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Mitigating Urban Heat Islands in Abuja, Nigeria: Adopting Cool Pavement Technology – A Review

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Abstract: Urban heat islands (UHI) are caused by the heat absorption and reflectance from solar energy by dark surfaces, which can cause the temperature in urban areas to be significantly warmer in the summer months. This excess heat increases the peak energy demand, as people rely on air conditioning to cope, which contributes to elevated levels of greenhouse gas emissions and air pollution. Efforts to mitigate these adverse effects focus largely on increasing the reflective or radiate properties of the built environment, such as cool pavements. Cool pavement technologies create cooler surfaces through convection or higher reflectance. The aim of this paper is to review the strategies to reduce the heat-island effect that are among the climate change mitigations being considered by cities around the world with particular reference to the case of Abuja Nigeria, which will reveal the extent of road pavement contribution to UHI. Road pavement is the durable surface material laid down on an area intended to sustain vehicular or pedestrian traffic. The causes and effects of UHI with respect to the pavement structure at Abuja Metropolitan City, Nigeria were reviewed. The paper concluded that cool pavement technology could be used to control differential temperature induced by road pavement in Abuja, Nigeria.

Keywords: Urban Heat Islands, Cool Pavement Technologies, Climate Change, Abuja Metropolitan City

1. Introduction

The urban heat island (UHI) effect is a measurable increase in ambient urban air temperatures resulting primarily from the replacement of vegetation with buildings, roads, and other heat - absorbing infrastructure [1]. This occurrence is due to the reduction of natural vegetation, increased human activity and the absorption and radiation of solar energy in all built surfaces. Roofs, parks, water bodies and pavements all have different properties that determine how much of the sun's heat is absorbed and released, and they all interact together and with other systems in an urban area to produce a total Heat Island Effect (HIE). The UHI effect should not be confused with climate change (global warming); they are separate and rather unrelated items. The UHI effect is specifically a local temperature increase (generally the difference between urban and surrounding rural areas) while climate change refers to larger scale variations in global climate caused, in general, by greenhouse gas emissions resulting from human activity. The study by [2] shows that as built-up increase by 72.6sq km/yr at the expense of other land use types at Abuja, the Federal Capital Territory (FCT) Abuja, surface temperature increase by 0.28°C/yr. Studies and simulations performed for 10 large cities in the U.S. indicate an average UHI effect of about 2°C compared to surrounding rural areas [3] and some cities are as much as 5.6°C warmer than surrounding natural land cover [1]. UHI can impact sustainability in the following ways [1]:

Energy consumption: Higher temperatures increase artificial cooling (air conditioning) demand. Akbari [4] claims that increased cooling demand can account for 5 - 10% of urban peak electricity demand.

Emissions: Increased electricity demand results in more power plant operation and resultant air pollution and greenhouse gas generation.

Human Health: The UHI effect can contribute to general discomfort, respiratory difficulties, heat cramps and exhaustion, non−fatal heat stroke, and heat - related mortality [5].

Water Quality: Higher pavement temperatures can heat stormwater runoff. Higher water temperatures can, in turn, affect metabolism and reproduction of aquatic species.

1.1. Pavement Contribution to the Urban Heat Island Effect

Pavements have become an important contributor to this effect by altering land cover over significant portions of urban areas. Pavements are found to be a significant contributor to the UHI temperature increase because (1) they constitute a substantial portion of total urban land coverage and (2) pavements can store and radiate a significant amount of heat. Researchers have studied ways to reduce the urban heat island effect, and have identified vegetation, "cool roofing" materials, and "cool pavements" as mitigation strategies. While good ways to use vegetation are understood and cool roofing products have been identified, the idea of cool pavements has yet to gain wide dissemination and acceptance among local transportation and public works agencies and private-sector developers and owners. Several reasons account for this situation. First, there are technical hurdles in identifying the best cool pavement technologies and their different applications in varying climates. Second, the benefits from cool pavement are indirect. Third, institutional complexities surround pavement type selection throughout a metropolitan area, and more information on the economics of cool pavements, as well as funding mechanisms to support these technologies, are needed [2].

