Caroline Zepecki: Market Analysis of Reflective Surface Coatings and Potential for City-wide Applications

Caroline Zepecki, a Research Analyst Intern at SSC, researches the potential for implementing reflective coatings on roadways and parking lots city-wide. Reflective surfaces are an important element of a Smart Surfaces strategy.

Introduction

Due to the solar absorbent nature of many human-made surfaces, urban areas regularly experience increased temperatures, a phenomenon known as the Urban Heat Island effect (UHI). City departments and agencies that handle infrastructure decisions traditionally opt for the lowest cost, dark and impervious surfaces as the design standard in development. These conventional surfaces, like dark asphalt, absorb the most sunlight and significantly contribute to urban heating. Also, when pavements regularly experience warming during the day and cooling at night, thermal expansion and contraction occurs, which can cause cracks. Business-as-usual development comes with significant costs resulting from infrastructure repair and maintenance, worse air quality, and increased heat, especially in low-income and BIPOC communities.

Roadways, where much of the work done today and opportunity for growth are, also include streets, parking lots, and walkable areas like sidewalks. Roadways are traditionally composed of dark, impervious asphalt that, in densely developed areas, contribute drastically to the UHI. Dark asphalt, with traditionally low solar reflectance, absorbs most sunlight that then contributes to the heating of the surrounding area. Depending on the characteristics of the city, “pavements could contribute to as much as 44% of the Urban Heat Island (UHI) phenomenon in cities,” (1). Considering that over a third of developed areas are covered by paving materials (2), as urban areas develop, applying highly reflective pigments to roadways and other paved surfaces is a tool that can be utilized on city-wide scales to drastically reduce UHI and increase livability. Overall, increasing the solar reflectance of roadways can lead to increased negative radiative forcing: when the solar energy reflected into deep space outweighs the energy input from the sun, cooling occurs.

Smart Surfaces—referring to the deployment of an integrated set of green, porous, and reflective surfaces, solar PV, trees, and carbon sequestering concrete—can greatly reduce urban heat and make cities more livable and vibrant. Pavement coatings applied to parking lots and roads are just a couple solutions under the suite of options that comprise a comprehensive Smart Surfaces strategy. This analysis goes into detail on how the implementation of highly reflective coating products on traditionally dark surfaces would allow cities to improve public health, livability, and equity.

Solar Reflectance

Solar reflectance (SRI), is a measure of a surface's ability to reflect solar heat, standardly measured on a range of wavelengths from 300 nm–2500 nm and averaged to produce an SRI value from 0–1. The measure of SRI takes into account both solar reflectance and thermal emissivity. Solar reflectance is the ratio between the energy reflected globally by a surface and total incident solar energy; thermal emissivity is a material's property to radiate energy with respect to a black body (values closer to 1.0 indicate the maximum threshold of accumulated heat is dissipated without further radiative transfer) (19). The SRI index is defined such that the value of a standard black surface is 0.05, and that of a standard white surface is 0.80.

When utilizing SRI as an indicator of heat reduction effectiveness, it is imperative to consider that visible light only comprises 40% of the energy in the solar spectrum. Therefore, color may not necessarily be a good indicator of reflectance: a completely white surface doesn't necessarily indicate ultra-reflectiveness.

Traditional dark pavements have been found to eclipse 120–150°F in peak summer months, largely contributing to increased heat absorption and greenhouse gas emissions in urban areas. The concrete industry alone currently accounts for about 8% of global anthropogenic carbon dioxide emissions, a figure likely to increase with significant industrialization of the developing world (18). Asphalt in particular is extremely energy-intensive, as bitumen (the substance used as the binder in asphalt production) is a residue product of crude oil distillation. Bitumen distillation requires temperatures of 425°C as well as extremely high-pressure levels, contributing to the significant GHG emissions associated with asphalt concrete 12. Continuing to utilize traditional dark pavements in new construction poses a dramatic environmental threat in the form of massive energy usage and extreme heat in urban areas.

