Reflective Pavement Pilot Report

Trevor Brooks, Naveen Sudharsan, Deidra Miniard, Angela Johnson, Ed Poppitt, Marc Coudert, Junfeng Jiao, Patrick Bixler, and Dev Niyogi

Final Report- Submitted to the City of Austin Department of Transportation and Public Works

Executive Summary

This report provides a summary of the Los Angeles, Phoenix, and San Antonio studies, details the methodologies employed in Austin's pilot study, and presents the findings from the research. Based on these insights, the report offers recommendations for how the City of Austin might proceed with reflective pavement initiatives as part of its broader heat mitigation strategy.

The City of Austin faces many extreme weather-related challenges, with extreme heat being one of the most pressing. High temperatures have significant impacts on human health, energy consumption and utility costs, built infrastructure, the economy, and countless other aspects of urban and suburban life. Given the hazards associated with extreme heat, many cities around the U.S. have begun exploring a popular heat mitigation tool known as reflective pavements.

In the summer of 2024, the City of Austin implemented a pilot program by installing 6.4 lane miles of reflective pavements in The Reserves at McKinney Falls, a neighborhood in southeast Austin. The chosen reflective pavement product was GuardTop's CoolSeal. This initiative was conducted in collaboration with the UT-City CoLab, an interdisciplinary research collaboration between the City of Austin, The University of Texas at Austin, and community groups aimed at addressing extreme weather challenges.

The team was tasked with assessing how reflective pavements influence surface and air temperatures, as well as their impacts on human thermal comfort.

To begin, the team conducted a literature review of the three main reflective pavement pilot studies that have been conducted in the US. Specifically, those in Los Angeles (California), Phoenix (Arizona), and San Antonio (Texas). After the literature review the next step was to conduct field measurements. Data was collected at two different locations; 1. The reflective pavement site, 2. A reference neighborhood with no treatment. Continuous air temperature sensors were installed in key locations in both neighborhoods. A Forward-Looking Infrared Radiometer (FLIR) C-5 Thermographer was used to evaluate surface temperature to develop a unique 17-hour daily profile at those same locations. As a third part of this study, two surveys were conducted to determine the effect of the pavements on perceived thermal comfort. One survey examined residents to gather feedback. The other survey was a "blind" study/walking activity where individuals who had not been previously exposed to the reflective pavements were asked to walk on the treated and untreated surfaces to determine if they felt a difference in temperature.

Study results indicate that reflective pavements; 1. Significantly affect the surface temperature of roads, hinting at potential benefits to extending the life cycle of the base pavement. 2. The effects on air temperature were modest and followed a diurnal pattern of slightly warming the area during peak solar hours but cooling the area in the evening and night. 3. The survey and experiment results indicated that people (both residents and walkers) did perceive like they were moderately cooler on the reflective pavements. However, due to a potential placebo effect these results should be interpreted with caution until additional studies are conducted. Additionally, while residents were generally happy with reflective pavements, many provided negative comments about the glare and aesthetics, identifying a potential barrier for future implementation. Mean radiant temperature (MRT, a thermal comfort index) was not directly observed in this study, but it is well demonstrated that MRT becomes slightly elevated over reflective pavements during peak solar activity, moderately decreasing thermal comfort. Though this effect is comparable to the increase seen in light-colored sidewalks. It is important to note that this study did not evaluate potential air and water quality related issues nor does the study have a time frame that would be appropriate to evaluate the pavement's effects over a (relatively) long time. This means that there may be other externalities that should be evaluated and fully understood before reflective pavement is widely implemented within a city.

Acknowledgments

This study was conducted with approval from the University of Texas at Austin Institutional Review Board (IRB Protocol # STUDY00006105). This work is possible due to the work of the UT City CoLab (2023-02-OOR-UT). It is also part of the NIST project (60NANB24D235) through Representative Lloyd Doggett, NOAA NIHHIS (NA21OAR4310146), NASA Interdisciplinary Science with the University of Georgia (80NSSC20K1268) and Planet TEXAS 2050. We also gratefully acknowledge the advice and support received from the following.

Councilwoman and Mayor ProTem Vanessa Fuentes and Staff

Former Councilwoman Alison Alter

Zach Baumer- OCAR Director

Congressman Lloyd Doggett

Alyssa Dallman- Program Coordinator for the TExUS Lab

Alexia Leclerc- UT City CoLab Project Manager

Hannah Risinger- Jackson School of Geosciences

TE(X)US Lab Members and All of our Walking Activity Participants!

We are extremely grateful and would like to sincerely thank the residents of The Reserves at McKinney Falls and the Vista Point neighborhoods for allowing us to conduct research in their neighborhoods. We appreciate that many of you welcomed us with open arms and met us with genuine curiosity and eagerness. Because of you, we now have a better understanding of how these pavements may be best implemented to make the city a more livable and sustainable place! The progress of our city is written in the streets we walk together!

The UT-City CoLab Team

Trevor Brooks
Lead Researcher, PhD Student, Jackson School of Geosciences and LBJ School of Public Affairs

Naveen Sudharsan
Research Scientist, Jackson School of Geosciences

Dev Niyogi
Professor, Jackson School of Geosciences

Patrick Bixler
Assistant Professor, LBJ School of Public Affairs

Deidra Miniard
Post-Doctoral Research Associate, LBJ School of Public Affairs

Jung Feng Jiao
Associate Professor, School of Architecture

Ed Poppitt
Consulting Engineer, City of Austin, Street and Bridge Operations

Angela Johnson
City Engineer, City of Austin

Marc Coudert
Climate Adaptation and Resilience Manager

Table of Contents

1. Introduction

Extreme heat is the leading weather-related killer in the USA, killing 555 people in 2023 alone (US Department of Commerce, 2023). Urban areas experience warmer temperatures than their rural counterparts due to a phenomenon known as the urban heat island effect (UHI). This phenomenon causes a multitude of cascading impacts other than health related fatalities and illnesses such as; decreased air quality, increased energy usage, increased maintenance costs for infrastructure, and a multitude of other environmental, social, and economic effects. This effect occurs due to the ability of engineered infrastructure (such as pavement and asphalt) to store and trap heat compared to natural surfaces and structures. This increased heating is not distributed equally throughout cities, with areas that have high concentrations of impervious surfaces experiencing warmer temperatures. Thus, making some neighborhoods more susceptible to experiencing higher temperatures than those that have access to greenspace and shading. Due to urban heat's multitude of negative effects, many cities around the world have begun evaluating innovative ways to mitigate this issue and improve livability within their municipalities.

One strategy for heat mitigation is the application of a reflective pavement coating on asphalt roads. Reflective pavements are part of a broader set of road-based mitigation strategies and are also commonly referred to as cool pavements (Anupam et al., 2021). This category of strategies ranges from photovoltaic pavements (solar panel-based pavements) to permeable pavements (Santamouris, 2013). Their overarching goal is to transform critical roadway infrastructure from something that contributes to urban heat into something that can help cool the city down. Reflective pavements attempt to achieve that goal by increasing the surface albedo (or the reflectivity) of the road surface to reflect more solar radiation back into the atmosphere so that less gets absorbed in the first place. This lowers the surface temperature of the pavements and the amount of heat that is absorbed into the surface.