1.2. Cool Pavements

Cool pavements refer to a range of established and emerging materials. These pavement technologies tend to store less heat and may have lower surface temperatures compared with conventional products. They can help address the problem of urban heat islands, which result in part from the increased temperatures of paved surfaces in a city or suburb. Cool pavements are designed to reduce the absorption of the sun's energy and consequently radiate less heat to the surrounding environment. Solar energy is absorbed by the pavement surface and becomes stored as heat in the pavement. Paving materials can reach as much as 65°C [1] on sunny days, radiating this heat during the day and during the night back into the air as well as heat storm water that reaches the pavement surface.

Cool pavements describe pavements which either have a more reflective surface than traditional pavements, enable evaporative cooling, or other methods that allow the paved surface to remain cooler than traditional pavements. All of the research and developments are based upon the work of the Environmental Protection Agency (EPA) and the Heat Island Group from Lawrence Berkeley National Laboratory (LBNL). Their research established the definition of cool pavements which is now part of the Leadership in Energy and Environmental Design (LEED) certification system:

i. Shading hard surfaces with landscaping or design elements.
ii. Using materials with a SRI of 29 or greater.
iii. Using an open-grid paving system that is at least 50% pervious.

Thus the aim of this paper is to review the strategies to reduce the heat-island effect that are among the climate change mitigations being considered by cities around the world.

The objectives are

i. To create awareness on the causes and effects of Urban Heat Islands (UHI),
ii. to investigate the extent of UHI associated with road pavement,
iii. present ways of mitigating the effects of UHI using Cool Pavement technology.

Cool pavements can be achieved by the use of existing pavement technologies, e.g., surface modifications or novel constructions. Four main research streams are to develop highly reflective paved surfaces, to make pavement evaporative, to increase the thermal inertia of the pavement, and to harvest renewable energy for pavement layers. Among them, the first two may be the most practical approaches to develop cool pavements. The third one reduces the daytime sensible heat but may increase this factor during the nighttime. The results from the heat-harvesting pavement prototype require detailed scrutiny on the power output, durability, and lifetime of the pavement system [6].

2. Urban Heat Island (UHI) Effect in Abuja Metropolitan City

An urban heat island (UHI) is a city or a metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. The properties of urban roofs and pavements, as well as human activity, contribute to the formation of urban heat islands. As the name implies, the effects makes cities into islands of heat. The Study area, Abuja, the Federal Capital Territory (FCT) is located between latitudes 8° 25' and 9° 25' north of the equator and longitudes 6° 45' and 7° 45' east of Greenwich Meridian. The territory covers an area of 8,000 square kilometers and occupies about 0.87% of Nigeria [7].

According to [2], the study area is experiencing an increasing level of land transformation and conversion due to the increase rate of urbanization. The high rate of depletion of the vegetal resources at the expense non - evaporative land uses such as concrete, asphalt and other such impervious materials are seriously responsible for the rise in the land surface temperatures in the Federal capital Territory. The heat experiencing in the built up areas of the study area is more than the surrounding.

Land surface temperature is gradually rising in all cities in the world due to increasing levels of land use change and conversion especially in urban centers. The study by [2] examined the pattern of surface temperature change between (between 1987 and 2001, and between 2001 and 2011) 1987, 2001 and 2011 using geospatial technology. Satellite imageries of 1987, 2001, and 2011 covering Abuja Federal Capital Territory were acquired to detect the changes in land use, their transformational effect on land surface temperature within period of study. Spatial analytical tools of Arc GIS 9.2, ILWIS 3.3 and IDRISI Andes were deployed in establishing a relationship between Land Surface Temperature increase and changes in Land use types. The result revealed a rapid growth in built-up land between 1987 and 2001 while the periods between 2001 and 2011 also witnessed a massive increase. As built-up increase by 72.6sqkm/yr at the expense of other land use types, surface temperature increase by 0.28°C/yr. It was also projected that by 2025 built up land would have taken over 50% of the entire land mass of Abuja Nigeria, which may also go along with increase in surface temperature with its consequence on human health.