Reflective pavement coatings increase the solar reflectance of existing roadways, sidewalks, and roofs. This leads to an increase in the cooling effect of existing surfaces, a technique not limited to special climate areas. New asphalt has a solar reflectance ranging between 0.05–0.10, whereas the SRI of aged asphalt might increase from 0.10–0.15 (13); this reduction occurs as a result of weathering, dust, and dirt accumulation that taints the pigment reflectivity. By manually applying reflective coatings though, it's possible to increase the SRI of existing paved surfaces to up to 0.85 using new barium sulfate pigment technology. Applying reflective coatings is generally non-invasive, much cheaper than replacing existing roadways, and plausible for city-wide application. By increasing the albedo of paved surfaces by 0.20, average summertime outdoor temperatures in California cities have shown about a 0.2–0.9°F reduction, depending on city geography and climate (20). Benefits to this include reduced outdoor temperatures and reduction of air conditioning energy usage, which saves people money and helps mitigate climate change.

City-Wide Applications

Two national leaders in large-scale cool roadways implementation experiments are Los Angeles, California (average summer high temperatures ~83°F) and Phoenix, Arizona (average summer high temperatures ~105°F). Both Los Angeles and Phoenix have begun looking towards reflective coatings to cool down the city and increase livability as their number of extreme heat days continues to increase. By implementing reflective coatings and thereby increasing solar reflectance on existing infrastructure city-wide, cities can become more resilient as extreme heat worsens. By mid-century (between the years 2036 and 2065), more than 250 U.S. cities will experience the equivalent of a month or more per year on average with a heat index surpassing 100°F, compared to just 29 cities historically (14). In the coming decades, the number of cities experiencing ill effects of extreme heat days will vastly increase, and the city-wide reflective coating application projects of Los Angeles and Phoenix provide promising solutions.

Phoenix

The City of Phoenix's Office of Sustainability teamed up with Arizona State University's Urban Climate Research Center in 2020 to execute one of the largest cool pavement implementations ever studied in the US. This experiment laid 36 miles of cool pavement with a non-toxic seal coat (CoolSeal by Top Guard LLC) over 8 neighborhoods and 1 city park, and measured air temperature, surface temperature, and radiant temperature over 10 months.

The first year of the City of Phoenix's Cool Pavements Program saw promising results from the wide-scale application of reflective pavement coatings. Despite variability due to tree cover and vegetation, differences in the sample neighborhoods, maximum average daytime surface temperature differences (measured at 1 pm), reached up to 11°F in experimental application areas (18). Additionally, in the same sample areas, surface temperatures at sunrise were an average of 2.4°F cooler. Reduction of surface temperatures directly impacts low-level ambient air temperature which in turn increases pedestrian and driver comfortability. The City of Phoenix, now the 5th most populous city in America, aims to expand the reach of this pilot program to address extreme heat and increase livability. With further applications, reflective coatings have the potential to transform the landscape of cities in hot-dry climates on a massive scale.


Figure 1: City of Phoenix's Cool Pavements Program

Los Angeles

Studies evaluating the climatic impact that implementing highly reflective coatings has on ambient temperatures have been conducted in Los Angeles as well. The first evaluation (1995) assumed an increase in downtown surface albedo by 0.14 within the realm of the experimental rooftops. In downtown areas, peak urban temperatures were reduced by 1.4°F(4). Additionally, a 1990 study conducted by Lawrence Berkeley National Laboratory determined that if all pavements were able to increase their reflectance by up to 25%, there would be around a 3-degree cooling effect in Downtown Los Angeles (5). Highly reflective cool pavement products may provide daytime heat reductions up to 7°F on vehicular roads, and daytime heat reductions up to 20°F on non-vehicular roads. To maximize heat reduction, a combination of solar reflective coatings on roofing materials and paving materials provides the most effective solution.

Promising heat reduction results in experimental East Los Angeles neighborhoods have prompted UHI mitigation efforts by the city. Since 2015, the City of Los Angeles has run similar pilot experiments coating over 50 different city blocks in East LA. The first experiment, conducted in 2017 (stage 1), coated one street block in each of Los Angeles' 15 districts. The promising results from this preliminary stage tracked an overall 10°F average surface temperature across the fifteen sites. The most recent pilot project in 2019 (stage 2) focused specifically on the Winnetka and Sun Valley areas of East Los Angeles for coating projects.