Reflective pavements have been installed in various cities in the U.S., including Los Angeles, Phoenix, San Antonio, and more recently other cities belonging to the Smart Surfaces Coalition. They have also been installed in different cities globally such as Athens, Greece (Kyriakodis and Santamouris, 2018). In the summer of 2024, the City of Austin initiated a reflective pavement pilot program to test its efficacy as a heat mitigation tool in a real-world setting. To achieve this goal, the Department of Transportation and Public Works (ATPW) partnered with the newly created UT-City CoLab (CoLab). The CoLab is a joint partnership between the City of Austin and UT Austin, that brings together academic researchers, city officials, and community members, to develop data that amplifies lived experiences and can help with city decisions. The CoLab collected meteorological measurements, resident surveys, and experimental data throughout the summer of 2024 and preformed subsequent analysis. The findings of the CoLab study, together with the accompanying summary, are intended to inform the Transportation and Public Works Department, the City of Austin, and the general public in their evaluation and decision-making regarding the performance of reflective pavements.

2. Austin Pilot Program

Austin is known for its extreme summers. For example, the summer of 2023 brought along 80 days of temperatures greater than or equal to 100°F, with 42 of those days having daily maximum temperatures of 105°F or higher (City of Austin Office of Resilience, 2024). This extreme heat makes Austin an exemplary candidate to act as a living laboratory to assess innovative strategies for mitigating extreme heat. Testing these strategies through pilot programs enables cities to conduct small-scale evaluations with limited costs and investments while facilitating robust data collection and stakeholder engagement. This approach helps assess feasibility, as well as the costs and benefits of a particular mitigation strategy, to inform future decisions and investments into these innovations (Hughes et al., 2020).

In the summer of 2022, ATPW launched a reflective pavement pilot project, beginning with a small-scale application at its St. Elmo facility in Southeast Austin. As per the Transportation and Public Works Team, the initial motivation was the potential for long-term cost savings in road maintenance due to the documented surface level cooling effects of reflective pavements. By the summer of 2024, the department expanded the study to explore additional co-benefits, partnering with the UT-City CoLab to conduct a comprehensive evaluation.

2.1 Cool Seal

The City of Austin selected Guard Top's CoolSeal product as the reflective pavement product for this pilot study. CoolSeal is a water-based, asphalt emulsion pavement coating applied over an asphaltic pavement surface. It contains fine aggregate, with asphalt comprising at least 10% of its weight and overall asphalt content reaching a minimum of 32%. The product has a solar reflectance of 0.33 and a final cured light grey color similar to the typical appearance of aged asphalt (Guard Top, Solar Gray, 2023). Conversations with the Transportation and Public Works Team revealed that reflective pavement coatings were considered an ideal pavement preservation strategy for the city due to their low cost (compared to other methods), and also because traditional surface treatments are already widely employed in Austin. Additionally, the water-based sealcoats are more environmentally friendly than their polymer-based counterparts as the sealcoat degrades over time, leaching less chemicals into the surrounding environment (Witter, 2024).

According to Guard Top's safety data sheet, CoolSeal includes 15-45% titanium dioxide, a common reflective material that is used in many other reflective coatings. The exact level of Titanium Dioxide within the product was not directly available as it is proprietary information. Titanium Dioxide is considered a common ingredient used for whitening and reflective properties used often in numerous types of paints, coffee creamers, and sunscreens. Beyond its reflective properties, some studies have indicated that titanium dioxide (when it is exposed to sunlight) can even provide potential air quality benefits (Jenima et al., 2024 and Mohammad et al., 2012). CoolSeal has also been previously implemented in cities such as Los Angeles, San Antonio, and Phoenix. This made it an effective choice for the City of Austin to evaluate its efficacy in one of its neighborhoods.

2.2 Study Location

The city established specific criteria for selecting a study location for the pilot project. Since the chosen product was a sealcoat, the site needed to be an area already slated for sealcoat treatment. Additionally, to effectively compare the effects of the reflective pavement on the ambient microclimate, the city sought a location with minimal to no tree cover. Finally, there needed to be a similar neighborhood nearby that could be used as a reference site. Based on these criteria, a neighborhood in Southeast Austin called the Reserves at McKinney Falls, henceforth called The Reserves, was chosen as the treatment site. A neighborhood just south of The Reserves was chosen as the reference neighborhood known as Vista Point. *Figure 1* shows satellite imagery of these two neighborhoods and their proximity to one another. Both neighborhoods are relatively new (less than a decade old), upper-middle class neighborhoods with little to no tree cover (or have very young trees that do not offer shade). They are similar in size and population and are connected by Janes Ranch Road, with an elementary school, a major apartment complex, and a main road bisecting them. Before application, the city contacted the homeowner's association (HOA) of The Reserves to inform them of the application process and finalized a contract with Guard Top for the installation of CoolSeal. The reflective pavement coating was applied following GuardTop's standard two-day process, beginning on June 25, 2024, and concluding on June 26, 2024. In total, 6.4 lane miles of reflective pavement were installed throughout The Reserves neighborhood. The project team reviewed the installation to understand the application process. The project team was also present during the application process to document and understand it (*Figure 2*).

Figure 1. Satellite Image of the treatment site (The Reserves in blue) and the reference site (Vista Point in red). The treatment was applied to all roads in The Reserves including those outside of the blue circle.

Figure 2. An image of the application process of Cool Seal by Guard Top. You can see the reflective pavement coating being sprayed on the pavement out of the back of the distributor truck.

3. Summary of Other Cool Pavement Pilots

When designing the methods for this study, the research team reviewed major pilot projects throughout the U.S. to assess existing knowledge and identify areas where this project could contribute to the broader discussion on the efficacy of reflective pavements. Notable pilot projects have been conducted in Phoenix, AZ, Los Angeles, CA, and San Antonio, TX. Each project examined similar aspects of reflective pavements (albedo, air temperature, surface temperature, mean radiant temperature), though with slight differences in approach. It is important to note that these projects are ongoing and in subsequent phases.

3.1 Los Angeles

The program in Los Angeles (LA), California, was the earliest to be established in the US, starting with the city's Cool Streets program in 2015 (Zaidi, 2020). This initiative involved the distribution of different kinds of reflective pavements over fifteen separate council districts within the city. An initial study that focused on the Sun Valley site, collected field-based data, ran micro-climate simulations, and collected residential surveys. The study aimed at collecting mean radiant temperature (MRT) metrics using a commercially available Kestrel Heat Stress tracker (Kestrel Instruments, 2025a) alongside an ambient temperature sensor to manually calculate MRT. MRT describes what humans may feel as heat stress and is considered more representative then only using air or surface temperature metrics.

The results showed no significant differences in MRT between any pavement type, nor did they discern any differences in air and surface temperature It should be noted that field data for that particular project was collected in November on a singular day and is not likely representative of true long-term values. Additionally, the study noted that the use of the Kestrel device to measure MRT was likely insufficient.

The initiative also examined the expected microclimate in summer months using ENVI-Met simulations. ENVI-Met is a popular software often used in the architectural community for microclimate simulations (Envi-Met, 2019). These simulations estimated that reflective pavements being in place during the month of August would result in significantly higher MRT from the hours of 12:00-6:00 PM due to the higher reflectance of the surface. However, according to the study, those simulations were somewhat flawed as they overestimated radiation from walls during the daytime.

As part of the initiative, 20 people were surveyed. and most of the respondents found the experience of walking on open spaces as either being cooler or feeling fresh with the reflective pavements. These responses should be interpreted with caution, as these residents were likely aware of the purpose of reflective pavements before the questionnaire, possibly leading to a placebo effect. Furthermore, this study sampled participants by knocking on doors in the neighborhood, resulting in possible sampling bias.