2.1. Land Surface Temperature Distribution in Abuja, Nigeria

Table 1 shows the average values of surface temperatures (°C) by land-use type in 1987, 2001 and 2011. To understand the impact of Land use/Land Cover (LULC) on surface temperature, the characteristics of the thermal signatures of each land-use type must be studied first. Rock outcrop, Built-up and Bare surface exhibit the highest surface temperature (51.83, 48.50, and 45.17°C in 1987, 55.50, 51.99, and 48.48°C in 2001 and 58.60, 54.78, 50.96°C in 2011 respectively), followed by Light vegetation (36.85°C), and thick vegetation, 31.86°C in 1987, 40.44 and 32.42°C respectively in 2001, and 41.41 and 35.68°C respectively in 2011). The lowest surface temperature in 1987, 2001 and 2011 is observed in water body (26.87, 29.18 and 29.95°C respectively) [2]. Table 1 shows land surface temperature Maps of Abuja Nigeria in 1987, 2001, and 2011.

Table 1. *Land Surface Temperature over different Land Use/Land Cover categories.*

	Built -up	Bare surface	Thick vegetation	Light vegetation	Rock outcrop	Water body
Min & Max LST (1987)	48.50 – 46.84	45.17 – 43.51	31.86 - 30.20	36.85 – 35.19	51.83 – 50.17	26.87 – 25.20
Min & Max LST (2001)	51.99 – 50.24	48.48 – 46.73	35.42 – 33.75	40.44 – 38.77	55.50 – 52.90	29.18 – 27.42
Min & Max LST (2011)	54.78 – 52.87	50.96 -49.05	35.68 – 33.77	41.41 – 39.50	58.60 – 56.69	29.95 – 28.04
Change in LST	+6.28	+5.79	+3.82	+4.56	+6.77	+3.08

Source: [2].

Increase in built up area, development and increased population bring up surface temperature by replacing vegetation with non- evaporating surfaces such as stone, metal and concrete. The change in LST values are high for Built-up land (+6.28 in 1987 to 2011), indicating that built up area experiences a wide variation in surface temperature. The lowest surface temperature in 1987, 2001 and 2011 was observed in water (26.87, 29.18, and 29.95°C), followed by light and thick vegetation. The rise in temperature can be said to be as a result of the disruption in the ecosystem services provided by the vegetation and water bodies in terms of temperature regulation and cooling of the environment [8, 9, 10].

2.2. Causes and Effects of UHI (With Regards to Pavement Structures)

2.2.1. Causes of UHI

- Solar Energy: Solar energy is composed of ultraviolet (UV) rays, visible light, and infrared energy, each reaching the Earth in different percentages: 5 percent of solar energy is in the UV spectrum, including the type of rays responsible for sunburn; 43 percent of solar energy is visible light, in colors ranging from violet to red; and the remaining 52 percent of solar energy is infrared, felt as heat. Energy in all of these wavelengths contributes to urban heat island formation [1].
- Solar Reflectance (Albedo): Solar reflectance, or albedo, is the percentage of solar energy reflected by a surface. Most existing research on cool pavements focuses on solar reflectance, which is the primary determinant of a material's maximum surface temperature. Albedo also affects pavement temperatures below the surface, because less heat is available at the surface to then be transferred into the pavement. Researchers, engineers, and industry have collaborated to develop methods to determine solar reflectance by measuring how well a material reflects energy at each wavelength, then calculating the weighted average of these values as shown in Figure 2 [1]. Conventional paving materials such as asphalt and concrete have solar reflectance of 5 to 40 percent, which means they absorb 95 to 60 percent of the energy reaching them instead of reflecting it into the atmosphere, as shown in Figure 1 [1].

