and Fasano	2009	cool white paint obtained with a special mixture of milk and vinegar	up to 20 °C lower superficial temperature than the conventional
Ferrari *et al*	2013	engobe manufactured by recycled glass and alumina	albedo equal to 0.9 was achieved
Kousis *et al*	2020	development of cool paving binders with waste bio-oils	(i)solar reflectance > 50% within 750–1600 nm (ii) 2° C lower surface temperature than cool reference during hot-hours of day

Table –19 sustainable for cooling Materials [39]

Next generation multifunctional surfaces.

UNI mitigation	UHI mitigation	Air pollution mitigation	Implementation field
porous natural fibers, inorganic foams	cool natural, recyclable	titanium/silicon dioxide zinc-oxide	pedestrians' pathwalks, parking areas, cycle paths
porous natural fibers, inorganic foams, membrane panels	cool natural, membranes	titanium/silicon dioxide zinc-oxide	roofs, facades
porous metal fibers, foams	cool colored, fluorescent	titanium/silicon dioxide zinc-oxide	roads
porous fibers, foams	nano- thermochromic	titanium/silicon dioxide zinc-oxide	building envelope

COST CONSIDERATIONS - VII

The costs of competing cool pavement technologies are an important factor in selecting the type of pavement or maintenance technique to employ [11]. Developing comparable data on costs is complicated, however, by differences in practice among agencies nationwide and by local economic factors. In addition, similar units have different meanings for each pavement technology; a ton of asphalt and a ton of concrete will not produce the same amount of road. [16,1,24,25]

Costs also depend heavily on the overall design of an individual roadway; a road constructed to bear heavy truck traffic would be expected to cost significantly more per square yard of pavement surface than one built for light residential use. Finally, local availability of materials will strongly influence the cost of certain cool paving technologies, especially those involving light-colored aggregates; it is cost prohibitive to ship aggregate very far.

For these reasons, it is difficult to meaningfully compare costs between candidate technologies without a full consideration of project type and location. Ultimately, local pavement contractors and engineers are the ones who can generate meaningful costs. Nonetheless, it is useful to know general cost ranges for potential pavement technologies.

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.

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. Also given the wide range of materials, techniques, Properties and applications as discussed in above Chapters.

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. Technology – cool pavement strategy evaluated in this study. [11,15,1,50]

i. Albedo – ratings at initial construction and over time, as light-colored pavements will darken over time, and dark pavements will get lighter over time.

ii. 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.

iii. 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.

iv. 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 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.

there are other factors that should be considered by the City in any decisions on treatment selection.

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.

Ease of implementation -this rating is based on three criteria:

1) is the pavement technology currently used by city?

2) does the City currently have specifications for construction?

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.

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.

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.

New research findings on consequences of deploying cool pavements.

Recent research in California has led to important findings on penalties and benefits from deploying cool pavements in cities across the state. See the key take-aways from this research below.

- Cool pavement materials usually require more energy and carbon to manufacture than conventional pavement materials. An exception is concrete with substantially reduced levels of energy- and carbon-intensive ordinary Portland cement.
- Raising by 0.20 the albedo of all paved surfaces is projected to reduce summertime outdoor air temperatures in California cities by about 0.1 to 0.5 °C (about 0.2 to 0.9 °F), depending on city geography and climate.[15,49]
- In California cities with a lot of air conditioning, the savings of air conditioning energy due to lowered air temperature is less than 1 kWh (saving less than US$0.60) a year per m^2 of pavement modified. The avoided CO_2 is valued at less than a penny a year per m^2. [48,47]
- The energy and carbon saved in buildings is typically much less than the extra energy and carbon needed to make the cooler pavements.
- For comparison, building energy savings from cool pavements are about an order of magnitude smaller than those from cool roofs.
- Reflective pavements offer a one-time carbon offset (benefit) that exceeds the 50-year life-cycle carbon penalty (or 50-year life-cycle carbon savings).
- And this is based on upcoming technology and important challenge is to create cool pavement materials that reduce life-cycle energy, carbon, and cost.

CONCLUSION - VIII

Urban Heat Island manifests in the form of increased urban air temperatures, and influences water use, air quality, public health, and so on. Cool surfaces, including pavements, roofs, and walls, have been suggested to mitigate UHI. However, the UHI is a heterogeneous effect, with local land-use patterns, construction materials, building forms, and climatic factors affecting possible mitigation functions. About 1/3rd or around 40% of urban surfaces are paved and One reason for cities being hot is that have many dark surfaces. Cool surfaces are a cost-effective and simple way to achieve reduced urban temperatures in pavements.

If pavement reflectance throughout a city were increased from 10 to 35%, then air temperature could potentially reduce. Cooler air temperatures also slow the rate of ground-level ozone formation and reduce evaporative emissions from vehicles. Permeable pavements allow water to soak into the pavement and soil, thereby reducing stormwater runoff. Reducing pavement surface temperatures reduce the risk of premature failure of asphalt pavements by rutting. Nighttime illumination: Reflective pavements can enhance visibility at night, reducing lighting requirements and saving money and energy.

This study is more significant to improving the attention of problem-solving and finding the ways of various techniques for improving the urban climate with the help of cool pavements technologies. As discussed above, these needs encompass not just technical pavement and construction research, but also institutional research and development studies for the future to get clearer on Global impacts and solving possible Strategies.

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