Subsequent studies have continued at the LA sites, such as one from Ko et al., (2022) and one from Middel et al (2023). The Ko et al., study (2022) examined albedo degradation, using two Kipp & Zonen SMP6 Smart Pyranometers (Kipp & Zonen, 2016), to measure changes before and after installation of reflective pavement. Air and surface temperatures were measured through mobile transects, with sensors attached to vehicles. Additionally, stationary air temperature readings were taken over the months of August-November of 2019 using External Temperature Data Loggers and the HOBO RS3-B radiation shields (HOBO, 2025). The study found that albedo decreased over the 10-month period after installation and the range of degradation was 12-49%. This reduction in the albedo was considered as the natural degradation of sealcoats, as well as due to tire tracks, markings, and road grime that reduced the pavement’s albedo (evident by the subsequent increase in albedo after rain events). Interestingly, albedo degradation led to values similar to those of aged asphalt, suggesting that reflective pavements reach a steady-state albedo more quickly than traditional asphalt. In simple terms, the study found that reflective pavements lost much of their initial brightness within ten months, eventually resembling older asphalt in appearance. However, even as they darkened, they consistently maintained some additional energy reflectivity and thus, stayed cooler than traditional asphalt. This happens because the two pavement types age differently: new black asphalt gradually lightens over time and becomes somewhat less heat-absorbing, while reflective pavements start out bright, lose some reflectivity but then stabilize. Despite this loss of brightness, reflective pavements still maintained a cooler surface for a longer period compared to conventional asphalt.

As an example, Ko et al. (2022) noted that, when freshly laid down, reflective pavements resulted in a surface temperature reduction of about 5°C and a reduction rate of 2.7°C for every 0.1 increase in pavement albedo. Middel et al. (2023) found a similar result in their study. Additionally, Middel et al. (2023), observed that cool pavements reduced 3-meter air temperature between 7:00 and 11:59 PM LST, with statistically significant reductions at 8:00, 9:00, and 10:00 PM, peaking at 0.19°C at 9:00 PM. Mobile transect measurements also showed a 1.6-meter air temperature reduction of 0.20 ± 0.06°C at 12:00 PM LST. Ko et al., also examined air temperature and, after controlling for compounding factors, actually found a slight reduction in air temperatures by .2 degrees Celsius at noon.

Finally, Middel et al.'s main finding was that cool pavements increased shortwave radiation exposure for pedestrians standing above them by up to 168 W/m^2, leading to a 4°C rise in MRT during peak solar radiation. The study employed a biometeorological cart with various sensors, which proved more sensitive than previous methods. This study indicated that there is a trade off when using reflective pavements where thermal comfort can be reduced during peak solar radiation while still achieving cooler surface temperatures. In other words, the cooling of the surface meant that the heat radiation was reflected back into the atmosphere and onto any pedestrians standing on the pavements. This means that there may be a thermal trade off when using reflective pavements where thermal comfort is actually reduced slightly during peak solar radiation (due to higher MRT readings) in exchange for slightly cooler MRT temperatures in the evening/night (when emission from pavements drive heating). The LA projects, as the first of their kind, provided an important baseline for future studies.

3.2 Phoenix

Phoenix, Arizona was another major U.S. city to launch a cool pavement pilot initiative, beginning in 2020 (Middel et al., 2021). The project involved the application of CoolSeal by Guard Top to 36 miles of residential neighborhoods and roads. In 2022 the project entered its second phase applying new kinds of reflective pavements and refined analysis methods. Similar to Los Angeles, Phoenix evaluated metrics such as surface temperature, air temperature, mean radiant temperature (MRT), albedo, and residential opinions, but employed slightly different techniques and sensors for measurement. Phoenix also measured subsurface temperature beneath the reflective pavements.

For data collection, Phoenix performed traverse measurements using vehicles to assess surface and air temperatures. They also used the MaRTy biometeorological cart (Crank et al., 2023), that was used in the later studies in LA. However, Phoenix employed a spectroradiometer to measure albedo and buried iButton sensors (iButtonLink Technologies, 2021), under the pavements to continuously record subsurface temperatures.

The first phase of the study yielded several key recommendations for the city. The main conclusion from the evaluation of air and surface temperature was that cool pavements improve pavement lifespan and performance, particularly when applied early in a road's life. However, the study emphasized the need for long-term testing to track changes in reflectivity, traction, degradation, and subsurface temperature as the material ages. They also stated that while surface temperature reductions were significant, air temperature reductions were minor and influenced by various environmental factors. They indicated a need for more precise assessments to evaluate energy, water, health, and other cascading impacts that could occur by wide adoption of reflective pavements. Additionally, it highlighted the challenges posed by Phoenix's hot, dry climate, such as surface dirt and tire markings, which could affect pavement performance. In interviews with residents, researchers found wide variation in resident feedback, with one major takeaway being that alternative pavement coatings with darker colors could improve public acceptance, as many residents expressed displeasure with the appearance of the reflective pavements.

The second phase of the study aimed to address additional questions beyond the first phase (Middel et al., 2024). They continued to monitor air, surface, and MRT and found similar results. In addition, the study explored residential energy use, water use, and UV exposure. The findings suggested that city-wide implementation of cool pavements could save the city and its residents "millions of dollars" in water and residential energy costs, based on modeling studies. In the models the widespread implementation of reflective pavements significantly reduced air temperatures as well as surface temperatures resulting in the energy savings. The study also found that reflective pavements emit lower UV radiation than traditional asphalt, indicating no increased risk of sunburns or skin cancer due to the cool pavements. As of 2025 this project is ongoing.

3.3 San Antonio

San Antonio, Texas became the third major U.S. city to implement a reflective pavement program, launching a pilot program in 2023 in collaboration with the University of Texas at San Antonio (Debbage et al., 2024.). Similar to LA, the program evaluated three types of reflective pavement simultaneously. To study surface temperature, the study followed Phoenix's methodology and used FLUKE 572-2 Infrared Thermometers (Fluke, 2025), and a FLIR E4 camera (Teledyne FLIR, 2014). A Kestrel 5400 Heat Stress Tracker (Kestrel Instruments, 2025b), was employed to assess some meteorological conditions (like air temperature) and wet bulb globe temperature (WBGT, a thermal comfort metric). They used a Hukseflux NR01 4-component net radiometer (Hukseflux, 2025), to measure the radiation budget and therefore the albedo of the pavements.

A total of fifteen days equivalent of measurements were undertaken between June to September, 2023. The data collection was split into two phases: phase one focused on air temperature, WBGT, and surface temperatures, while phase two examined net radiation budgets. The study found significant differences in surface temperature and minimal differences in air temperature and WBGT. These results conformed with the results found for Phoenix and LA.

3.4 Summary of other Cool Pavement Pilots

A summary chart of the different findings from the reflective pavement studies can be seen in *Table 1*. below

Table 1. Summary of three previous reflective pavement studies in Phoenix, LA, and San Antonio.