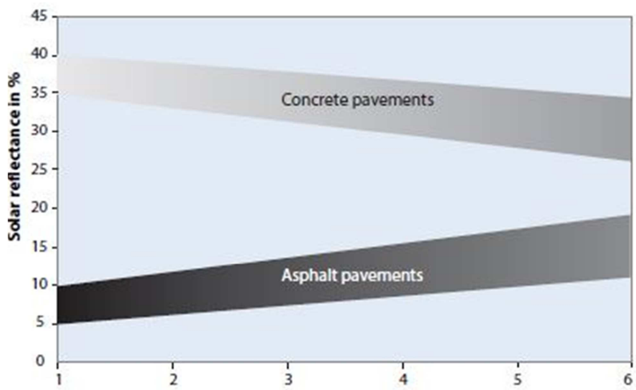

Figure 1. *Typical Solar Reflectance of Conventional Asphalt and Concrete Pavements over Time. Source: [5].*

However, these values depend on age and material, and thus usually change over time. Figure 2 shows how changing only albedo can significantly alter surface temperatures. Although researchers, including those at Lawrence Berkeley

National Laboratory, California, U.S. (LBNL), have made light-colored pavements with solar reflectances greater than 75 percent, these high albedo pavements do not have widespread commercial availability.

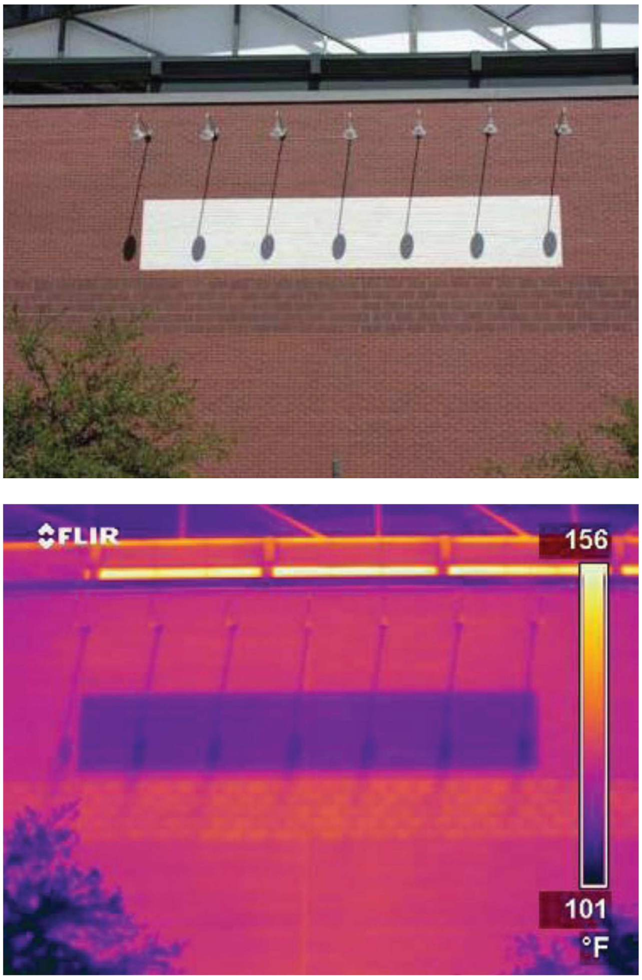

Figure 2. *The Effects of Albedo on Surface Temperature. Source: [8].*

Albedo alone can significantly influence surface temperature. It is observed that Albedo influences surface temperature, with the white strip on the brick wall about 3-5°C cooler than the surrounding darker area.

