Arizona State University

Cool Pavement Pilot Program

A report prepared for the City of Phoenix
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Walton Sustainability Solutions Service
and
Urban Climate Research Center

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Background

Intensifying summertime heat in Phoenix and many cities globally is a public and environmental health risk. Energy and water use, as well as the health of residents, are primary concerns during hot Phoenix summers—outcomes that are critical to quantify across various heat mitigation types. Critical assessments of interventions attempting to reduce these impacts help determine the value of more widespread implementation.

Reflective coatings are one of the many strategies to mitigate increased heat storage and temperatures in pavements. These coatings reflect a larger proportion of solar radiation than traditional darker asphalt coatings and thus reduce heat storage in the pavement.

In 2020, the City of Phoenix initiated the Cool Pavement Pilot Program, in which the City applied the product CoolSeal by GuardTop® to 36 miles of residential neighborhood roads and one public parking lot. Researchers at Arizona State University (ASU) evaluated the thermal performance of the reflective coating, along with resident perceptions. An overview video and results of this Phase I initiative have been provided by the Global Institute of Sustainability and Innovation at ASU.

The City-University partnership continued into Phase II in 2022, building upon findings from Phase I. In the summer of 2022, researchers continued investigating the thermal performance of the “cool pavement” (CP) surfaces in residential areas. Products tested included the new “Phoenix Gray,” or CoolSeal 2.0, created by CoolSeal by GuardTop® in response to the City of Phoenix residents asking for a darker color and different CP formulations used at a local testbed site in North Phoenix.

Project information, results, and recommendations are provided to support ongoing innovation, implementation, and effectiveness of cool pavement and similar urban heat mitigation technologies.

The Project

The City of Phoenix Street Transportation Department partnered with the Rob and Melani Walton Sustainability Solutions Service at ASU and researchers from various ASU schools to evaluate the effectiveness, performance, and potential co-benefits of the new CoolSeal 2.0 pavement coating. Residential data collection and analysis occurred in one homogeneous residential neighborhood in West Phoenix at varying times across days throughout the summer and fall of 2022. Field data at a testbed were also collected over multiple days in the summer of 2022, with samples from the residential area and testbed taken to ASU laboratories for further analysis.

Data Collection

Numerous platforms and sensors were used to collect on-site data, with further analysis completed on field samples brought to ASU laboratories.