	Los Angeles	Phoenix	San Antonio
Year Started	2015	2020	2023
City/University Partnership?	UCLA	Arizona State University	University of Texas at San Antonio (UTSA)
Surface Temperature Findings	Reduction rate of 2.7°C for every 0.1 increase in pavement albedo	Significant reductions in surface temperature (10.5°F - 12°F)	Maximum cooling of 2.2 °C
Air Temperature Findings	Reduction of Tair by 0.20 ◦C around noon, and at least 0.19 ◦C in the late evening	Average evening reduction of 0.5°F Daytime differences averaged 0.3°F lower above the CP (ranging from 1.2°F lower to 0.2°F higher).	Marginal differences between CP types, some slightly warmer during the afternoon and cooler at night some cooler in afternoon and night
Albedo Findings	Reflective pavement albedo: 0.18 (Sun Valley), 0.25 (Pacoima). Uncoated asphalt: 0.06–0.08. Sidewalk: 0.20.	Albedo declined overtime from 33-38%-19-30 % after 10 months	Slight differences between reflective pavements and worn asphalt pavements
MRT Findings	Coated surfaces reflected 118 W/m² more on average, peaked at 168 W/m² at noon. Evening sidewalks saw 20–30 W/m² added reflection. Midday mean radiant temperature was 4°C higher over reflective pavement.	Higher at noon but minimally lower at night, similar to walking on concrete	N/A

Other Thermal Comfort Findings	N/A	N/A	Heat stress at cool pavement site was marginally lower (-0.13°F)
Energy and Water Use	N/A	Overall reduction in building energy/water use if ALL roads paved	N/A
Survey Findings	Dissatisfied with appearance/glare	Dissatisfaction with appearance, concern for driving conditions	N/A
UV Radiation	N/A	Less than traditional roads and concrete	N/A
Subsurface	N/A	Reduction of a few degrees	N/A

Overall, the findings from these studies indicate that reflective pavement significantly reduces surface temperature, but generally has minimal effects on reducing air temperature. Most studies observed an overall degradation of the albedo of reflected pavements, which diminished their effectiveness. This degradation results in an albedo comparable to that of worn traditional asphalt pavements. It is important to note that dark, black new asphalt fades much more slowly, remaining darker for a longer period before reaching an albedo similar to that of worn reflective pavements.

Regarding MRT and other thermal comfort metrics, it was shown that midday MRT was higher, thereby reducing thermal comfort. However, the reverse is true in the early morning and evening. Fortunately, generally most people in hotter climates like Texas are more likely to schedule the bulk of their outdoor activities outside these peak heat hours. Studies using Kestrel heat stress trackers found these differences more challenging to detect across multiple studies compared to those using a biometeorological cart.

The Phoenix study examined potential reductions in energy and water use through simulations and found potential substantial savings. However, these models assumed that the entirety of the city of Phoenix was paved with reflective coatings. The Phoenix and LA studies conducted residential surveys and found people were generally satisfied with the cool pavements, and negative comments were largely related to aesthetics (such as glare and tire marks). The Phoenix study noted that road drivability, particularly regarding potential friction issues, was raised by the residents.

Regarding UV radiation, the Phoenix study found that there was a reduction in UV exposure for pedestrians on the reflective pavements. Finally, subsurface temperatures also significantly reduce due to the installation of reflective pavements. Overall, the studies were largely in agreement with each other. Though some questions remain unanswered because of the challenges in measurements and variability in the road and ambient conditions. As a result, most studies emphasized the need for continued monitoring in unique cities.

4. City of Austin Reflective Pavement Methodology

The team reviewed the results and methods from the other pilot projects to inform the study design of this research. There have been three main metrics to evaluate reflective pavement's effects on the local thermal environment: (1) surface or road skin temperature which represents the temperature a person would feel if they were to touch the pavement itself (2) air temperature, which refers to the ambient temperature of the air above the reflective pavements, typically measured at a height of 2-3 meters, and (3) thermal comfort, which is a metric that assesses how humans perceive and experience their thermal environments. In designing the study, the team aimed to capture these metrics to develop a understanding of reflective pavement's effects on both humans and the surrounding environment. To achieve this, the study included field-based temperature sensors to measure both surface and air temperature, alongside an experimental study to assess human thermal comfort and a survey to gather residents' opinions on the effectiveness of the pavements.

4.1 Air Temperature

Two-meter air temperature sensors were installed at approximately 2 meters above the road surface to evaluate the diurnal temperature profile. Onset's HOBO MX2300 temperature and relative humidity loggers (HOBO Onset, 2025), were chosen due to their high accuracy (with an error of +/- 0.2 degrees Celsius) and relatively low cost. These sensors feature adjustable logging rates, Bluetooth connectivity, and a drift rate of less than 1% a year, making them well-suited for long term deployment in suburban environments. These sensors were also given sun shields to protect the sensors from direct solar radiation interfering with readings.

The sensors were calibrated and installed according to World Meteorological Organization (WMO) standards for urban research, with the sensors facing north and south to minimize solar radiation exposure, and positioned at a height of approximately 2 meters. Sensor locations were chosen based on accessibility, ensuring they could be mounted on light poles while maintaining consistency in road orientation and other site conditions. Initially, 14 sensors were deployed (seven at each site) on June 22, 2024. However, after one week of deployment, it was discovered that a resident in the treatment site mistakenly believed that the sensors were cameras and cut the wires on all 7 sensors. This led to a loss of data for the first week of installation, and sensors were redistributed between the two neighborhoods with 7 sensors distributed across four sites in The Reserves and three in Vista Point. These locations are marked as points in *Figure 1*. To improve communication, more explicit signage was displayed (*Figure 3* and appendix), and the Homeowners' Association (HOA) was contacted. The sensors were programmed to record the temperature and relative humidity every 15 minutes, for 24 hours, every day for over 12weeks during the summer and early fall of 2024. Data was manually collected by research team members driving to the site once every 2-3 weeks and downloading the data from each sensor (each logger can store data for up to a month). Once the data was downloaded, it was processed and uploaded to a GitHub repository (https://github.com/nvnsudharsan/coolpavement_app). The data from both the reference and treatment sites were then plotted and compared to measure the temperature difference between the two sites throughout the day. This approach provided a consistent air temperature measurement and assessed how the reflective pavement influenced the surrounding ambient environment. For easier communication with City of Austin partners, a streamlet app was also

Figure 3. HOBO Sensor and poster mounted on light poles in the Treated Site.

created to ensure that there was access to easily digestible data at all times as well as to ensure the quality of the data itself (https://austincoolpavement.streamlit.app/).

4.2 Surface Temperature

To measure surface temperature, a C-5 forward looking infrared radiometer, or FLIR camera was used to capture thermal images at each of the sites shown in *Figure 1*. The C-5 camera (*Figure 4*) has an IR resolution of 160 X 120 pixels. The camera had been calibrated by FLIR prior to its acquisition. Following FLIR's recommendations, the camera was allowed to warm up for at least five minutes before taking images to adjust to ambient conditions. Various factors, including emissivity (how efficiently a surface emits heat as infrared radiation), reflected temperature, height, angle, ambient air temperature, and relative humidity were all standardized or accounted for before each measurement. Emissivity was standardized using electrical tape with a known emissivity of .96. A diffuse reflector was used to measure reflected temperature at any given site before measurements were taken. This metric was accounted for before each individual image was taken. Furthermore, each image was captured by the same individual, keeping image height and angle consistent.

Figure 4. FLIR C-5 camera used in this pilot program and an example FLIR image from an urban canyon in Austin, Texas.

Perpendicular angles were avoided for images to reduce error. These images were taken over a 17-hour period on August 15th from 6:00 AM – 10:00 PM. On the hour, every hour, two images were taken at sites in The Reserves, and two images were taken at Vista Point, with a maximum temporal difference of 15 minutes between images (it was usually less than that). While ambient conditions undoubtedly changed during this time, the 15minute interval is within the thresholds of acceptability used in other sensor-based studies that allow for hour-long measurement windows. Once the data was collected it was then processed using FLIR's Ignite software and compared across sites. The values measured were then processed into an Excel spreadsheet, and the measurements from the two sites were averaged and compared with each other to demonstrate the general diurnal changes in surface temperature throughout a typical summer day.