Thermal Emittance: A material's thermal emittance determines how much heat it will radiate per unit area at a given temperature, that is, how readily a surface sheds heat. Any surface exposed to radiant energy will heat up until it reaches thermal equilibrium (that is, 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. 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.

Impervious Surfaces: Impervious surfaces are mainly constructed surfaces; rooftops, sidewalks, roads and parking lots- covered by impenetrable materials such as asphalt, concrete, and stone. These materials effectively seal surfaces, repel water and prevent precipitation and melt water from infiltrating soils. Surfaces covered by such materials are hydrologically active, meaning they generate surface runoff. Paving watershed areas with asphalt and concrete makes these surfaces "desertlike" in terms of hydrology and climate. Storm water washes over paved, sparsely vegetated urban surfaces in much the same manner as it does over desert landscape. Rapid runoff and the paucity of vegetation over these surfaces also reduce the amount of water available for evapotranspiration. Therefore much of the incoming solar energy that could have been utilized to evaporate water is instead transformed into sensible heat. This effectively raises the temperatures of these surfaces and of the overlying atmosphere contributing to UHI effects. Moreover, impervious urban surfaces behave like rocky desert surfaces in that they tend to have high thermal conductivities and heat storage capacities in comparison to vegetated, pervious surfaces [11].

Pavement Thickness: The thickness of a pavement also influences how much heat it will store, with thicker pavements storing more heat.

2.2.2. Effects of Urban Heat Islands

Some effects of UHI include:

The effect of UHI makes cities into islands of heat. According to US Energy Policy Act; [12], temperatures in U.S. cities can get as much as 7°C higher than their surrounding areas.

There is increased energy consumption. The demand for air conditioning in the heat period leads to higher energy bills.

There is elevation in emissions of air pollutants and an increase in greenhouse gas emissions from power plants that provide the extra energy.

Compromised human health and comfort and Impaired water quality. Excessive heat cause exhaustion and may even lead to death. In the U.S., heat typically kills more people each year more than tornadoes, hurricanes, floods and lightning put together (National Oceanic and Atmospheric Administration NOAA) [13].

3. Standards for Measuring Thermal Reflectance (Albedo) and Thermal Emittance

To evaluate how "cool" a specific product is, 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. (See Table 2) 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.

The final method listed in Table 2 is not an actual test but a way to calculate the "solar reflectance index" or SRI. 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). Albedo is typically measured on a scale of zero to one, it can also be measured as a percentage; an albedo of 0.05 corresponds to a solar reflectance of 5 percent.

Table 2. *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 E 408-17 – Standard Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques.	Portable, Inspection-meter Instrument	Laboratory or Field
Solar Reflectance Index	ASTM E 1980 – Standard Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surface.	None (calculation)	

Source: [5].

According to [14], techniques for increasing albedo include resurfacing, sealing treatments, and white-topping. Research has shown that permeable pavements lower surface temperature through enabling evaporation to happen close to the surface. Most of the strategies to reduce pavement temperature deal with either treating the surface of existing pavements or the design and construction of new pavements.

3.1. Pavement Preservation and Rehabilitation

Traditional pavements, particularly asphalt pavements, have a low albedo and retain the capturedheat quite well. The most cost effective way to make these existing pavements "cool" is to treat their surfaces, which can also preserve the life and improve the performance of the pavement, due to less thermal and environmental stresses for the pavement.

3.2. Reflective Coatings and Seals

Treating the pavement surface with lighter colored material to increase reflectance is a relatively straight forward procedure. There are a number of different techniques, but the overall approach is the same. By covering the exposed surface, typically of existing pavements, the albedo is increased without reconstructing the whole roadway or parking lot. In many cases these applications can be part of regular pavement maintenance and preservation [15].

Chip seals (or seal coating, BST, Bituminous Surface Treatment), an application of a special protective wearing surface to an existing pavement, are commonly used as a low cost and quick method of resurfacing roads. Using a light-colored aggregate with polymers, emulsion or resin for the binder, these chips seals create a marked improvement of the pavement's SRI as measured for the top coat. They also extend the life of the road surface.