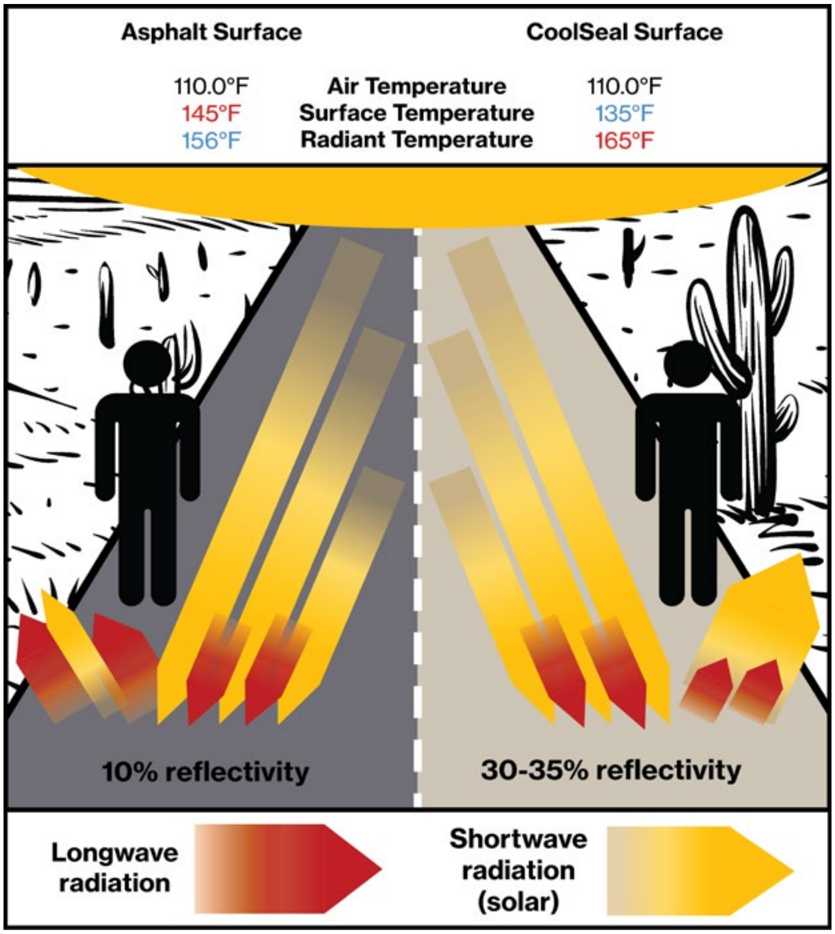

Figure 1: Interaction of shortwave (solar) and longwave radiation with traditional asphalt (left) and CoolSeal surface (right). People standing on the surfaces experience different radiative loads, as exhibited by arrows.

Data were collected in mobile and stationary fashion in the field (residential areas and testbed) with the MaRTy platform, as well as Thermocouple Gradient platforms in residential areas.

MaRTy is a mobile biometeorological platform that measures mean radiant temperature, air temperature, relative humidity, and wind speed and direction at the pedestrian height at two-second intervals. MaRTy measurements were performed for 45–60 seconds at pre-defined stops.

First, we compared mean radiant temperature (MRT) and surface temperature over roads treated with CoolSeal versus untreated roads using MaRTy. New methods to examine fine-scale air temperature gradients above the surface were deployed using a new mobile temperature gradient platform. Phase II also used residential data to assess CP impacts on water and energy use and human health based on residential data.

Figure 2: MaRTy, the biometeorological weather station.

A vertical air temperature gradient array (left) was used to measure the air temperature gradient above the surface at 0.5m increments from 0m to 2m. The vertical array used high-end, 3-wire thermocouples fastened to a bike for mobile transects or connected to stands for stationary measurements, ventilated naturally by wind flow and shaded from the sun.

For both platforms, traverses were completed across one large, relatively homogeneous neighborhood treated with CoolSeal and directly compared to measurements on untreated roads.

A local field site (testbed) was established at the Union Hills Service Center facility in northern Phoenix to compare CP products of differing formulations based on MRT, surface temperature, and visual degradation. The two products can be described as:

- Cool Pavement – A (CP-A): asphalt-based seal coat with other ingredients.

- Cool Pavement – B (CP-B): two components waterborne epoxy-modified acrylic coating

Fig. 3: High-precision vertical air temperature gradient

Finally, lab testing of field samples continued to investigate future CP impacts on future pavement recycling, test surface durability, determine thermal properties of CP, and collect solar reflectance data.

The project also includes a modeling assessment of CP impacts on residential water and energy use. Water use effects are quantified based on a literature review on air temperature-irrigation relationships in the Southwest US. Potential air conditioning energy savings associated with ambient temperature reductions that may result from CP were estimated using EnergyPlus energy simulations and empirical sensitivity analysis. Lastly, a health impact assessment was conducted to quantify changes to UV radiation and heat stress of pedestrians.

Findings

The main research findings, outlined below, are organized into three categories based on field campaign type and temperature metrics of importance. Together, these findings guide the holistic understanding of how the applied CP treatment impacts thermal performance across multiple metrics and potential co-benefits of the treatment.

Assessment 1: Residential area

- Surface temperatures of the CP were systematically lower than non-treated asphalt concrete across all times of day, confirming results from Project Phase 1. The CP surface temperature was, on average, 12.0°F and 10.5°F lower than the asphalt concrete at noon and afternoon hours (ranging from 9.0–16.0°F lower) and 2.4°F lower, on average, at sunrise. These lower surface temperatures indicate that the CP-treated roads are not absorbing as much heat as asphalt roads, which helps reduce overall urban heat levels.
- Mean radiant temperatures represent a human's radiant heat load over a surface. The mean radiant temperature was 5.8°F higher over CP than non-treated asphalt at noon and 4.5°F higher during the afternoon due to higher surface reflectivity. Temperature differences were negligible pre-sunrise and after-sunset. Measurements were not taken on sidewalks.
- Air temperature differences over CP and non-treated asphalt were minor but beneficial. Mobile measurements showed that air temperature generally decreased with height above ground as sensors were further from the influence of the underlying surface. On average, air temperature over CP was 0.13°F lower than over non-treated asphalt at all heights and times measured. The most significant difference occurred after sunset, with a 0.6°F cooler temperature over CP at all measured heights. However, the trend reversed between 8 pm and 9 pm, and air temperature over CP was warmer by 0.3°F. Stationary measurements showed an average 0.9°F cooler air temperature over the CP at all heights and times measured, yet a

similar reversal of this signal post sunset (1.8°F warmer at 0.5m, 0.3°C warmer at 1.5m).