4.3 Residential Survey

Figure 5. Front side of the door hangers designed for the Residential Survey.

When examining other pilot projects completed in the US, it became clear that end user perspectives were necessary to understand how people may respond to and perceive reflective pavements in their neighborhoods. Other studies clearly noted that citizen perceptions of thermal comfort in the evenings was greatly enhanced by these treatments. Pet comfort, less heat from pavement on feet, less radiated heat all added to enhanced quality of life that may not be as clearly evident from the sensor data alone. As noted earlier, projects in LA and Phoenix only conducted preliminary residential surveys. For example, the LA study consisted of only eight open-ended questions and surveyed residents' door-to-door over a single day.

This survey was useful because it gives the residents/ end users a sense of agency, knowing their opinions will directly influence future decisions about such infrastructure. Second, the introduction of any new infrastructure will inevitably affect the people in the neighborhood, creating a responsibility for both decision-makers and researchers to make substantial efforts in accurately capturing these effects, not only through sensors but also by listening to the residents themselves.

For this research we designed a study that aimed to build on the surveys conducted in LA and Phoenix, incorporating a mix of quantitative and open-ended qualitative questions to explore the potential benefits and shortcomings of reflective pavements from the perspective of residents.

The following research questions were considered:

1. **How effective was the city's communication regarding the reflective pavement's application?**
2. **What are residents' overall experience and opinions regarding reflective pavement?**

3. How well do residents understand the purpose and details of reflective pavements?

The survey was developed and approved by the UT's Internal Review Board (IRB) protocols and consisted of 32 questions. The surveys were distributed with the HOA's permission using door hangers (*Figure 5*). Each door hanger had a QR code on the back, allowing the participants to scan and fill out the survey electronically. Alternatively, participants could also choose to call a designated phone number to have the survey administered over the phone or discuss other aspects of the study.

Participants were asked how often they go outside each day, as those who spent more time outdoors would be more likely to notice any differences. Participants were asked if they were aware of the reflective pavement in their neighborhood, how they heard about it, and their existing knowledge of reflective pavement infrastructure. To gauge residents' experiences with the pavements, the survey asked participants to indicate whether they perceived a change in their comfort level as regards to heat, or the amount of glare off the road since the reflective pavements were installed. Participants rated the magnitude of these changes (1 – 5 Likert scale from no change at all to extreme change), and indicate whether they perceived them as positive (cooler/duller) or negative (warmer/brighter). Additional questions included: whether participants felt positive or negative towards cool pavements, their personal heat tolerance, preferences for different heat mitigation strategies, and demographics.

4.4 Walking Experiment

It was recognized that implicit bias might influence residents' responses as the city had already been in communication with the residents describing the purpose of the reflective pavements (through the HOA and informational letters). These communications referred to the pavements as "cool" pavements, which likely contributed to potential bias in residents' perceptions and survey responses. To minimize this bias and attempt to objectively assess whether a perceptible difference existed between reflective and traditional pavements, the research team designed the following experiment.

Figure 6. Map of the three sites for the walking activity. Site A is the treated site and sites B and C are the two reference sites that were used.

Two surveys were constructed, again in accordance and approval by the UT IRB protocols. The first was a recruitment survey that was designed to identify and reach out to potential volunteers who would be interested, willing, and able to participate in this study. This survey was designed to assess participants' prior knowledge of reflective pavement and their ability to participate in a field-based survey in a high-temperature environment with low to moderate physical activity. Flyers were created to advertise the study and distributed around the city in order to achieve a diverse and large sample (Copies of the recruiting materials can be found in the appendix). Participants were recruited from multiple places, but the sample that was obtained was heavily skewed with graduate level students from various departments at The University of Texas at Austin.

The walking experiment consisted of two groups: one that would walk on both reflective pavement and regular pavement, and one that would walk only on regular pavement. A total of 26 participants took part in this walking experiment. The neighborhood locations selected as walking sites were chosen based on their proximity to on-site sensors, ensuring researchers could monitor ambient conditions during the study. A clear, warm day in early fall (September 28th) was selected based on weather forecasts. Participants had the option to either drive to the central meeting site (*Figure 6*) or be transported from UT Austin's campus to the study site. Upon arrival, participants signed consent forms and were randomly assigned to one of two groups using a coin flip, resulting in two groups of 13 participants. Following a blind methodology, participants were not informed whether they would be walking on reflective pavement or not. Group One was transported to Site A (the treated site), while Group Two was taken to Site B (the first untreated site). After ambient conditions were recorded, participants were given 15 minutes to walk on the pavements and adjacent sidewalks within the designated site areas. This 15-minute threshold was determine based on existing literature that assessed outdoor thermal temperatures that also used a 15-minute threshold (Huang, 2022 and Wang, 2022). To simulate typical neighborhood foot traffic, they were encouraged to walk on both asphalt and sidewalks. Participants were instructed to avoid residential property, and the study was conducted with the intent to minimize disruption to the neighborhood. After the 15 minute walk, participants returned to the controlled environment of air-conditioned vehicles and completed the first portion of the field survey. They were then transported back to the central meeting site, where they were provided with frozen treats, water, and Gatorade to aid recovery. The 30 minute recovery period was designed to ensure that thermal stress from the first walk did not influence responses to the second walk. A rest period of 30 minutes has some precedent in thermal comfort / heat stress literature. For example, Morrissey-Basler et al., (2024) used a 30-minute recovery period after exposing participants to high heat and humidity, while collecting comfort / physiological metrics.

Following recovery, participants were transported to their second walking site. Group One was taken to Site B (the first untreated site), while Group Two was taken to Site C (the second untreated site). The same procedure was followed: ambient conditions were recorded; participants walked for 15 minutes and then completed the second portion of the survey. Afterward, all participants returned to the central site, where they filled out the final section of the survey. Once completed, surveys were collected and securely stored. Participants were then debriefed and compensated. Importantly, no one was informed which site contained reflective pavement until all surveys had been collected and stored to maintain the integrity of the blind methodology.

Figure 7 shows a diagram of the experimental design. Clipboard symbols indicate when sections of the survey were administered. Group One walked on the cool pavement first (walk #1) followed by the regular pavement (walk #2). Group Two walked on regular pavement during both walks (walks #1 and #2). This design allows for two crucial comparisons. First, looking at the blue arrow, we can compare the difference (Δ) in thermal comfort between Group One and Group Two on the first walk (comparing treatment to control). Second, the orange arrows show a more complicated but important comparison. Group 1 walked on both the cool pavement and regular pavement, and the average difference in thermal comfort between the two sites can be calculated. However, there are other crucial factors that could impact why thermal comfort changed from Walk #1 to Walk #2, such as the temperature increasing throughout the day, or participants growing more fatigued. The difference between Walk 1 and Walk 2 can be calculated for the control group (Group #2) as well because those participants were exposed to the same change in temperature increase throughout the day, and same level of fatigue as Group

One. The change from Walk #1 to Walk #2 for the treatment group (Group #1) can be compared to the control group (Group #2) as a way to account for environmental variables.