Scrub seals - when pavements deteriorate they crack. Often crack sealing is done but sometimes pavements can be so old and aged that crack sealing is not an option. Scrub seals are process by which a membrane of modified binder is pressed or scrubbed into a crack and aged surface, example of a scrub seal is Styrflex ERA and AR scrub. Scrub seal can also be used to raise the SRI of a surface by using light-colored aggregates for the application.

Micro-surfacing (a mixture of a polymer-modified cationic emulsified asphalt, mineral aggregate, mineral filler, water and additives that are proportioned, mixed, and spread with a machine over a properly prepared surface), or sealing the surface of the pavement with a thin layer of high albedo material, can increase the reflectance of the pavement and extend the life of the pavement. Many of these coatings have been engineered to provide enough friction to remain safe in wet conditions. Products, like Emerald Cool Pavements, are available on the market.

3.3. White-Topping

The traditional approach to resurfacing pavements through a concrete overlay, known as white-topping, can dramatically increase the pavement's albedo. The reflective benefits of normal white-topping, where the layer of concrete is greater than 100 mm thick, and ultra-thin. White-topping, where the application is only 50-100 mm thick, are comparable. The benefits of using this technique include:

i. Avoids traditional stresses of an asphalt overlay,
ii. Can be used on existing pavement systems,
iii. Quick to apply and reopen to traffic,
iv. Less sensitive to seasonal variations,
v. Easily serviced.

3.4. Construction of New Pavements

For new pavements, there are different techniques that can be used during construction to reducethe temperature of the surface, either through increasing the albedo or promoting evaporative cooling. These strategies go deeper than the surface, and require the use of different materials and techniques than traditional methods. Some of these techniques have other environmental benefits besides reducing the temperature of the pavement, such as using less hazardous binders, using a waste material from other industries as binders, and generating less erosion through water runoff.

3.5. Modified Mixes

Modifying the mix of both asphalt and concrete pavements can increase their reflective properties.

Modified Asphalt Pavements: Using a lightly colored aggregate will raise the albedo between 15-.20 when it's freshly laid. Another technique to be considered is the addition of colored pigments to the mix. Non-bituminous binders, such as tree resin, are clear and therefore depend on the aggregate for overall reflective property. Resin pavements are suitable for walkways, bike paths, and parking lots. One resin-based product currently on the market is Natural Pave.

Modified Portland Cement Concrete Pavements: While unmodified concrete pavements are moderately reflective, steps can be taken to improve their overall reflectivity. Using lightly colored aggregates and white cement can increase the albedo to 70. Using recycled materials in concrete mixes can also improve the reflectance. Fly ash, a byproduct of coal fueled power plants, and slag, a byproduct of blast furnace production of iron ore, can be used as aggregate. Slag is noted for its reduced heat generation, as well as higher strength and improved durability.

4. Results and Discussion

Most existing research on cool pavements focuses on solar reflectance, which is the primary determinant of a material's maximum surface temperature. If the urban surfaces were lighter in color, more of the incoming light would be reflected back into space, cooling the surfaces and ambient air. Cooler surfaces and air reduce the need for air conditioning, saving energy and reducing power plant emissions. Cooler air can also reduce air pollution by slowing the chemical reactions that produce smog. In pavement structures, the topmost surface is the only layer which affects albedo. Therefore, pavement type selection should also include a consideration of albedo where heat generation is a concern.

Field measurements indicate that new, cured gray-cement concrete pavement has an albedo in the range of 0.35 - 0.40. As concrete ages, it tends to darken because of dirt and tire wear, so older concretes have albedos in the range of 0.20 – 0.30. The use of white cements and slag cements can also influence a concrete's albedo immensely. White cement concrete pavements have albedos in the range of 0.70 - 0.80 when new, and 0.40 - 0.60 when aged. Asphalt, on the other hand, tends to get lighter as it ages, due to oxidation and wearing of the binder, revealing the lighter-colored aggregate. New asphalt is very dark, so it has an albedo of 0.05 - 0.10, and aged asphalt has an albedo of 0.10 – 0.15 (as shown in Table 3) [14].