- Residential energy use estimates from 48 building archetype EnergyPlus simulations and an empirical sensitivity analysis showed that CP, if applied across the entire city* for uniform cooling of 0.5°F, could save $10M-$20M in avoided residential air conditioning costs annually if applied on residential roads city-wide.
- Water use amounts to an estimated 3B gallons in residential households over the City of Phoenix each summer month. With an air temperature sensitivity of residential water use of about 1.8%/°F, if a uniform cooling of 0.5°F could be achieved throughout the summer across the entirety of Phoenix* (~600,000) residents using CP, 28M gallons of residential water could be saved each month, totaling 100M gallons of savings over the entire summer.
- Ultraviolet Radiation (UVR): The overall UVR was 5.9% on the CP, slightly lower than the reflection from the asphalt (8.8%) and concrete (6.0%), respectively, indicating there is no increase, but a potential decrease, in UVR due to the properties of the CP.
- Heat Stress: Due to higher MRT loads on the body midday (12 pm and 4 pm), the heat stress imposed on a person directly above the surface is slightly higher (~12Wm-2) on CP than non-treated asphalt. There is no difference in the morning or evening. Based on Phase I results, an individual walking on a sidewalk would not experience higher heat stress midday due to the CP.

Assessment 2: Testbed

- Mean Radiant Temperature over Products CP-A and CP-B did not differ significantly.
- Subsurface temperatures of one product were reduced by 9.6°F in June; the difference decreased to ~4.0°F during the winter. The other product reduced subsurface temperatures by ~3.0°F throughout the year.
- The visual condition shows that after nine months of heavy truck traffic, there is a visible difference in color between the sections. More wear is observed at the curve where more heavy traffic is turning. This wear is observed in both the CP-A and the Control.

Assessment 3: Lab Testing

- Using Recycled Asphalt Pavement millings from pavements containing these coatings has no detrimental effects. Dynamic modulus, tensile strength, and the Hamburg Wheel test showed no statistically significant difference to the control.
- The surface durability test showed that the laboratory-tested samples for product CP-A showed more wear than product CP-B. However, the field samples showed minimal damage after the test, which indicates that the difference in surface texture, the field application technique, and the longer curing time from the field might have contributed

to the observed differences in surface wear between the field samples and the lab-prepared samples.

- The thermal conductivity and the specific heat results show that the Control conducts and stores heat more than CP-A and CP-B. As the Control has a darker color, storing more heat at the pavement's surface is relevant and is supported by the measured temperatures in the field. Furthermore, the results show that the CP-B will increase and decrease temperature quicker. As for CP-A, the coating is expected to allow less heat (lower thermal conductivity) within the pavement, resulting in lower surface temperatures when compared to the other products.
- The thermal expansion and contraction results of this test are essential to further understand the thermal susceptibility of the three products. A lower CTE refers to a lower temperature susceptibility of the material and a lower potential to crack. The results show that Control had the highest coefficient, while CP-B had the lowest.
- Solar Reflectance measurements in the lab showed that Product A had a solar reflectance of 30.29%, Product B had a reflectance of 38.62%, and the Control's reflectance was 3.57%.

Limitations

For both residential energy use and water use, these estimates in savings are based on a uniform cooling across the entire City of Phoenix and using best-case air temperature results. The CP can only go on residential surfaces and certain types

of roads; therefore, air temperature benefits would not realistically extend across the entire city. Such uniform cooling would need to be achieved through other types of air temperature reduction strategies alongside CP.

Takeaways and Recommendations

Innovation

Pavement accounts for 30–40% of the total land cover of the Phoenix metropolitan area and significantly contributes to urban heat. As the hottest large City in the United States, Phoenix has recognized the importance of transportation infrastructure for effectively managing and mitigating extreme heat. The City is a national leader in the testing and implementation of CP as a promising strategy for reducing urban heat, and these efforts help drive innovation and continued improvement of these products. The Cool Pavement Project, in collaboration with ASU, is an excellent representation of a collective commitment to test innovative paving strategies in living laboratory settings, leveraging transportation infrastructure as a potential cooling solution. Numerous important takeaways and recommendations arise from Phase 2 of the Cool Pavement Pilot Program, listed below.