Eric Garcetti, Mayor of Los Angeles, has also announced a plan to coat over 250-lane-miles with cool pavement treatments by 2028 to contribute to urban heat island mitigation. Thus far, the project has been successful in cooling target San Fernando Valley neighborhoods; Greg Spotts, the Chief Sustainability Officer for Streets LA, reported that 2021 application trials found areas of the neighborhood to be on average 2°F cooler than the surrounding neighborhoods. Streets LA's partnership with NASA Jet Propulsion Laboratory has enabled close monitoring of preliminary sites where the reflective coating has been applied by mapping geographic heat variance using satellite imagery.

Figure 2: StreetsLA reflective coating trial applications using GAF Streetbond Durashield Cool pavement coating

Public Health Implications

Worker Error Rates

Heat-related injury has been found to increase with even a 5-degree increase of temperature on a given day. A study through UCLA's Luskin School of Public Affairs performed an analysis of injury compensation claims for California workers from 2000 to 2018 to determine the influence of outdoor air temperatures on outdoor workers. The study found that "on days with a high temperature above 90°F, workers have a 6–9% higher risk of injuries than they do on days with high temperatures in the 50s or 60s. When the thermometer tops 100°F, the risk of injuries increases by 10–15%" (6). Sensitivity to outdoor temperature is exacerbated in industries such as agriculture, utilities, manufacturing facilities, and construction, and thus disproportionately affects certain populations of workers. "NASA's heat stress report CR-1205 documents the negative effects of temperatures exceeding 80°F on both the productivity and accuracy of workers" (14). For outdoor workers, extreme heat poses an extraordinary safety risk, as well as potential economic losses due to reduced productivity.

Physical Health
Increased temperatures in urban areas are also a driver of smog formation, lowering overall air quality and posing long-term health risks to urban populations. Dangerous ground-level ozone forms in the troposphere through the reaction of nitrogen oxides, volatile organic compounds (VOCs), and heat and sunlight. From a public health standpoint, increasing the reflectivity of roadway environments is largely important, as “using high-reflectance pavement will reduce pavement surface temperature and consequently might help decelerate the formation of ground-level ozone and help improve the air quality” (4). Thus, the implementation of solar reflective coatings to increase pavement surface reflectivity and mitigate urban heat is directly linked to tropospheric ozone prevention and public health outcomes.

Equity
Additionally, it is essential to consider that low-income communities are disproportionately vulnerable to the consequences of extreme heating due to traditional redlining practices in the United States. Low-income neighborhoods and communities of color are commonly 8–10°F hotter than higher-income areas, imposing brutal heat vulnerabilities, high energy burdens, and increased heat deaths in much of urban America. This increase in temperature can be attributed to more dark asphalt parking lots, less vegetation, and fewer shaded areas. The ability to exercise, socialize, and just be outside, especially during the heat of the summer months, is a privilege that should not be limited to residents of wealthier neighborhoods (17). These patterns of urban inequality, imposed by the lowest first-cost, dark impervious surfaces, damage the health and upward mobility of a large part of society.

Overall, implementing cool roadways via the application of highly reflective surface coatings can reduce the number of heat-related illnesses and deaths as annual high heat days continue to increase. The largest benefits of reduced heat from increased solar reflectance will accrue in vulnerable communities including low-income neighborhoods, children, and the elderly.

Potential Drawbacks
Public opinions have expressed some concern over increased thermal discomfort as a result of heat absorption by humans in highly reflective paved areas. In areas with traditional asphalt (extremely low SRI), less heat energy is reflected and thus, more is absorbed by the medium. Accordingly, the surface itself will be very hot—think of the temperature of a paved road on a hot summer day.

Simply put, as the solar reflectance value (SRI) of a surface approaches the maximum value of 1, the maximum amount of heat energy (across all wavelengths) is reflected by the surface. In areas heavily trafficked by humans, there is significantly increased potential for humans to absorb this excess heat energy. In fact, “increasing the pavement reflectance will increase the risk of reducing human thermal comfort during hot periods by approximately 5–8% in the three locations analyzed in this study” (4). While slightly increased thermal discomfort on hot days is a disadvantage of implementing highly reflective coatings, in the context of UHI reduction, the resulting increased thermal discomfort is less meaningful. This side-effect can be reduced by focusing reflective coating application projects in areas that are not heavily frequented by pedestrians during the daytime, such as parking lots and roadways.