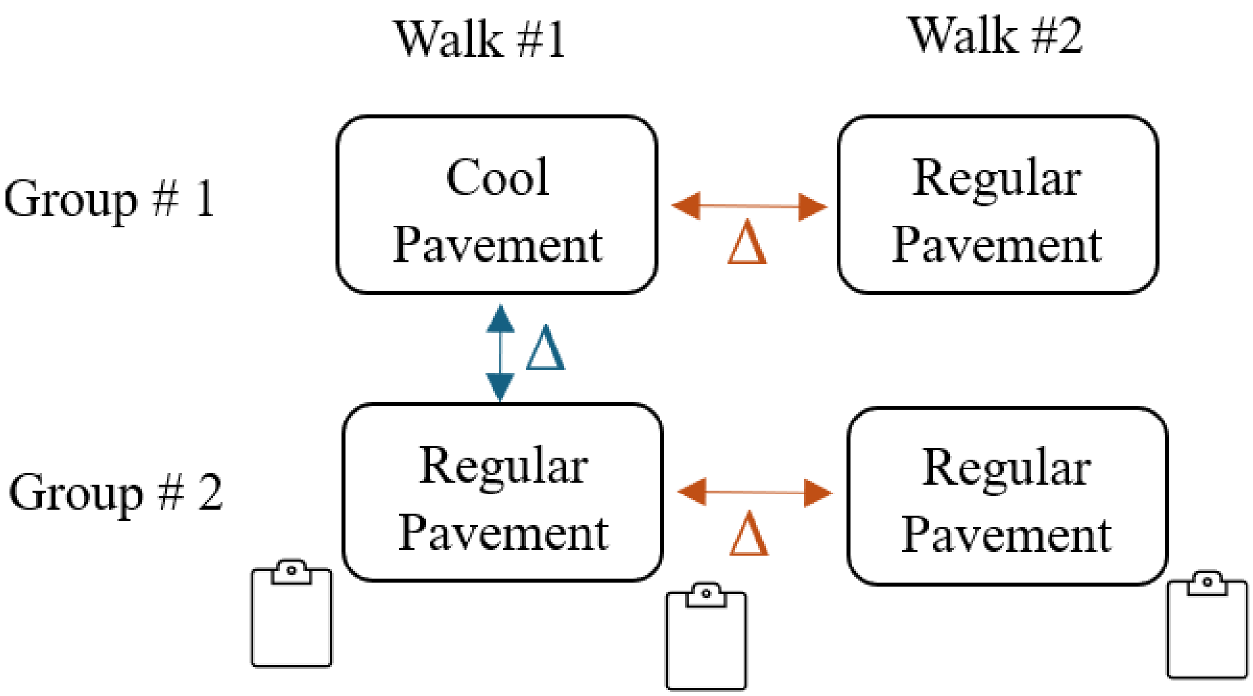

Figure 7. Graphic of the experimental design for the walking activity.

The second survey was designed to collect data during the experimental protocol. The survey was divided into three sections, completed sequentially: the first section before the first walk, the second section after the first walk, and the third section after the second walk. The first section asked information about the clothing participants were wearing relevant to thermal comfort (e.g., color, material). The second and third sections administered after each walk asked participants to rate their thermal comfort from a scale from intolerably hot (+5) to intolerably cold (-5). Participants were also asked whether they experienced any heat-related symptoms (e.g., sweating, dehydration), wind or calm conditions, and glare from the pavement. Similar to the resident survey, questions were included to capture demographics and gauge participants' understanding of reflective pavement technology.

4.4.1 Statistics of the Walking Activity

The survey results were manually transcribed into an Excel spreadsheet verbatim. This transcription was reviewed to ensure that the data sheet was error free. The demographics of the participant groups were compared to ensure there were no significant differences that could introduce bias between the two samples. Additionally, these demographics were compared with those of the broader U.S. population and the City of Austin. During the survey design, two key variables were identified as being beyond the researchers' control. First, interpersonal variation was inevitable. For example, when asked to rate heat perception on a Likert scale, one participant might respond with a 7, while another might choose 8, despite experiencing identical conditions. Second, ambient conditions were bound to change in a living lab environment between participants' first and second walks, as the temperature increased throughout the morning. These factors necessitated a statistical approach that could effectively isolate pavement type as the primary variable influencing individual responses.

To address this, a mixed-effects model was selected and defined as follows:

$$HeatPerception \sim PavementType + Scenario + (1 | ParticipantID)$$

In this model:

- **HeatPerception** is the response variable.
- **PavementType** is the primary independent variable being analyzed.
- **Scenario** represents one of four walking conditions (Site A at 11:35 AM, Site B at 11:35 AM, Site B at 12:30 PM, and Site C at 12:30 PM).
- **ParticipantID** accounts for expected individual variation.

This model was essential in ensuring that results could be properly analyzed despite variations in ambient conditions between the two walks. The model was coded using R (See Appendix).

5. Results

5.1 Air Temperature

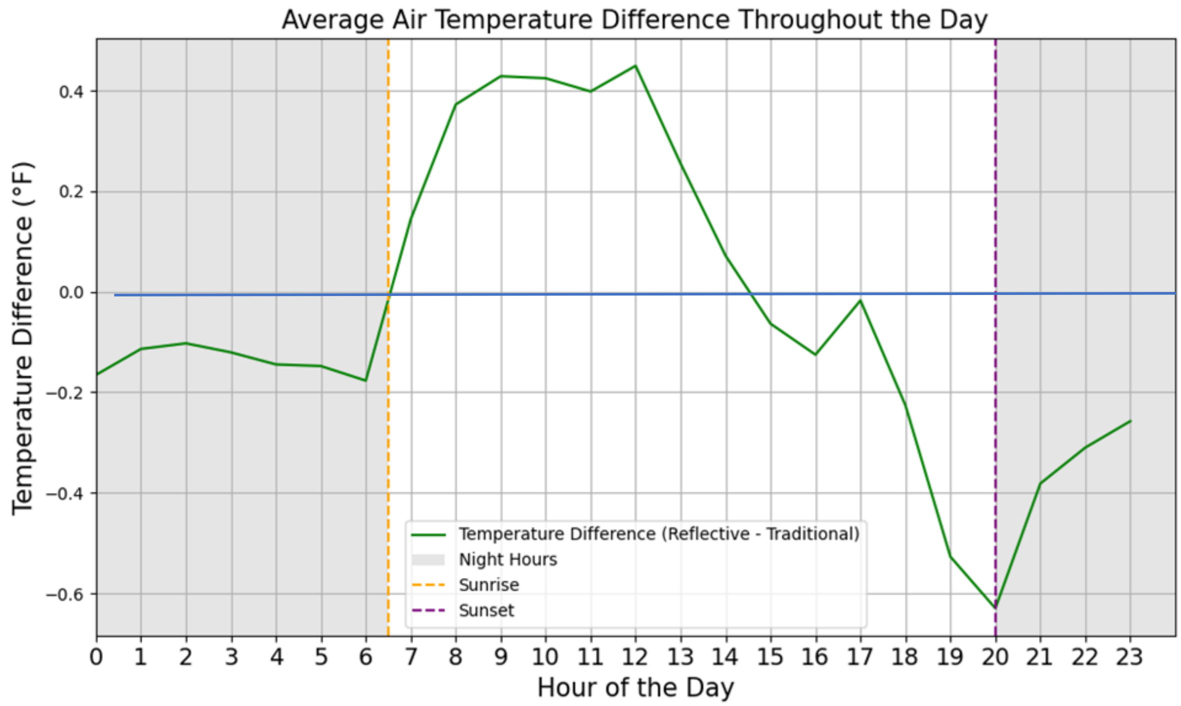

Figure 8. The difference in air temperature between the Traditional and Reflective Pavements for the months of June, July, August, and September. When the green line is below above zero the reflective pavement is warming the area up and vice versa. The horizontal yellow line indicates sunrise and the purple dashed line indicates sun set. With the shaded areas representing nighttime.