Table 3. *Albedos (reflectance) of pavement surfaces.*

Pavement Type	Albedo
Asphalt	0.05 – 0.10 (new) 0.10 – 0.15 (weathered)
Gray Portland Cement Concrete	0.35 – 0.40 (new) 0.20 – 0.30 (weathered)
White Portland Cement Concrete	0.70 – 0.80 (new) 0.40 – 0.60 (weathered)

Source: [15]

Studies sponsored by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA), researchers in the Heat Island Group at the Lawrence Berkeley National Laboratory investigated methods to develop cool concrete pavements by using white Portland cement and reflective aggregates.

In urban situations, most sidewalks and a varying percentage of roads and parking areas are paved with Portland cement concrete, which can be made even more reflective through suitable choice of cement and aggregate. Variations in mix design and environmental exposure of Portland cement concrete pavements were explored in the Berkeley study through laboratory fabrication and exposure of 32 different concrete mixes.

Excluding substandard samples that exhibited poor mixture characteristics, the albedos of the concrete mixes ranged from 0.41 to 0.77. Simulated weathering, soiling, and abrasion each reduced average concrete albedo, though some samples became slightly more reflective through weathering or soiling. Simulated rain (wetting) strongly depressed the albedos of concretes until their surfaces were dried. Concrete albedo grew as the cement hydration reaction progressed, but stabilized within six weeks of casting.

White-cement concretes (albedos 0.69 – 0.77) were on average significantly more reflective than gray-cement concretes (albedos 0.41 – 0.52). The albedo of the most-reflective white-cement concrete was 0.18 to 0.39 higher than that of the most-reflective gray-cement concrete, depending on state of exposure. Concrete albedo generally correlated well with cement albedo and sand albedo, and, after abrasion, with rock albedo. Cement albedo has a disproportionately strong influence on the reflectance of concrete.

Even though concrete pavements can be made lighter than they already naturally are, the benefit of using light-colored aggregates and white cement (as compared to normal aggregates and standard gray cements) needs to be weighed against the additional cost of obtaining these materials. Concretes made with white cement, for example, may cost up to twice as much as those made with normal gray cement.

However, certain blended cements (slag cements) are very light in color and may reflect similarly to white cement at an equivalent cost to normal gray cement.

The cost savings, however, from switching from asphalt pavements to normal gray concrete pavements can save a city millions of dollars a year. Simulations of the influence of pavement albedo on air temperature in Los Angeles predict that increasing the albedo of 1,250 km of pavement by 0.25 would save cooling energy worth $15M per year, and reduce smog-related medical and lost-work expenses by $76M per year [15].

5. Conclusion

i. The growing interest in lowering urban temperatures and designing more sustainable communities has helped spur activity in the cool pavement arena. Most of the effort has focused on research, due to information gaps and the lack of specific data quantifying cool pavement benefits.
ii. Although cool pavements are still in their infancy compared with the other heat island mitigation strategies - trees and vegetation, green roofs, and cool roofs - interest and momentum are growing. Research efforts these past few years have greatly increased and have revealed that UHI can be mitigated through the adoption of cool pavement technology, also in the area of permeable pavements, and more extensive research is encouraged.

Recommendations

i. Target should be made on alternative paving options for specific types of paved surfaces, such as highways or parking lots, or expanding residential or commercial roadways, this requires coordination with the relevant transportation agencies.
ii. Local and state decision-makers should be educated about public health, environmental management, and public works maintenance benefits of alternative pavements.
iii. There should be combination and embedding of alternative paving incentives into larger programs and regulations.

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