Higher incidence of reflected sunlight from cool pavements poses a potential hazard to vehicles and pedestrians and most counterarguments to reflective coating applications surround concern over glare. With the SRI level being discussed with current market products though, the effects of glare are minimal.

Cost Analysis and Considerations

Available Products

The following table provides information regarding the variety of overlay and seal products currently available to improve the heat resilience of roadways. The majority of these products utilize titanium dioxide or calcium carbonate as the primary reflective agent. Each product has variable upkeep pricing depending on whether it is sold as a slurry, sealant, or simply a pigment that also requires solvents and additives.

*Consider the Environmental Protection Agency (EPA) standard design goal of achieving a 33% solar reflectance (SRI >= 0.33) to increase cooling of paved surfaces (15).

Product Name	SRI value achieved with application	Pricing	Product Type
Gaurdtop (CoolSeal)	0.33	Cost of material estimated around $4.50 per square yard	Water based, asphalt emulsion sealcoat
GAF (DuraShield)	0.33	Costs from $8.90 per square yard for two coat applications	Two-part acrylic coating for asphalt pavement

ePave (Cool Pavement Technology)	0.30-0.40	Cost of product is $4.50 per square yard; If installed by a contractor, the material and installation would cost between $10.00 to $27.00 per SY	Polymer sealcoat for asphalt pavement
Pavement Technology Inc. (PlusTI)	0.40	Cost of product is $2-$2.50 per square yard	Rejuvenator/sealcoat for aging asphalt pavement
Endurablend	>0.29	Highly variant given desired color; wide variety of pigments available	Micro-surfacing system with polymer modified cement mix
Lhoist (Lhoist mineral slurry)	Specifications: n/a	Cost of product is anticipated to be less than 0.5$ per square yard; application price TBD for USA, depending on the job size and the contractor fees. Expected that application cost would be less than 1$/SY on top of material supply cost	Calcium Hydroxide Slurry
ThermaCote	0.83	Average cost of $10 - $20 per square yard depending on the thickness of the application.	Water based acrylic paint
Western Colloid (ArmorTop Stealth Grey)	Specifications: n/a	Material cost between $55.00 to $60.00 per yard for material a two-coat application. Labor charges are typically in the range of $1.00 to $1.40 per square yard.	Acrylic elastomeric base coating
Shepherd Color	Increase of 0.20 from existing	Pigment product is about $0.50 per square yard not including binder, solvent, and additives	Inorganic color pigment

Maintenance

Products require reapplication every 5-7 years depending on how heavily trafficked the application site is; average application rate of 6,000/sq yard/day. Films tend to have an initial thickness of 0.5mm to 3.0mm. In many cases, cleaning technologies can be used to restore the SRI of material close to the initial value, which reduces overall recoating costs.

Products with concrete light-colored, reflective concrete constituents applied over asphalt are less viable due to low durability. Due to differential drying rates and contraction/expansion behaviors of the materials in different weather conditions, these coatings have a tendency to crack at the surface.

Innovations in application techniques have accelerated the viability of wide-scale applications of highly reflective coating products. Most existing products can be applied in the form of a slurry seal, which may then be applied manually with squeegees or via a controlled spray from the back of a truck (21). Typically, after just a few hours of work for the application of reflective coatings, streets can then be opened back up to the public.

Innovations

With recent advancements in highly reflective pigment technology, Barium Sulfate-based white paint has been produced in a laboratory setting at Purdue University with an SRI value of 0.981—the highest ever engineered (16). While the commercialization of this particular technology is not currently viable due to the high cost of production, processes are in place to patent the material and collaborate with existing coating manufacturers. Materials engineering advancements provide marketable new technology with much higher solar reflectance power than products available today. As public interest in increasing solar reflectance of existing paving materials continues to grow, undoubtedly so will the market for highly reflective coatings, sealants, and paving materials.

Overall, cool pavements are just one promising, cost-effective solution to reduce urban heat that can be made more effective when integrated into a larger Smart Surfaces strategy. When other variables such as improved public health outcomes, support for environmental justice, and reduced worker error rates are factored in, the rationale to adopt reflective surface coatings is even more compelling.

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22. A special thanks to the Global Cool Cities Alliance Cool Roadways Partnership team, the Cool Roof Rating Council, the StreetsLA team, and Dr. Aaswath Raman at UCLA for their contributions to this research project.