The processed air temperature results, shown in *Figure 8*, represent over 6,500 measurements collected from multiple sensors. These measurements were averaged to produce temperature profiles for both the treated and untreated sites, recorded at 15-minute intervals over a 24-hour period from late June to early September. The temperature differences between the two sites (Reflective - Traditional) were then calculated to illustrate their relative thermal behavior**. When the difference is negative, the reflective pavement site is cooler than the regular pavement site, whereas a positive value indicates that the reflective pavement site is warmer. Thus, negative values indicate the reflective pavement is working as intended.** The diurnal profile reveals that the reflective pavement slightly increases ambient air temperature during peak solar hours but cools the area as the sun begins to set. However, the maximum average temperature difference is only 0.3°C (approximately 0.5°F), occurring around 8:00 PM.

5.2 Surface Temperature

Surface temperature is presented in *Figure 9.* Temperature data was averaged out from the treated and untreated sites and shown on a line plot for the 17-hour daily profile As shown in *Figure 9* the maximum difference between the two sites was around 6°F in mid-afternoon, and this difference was statistically significant. Differences in the morning and evening hours were smaller and not statistically significant. Although not explicitly included in these results, this variation aligns with additional thermal imaging data obtained throughout the study in addition

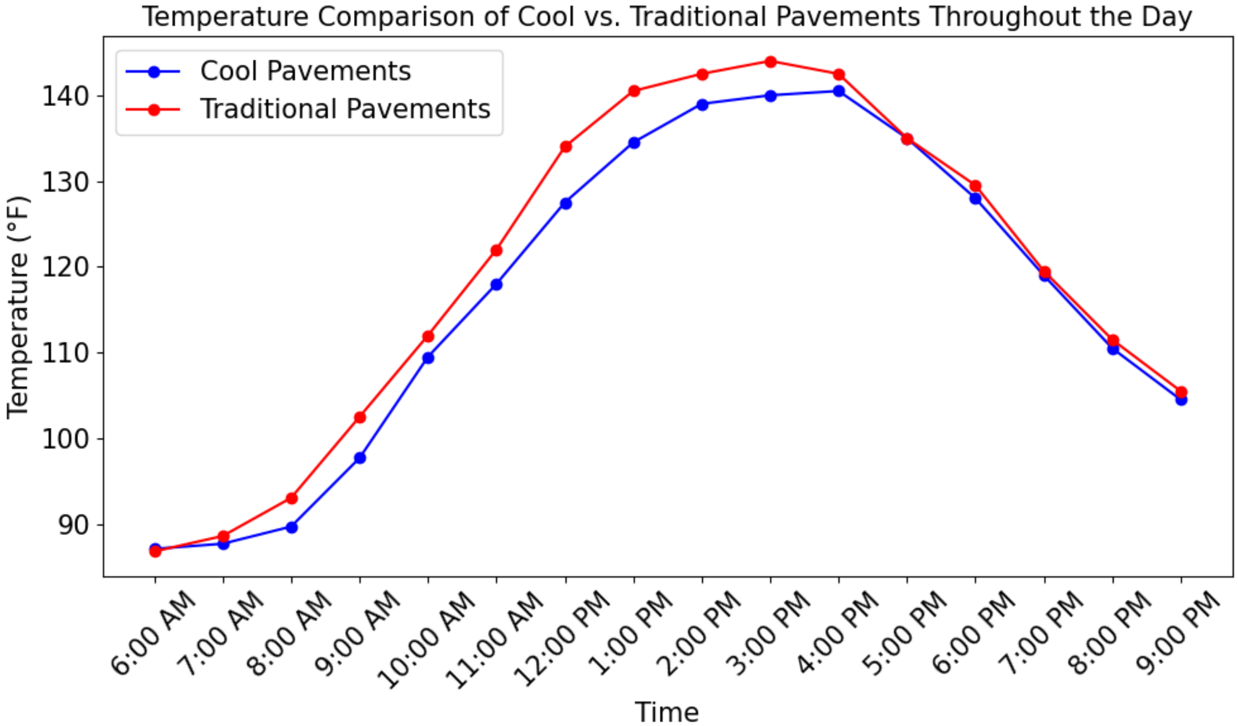

Figure 9. Surface Temperature Results from a 17-hour daily profile of surface temperature images. The red line represents the traditional pavement and the blue line represents the reflective pavement. Significant differences occurred during the afternoon.

air temperature measurements. However, direct comparisons are limited due to variations in ambient conditions. It is important to note that these temperature differences are considerably smaller than those observed in the immediate period after the reflective coating was first applied and the reflective treatment was fresh. *Figure 10* includes a thermal image taken just a few hours after the coating had dried, indicating the effects of a fresh coat. The image contains the newly laid down reflective pavement (marked as cool pavement in the picture), older worn-out pavement (denoted as Older Pavement), and newer dark asphalt that had been laid down after some recent road repairs (denoted as Newer Asphalt). It shows that the reflective pavement had a surface temperature as low as 104°F, whereas the lighter, aged traditional pavement reached 121°F, and darker, newly laid asphalt peaked at 137°F. This created a temperature difference of approximately 33°F between the new asphalt and fresh reflective pavement, and 17°F between the worn asphalt and fresh reflective pavement. However, this pronounced difference has seemingly diminished rapidly as the reflective pavement aged. This is also seen in *Figure 9*, which shows conditions just a few months after the initial application. This is likely due to wear and tear on the pavement, as well as lack of street cleanings leading to a build up of dirt, oil stains, and tire marks. These marks lower albedo and therefore reduce the effectiveness of the reflective pavement treatments.

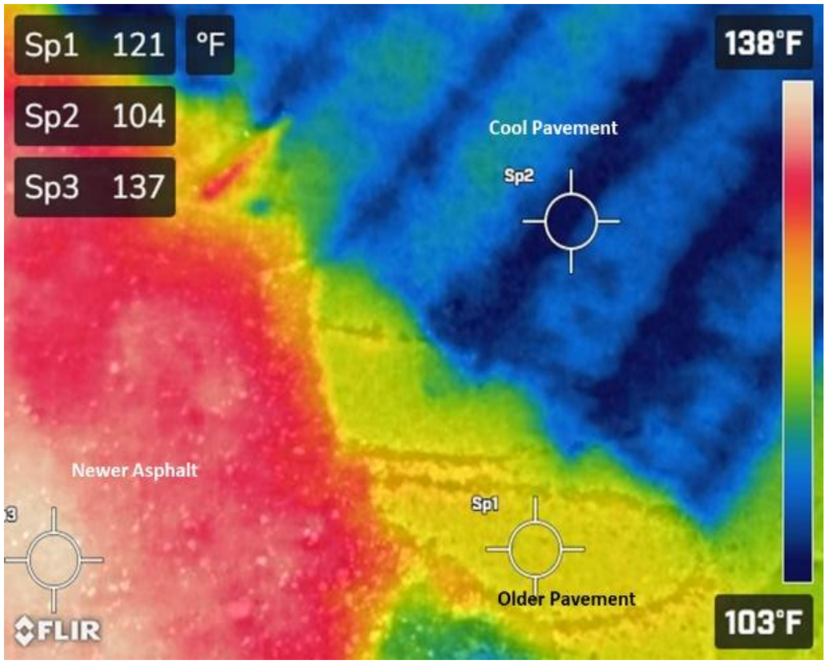

Figure 10. FLIR Image taken shortly after reflective pavement site was ready. The reflective pavement directly compared with traditional pavement that has naturally aged and worn and new asphalt that was recently laid down for maintenance purposes.