Surface and Subsurface Temperature and Pavement Lifespan

CP effectively reduces summer surface temperatures, up to 12°F, compared to conventional aged paving during the day. These results are significant for increasing the lifespan of the underlying material because it undergoes less thermal strain. CP may ultimately reduce long-term road maintenance needs and costs, which could yield substantive economic and environmental benefits. Continued evaluation of CP technologies, particularly performance via reflectivity, is needed to fully understand long-term performance concerning infrastructure protection and urban heat mitigation.

Air Temperature

CP impacts on air temperature thus far appear to be small but beneficial. The dynamic nature of the atmosphere makes it difficult to test air temperature differences in uncontrolled living laboratory conditions. However, even a slight reduction in air temperature could benefit energy consumption for cooling, water use for irrigation, and health outcomes, especially across such a large population as the City of Phoenix.

Mean Radiant Temperature Concession Tradeoff

The results show that a person standing in the middle of a cool paved street would experience more thermal stress (an increase in mean radiant temperature of 5.8°F) during midday hours (~12–4pm) than on a non-treated asphalt street. The effect is approximately equivalent to the difference between walking on asphalt and concrete. The variation in shortwave and longwave on asphalt versus cool paved streets is shown in Figure 1, where extra solar radiation is reflected from the surface and absorbed by a person. From Phase I results, a person walking on the sidewalk next to the road will have the same thermal experience regardless of whether the pavement was CP or non-treated asphalt. Given the magnitude of the difference is only moderate, and people will only spend short durations of time outside, these are not a large cause for concern, especially if using the sidewalk, but it is reported because this trade-off has important implications for CP placement within a city (see below).

UV Radiation

The CP is slightly lower than the reflection from asphalt, both being low. There is no increased risk of sunburn over the CP.

Solar Reflectivity Decline

A missing component of the Phase 2 assessment involves the change in reflectivity over time. The 2020 Phase I report indicated important declines that affect the performance of the surfaces and is thus a vital measure to continue to take to determine if the investment in these surfaces indeed provides a more sustainable, long-term solution than traditional asphalt. The team is working to analyze and begin to take further field measurements of the solar reflectivity across wavebands throughout the City.

Durability Testing

Continued monitoring of field conditions is necessary to correlate the laboratory test results to field performance.

Future Impact on RAP

More testing is recommended to expand the performance knowledge of these mixtures. Some of the further testing needed include asphalt binder extraction to study the aging behavior of asphalt binder. The other required testing plan should include a complete sweep of cracking tests such as IDEAL CT test, C* test, and Texas Overlay test.

Recommendations for Placement

Before adopting CP technology, it is essential to weigh various potential advantages or compromises, which can depend on local weather patterns, land use, shading patterns, the layout and structure of urban areas, the type of roads and traffic speeds, and how and when pedestrians typically use certain spaces. CP locations should be chosen carefully for maximum benefit throughout the day and summer season.

- Geographic Location: CP is most effective in mid/low latitude cities with hot climates, low annual cloud cover, and significant paved surface area.
- Urban Form: CP is most effective in car-centric cities with wide residential streets and on large parking lots that lack shade. CP is ineffective in high-rise downtown areas due to a lack of direct incoming solar radiation, highly shaded narrow streets, or shaded parking lots (e.g., with solar panels).
- Avoid areas with high pedestrian traffic: Because of the mean radiant temperature tradeoff, CP should not be used on playgrounds, plazas, parks, courtyards, or other paved areas where significant pedestrian traffic is expected. As such, it may be considered a disbenefit or a maladaptation to the experience of pedestrians, such as children, in these areas midday (~10 am–5 pm). Instead, heat exposure mitigation should focus on shading, such as trees and engineered shade, in these areas. CP cannot replace the benefits of shade trees for pedestrian cooling. In summary, CP should be implemented in locations with low foot traffic where alternative cooling strategies, such as trees and water features, cannot be placed.

By following these recommendations, the City can strategically implement CP technology in areas where it will maximize benefits for infrastructure, people, and the environment.

The City also continues to actively encourage and challenge the industry to improve and create cool pavement products to expand its application to additional street classifications and in varying states of condition. The City looks forward to continue working with industry and academia to evaluate new products as they become available.