5.3 Residential Survey

Flyers were distributed to all 300 occupied households within The Reserves neighborhood (excluding homes under construction or for sale). Of these, 36 households responded to the survey, yielding a response rate of approximately 12%. The typical respondent was a college-educated, white individual in their 30s, with an equal gender split (50% male, 50% female) and a high level of concern about the impacts of weather extremes on daily life. While this demographic is not representative of the broader population of Austin or the U.S., it is likely reflective of the upper-middle-class neighborhood where the reflective pavement was installed. When asked about their awareness of the reflective pavement installations, 97.1% of respondents indicated that they were aware of the project. The majority learned about it through the City's outreach efforts, such as parking notices and flyers, but over half also reported seeing discussions on their HOA's Facebook group. This suggests that social media played a significant role in disseminating information and could be leveraged by the City in future projects.

Residents were then asked, "Reflective pavement was laid down in your neighborhood in June 2024. Since then, have you noticed any change in your comfort level in regard to heat?" In response, 76.5% of participants reported experiencing a change in thermal comfort. When asked to specify whether this change was positive (feeling cooler) or negative (feeling warmer), 100% of those who noticed a change reported feeling cooler. However, the extent of this effect varied: 29.4% reported a slight improvement, 26.5% reported a moderate improvement, and 20.6%

reported a significant improvement. While a majority of respondents felt cooler, a plurality (29.4%) described the change as only slight.

One common concern about reflective pavement is increased glare, which can make roads more visually disruptive, especially in daylight. When asked, "Since the reflective pavement has been laid down, have you noticed a change in the glare given off by the road?" 74.2% of respondents reported that glare had worsened. However, the severity of this effect varied: 37.1% described the change as slight, 14.3% as moderate, 11.4% as significant, and 11.4% as extreme. Meaning that 25.7% of people did not notice any change in the glare at all. This suggests that while glare was an issue for many, a majority (62.8%) either did not notice it or only perceived a slight difference (37.1%+25.7=62.8%). It should also be mentioned that glare measurements could be do to heightened awareness and bias preferring traditional pavement appearance.

Regarding overall sentiment, the majority of respondents expressed a positive view of the reflective pavement, with 71.9% indicating they felt somewhat or extremely positive about its installation. Meanwhile, 17.1% expressed a neutral stance, and only 11.5% held negative opinions. Residents were then invited to elaborate on their perspectives through an open-ended prompt. Among the 23 respondents who provided additional comments, feedback was mixed. The most common complaints centered around aesthetics, with 48% (11/23) expressing dissatisfaction with how the pavement looked. One resident stated, "The color is ugly; the neighborhood looks cheap." Others noted that tire marks appeared more prominently on the reflective pavement, making it look dirtier over time. The second most common concern involved the application process, with multiple respondents highlighting the need for better communication and coordination regarding the scheduling of the application process.

Despite these criticisms, 52% (12/23) of qualitative responses provided only positive feedback. A particularly unexpected theme was the perceived benefit to pets, as several respondents noted that the cooler pavement was more comfortable for their animals. Others highlighted their own experiences walking on the pavement, with one resident stating, "However, the 'feel' of the pavement when walking on it (I walk several miles a day on these streets, for exercise, at different times of day) seems cooler." Several respondents also appreciated their neighborhood being chosen for the project and supported the City's efforts to create a cooler and more livable environment. Some individuals expressed both positive and negative sentiments, praising the project's intent while critiquing aspects of its implementation. In addition to providing feedback, residents raised key questions regarding potential long-term impacts. Concerns included environmental and human health effects, such as runoff contamination and aerosol emissions from the coating. Others asked logistical questions, such as whether the roads would need to be washed regularly to maintain reflectivity or whether the City planned to repaint lane markers obscured by the coating. These concerns and questions need to be considered into future iterations of the reflective pavement implementation and study.

To assess public understanding of reflective pavement technology, respondents were asked to estimate both its cost per square foot and the height above the pavement where its cooling effects could be felt. Responses varied widely, with cost estimates ranging from $4 to $50 per square foot. Similarly, 57.6% of respondents believed the cooling effects extended between one and five feet above the pavement, while 36.4% estimated over six feet, and 6.1% estimated less than one foot. Despite this variability, there was some consensus on cooling expectations for infrastructure projects. When asked, “How many degrees do you think cooling infrastructure should lower the temperature in order to be deemed effective?” 70% (21/30) of respondents stated a range between 5–10°F. This suggests that many residents may have unrealistic expectations regarding the degree of cooling those reflective pavements can provide. When asked about the City’s future investments in heat mitigation, 80% of respondents indicated a preference for a dual approach, supporting both cool infrastructure initiatives like reflective pavement and urban greening efforts, rather than prioritizing one over the other. Notably, even some residents who held negative views of the reflective pavement still emphasized the importance of investing in novel cooling technologies alongside traditional urban greening strategies.

4.4 Walking Activity

Figure 11. Picture taken from the walking activity.

Twenty-six participants were randomly divided into two groups of 13, and analyses confirmed no statistically significant differences in demographic variables between the groups that could have influenced their responses. Demographics and concerns about urban extremes were examined and compared. While the groups were comparable, the overall sample did not accurately reflect the demographics of Austin or the U.S. The sample overrepresented Asian participants (30% of respondents compared to 8.4% in Austin and 6.4% in the U.S.) while underrepresenting Black (4.0% vs. 7.9% in Austin and 13.7% in the U.S.) and Hispanic populations (15% vs. 32.2% in Austin and 19.5% in the US). Additionally, younger and highly educated individuals were overrepresented; 62.1% of participants were 25 or younger, and 84% held at least a bachelor's degree (compared to 61.7% in Austin and 37.9% in the U.S.). These discrepancies likely resulted from the study’s recruitment strategy, which was most successful on The University of Texas as Austin’s campus. Younger students, who generally have more flexible schedules, were more likely to volunteer. Future iterations of this study should employ diverse recruitment methods to achieve a more representative sample. Notably, the youthfulness of this sample is a critical limitation, as younger adults are generally less sensitive to heat than children and the elderly. A study that has a more diverse age sample may yield different results.

To compare both, inter and intra group differences between the first and second walk results, t-tests were initially conducted and, as expected given the study design, found no statistical significance. The mixed-effects model outlined in the methods section was then applied to better isolate pavement effects, revealing that (after conducting an Intraclass Correlation Coefficient calculation) 37% of the variance in participants' thermal comfort survey responses could be attributed to individual differences (i.e., some individuals tolerate heat better than others). The mixed-effects model showed that participants reported feeling slightly cooler on reflective pavement. However, this effect was only marginally significant ($p < 0.1$) and did not meet the conventional 0.05 threshold for differences to be considered statistically significant (in other words, there is weak evidence for a difference between perceived thermal comfort in the reflective and traditional pavements). It is important to note that the experiment was conducted in the early afternoon when mean radiant temperature (MRT) and ambient air temperatures were slightly elevated over reflective pavements compared to traditional pavements. These findings highlight a disparity between the residential and sensor-based results that warrants further investigation (further discussion in Section 5).

Figure 12. The reflective and traditional pavements side by side. Notice that the reflective pavement very obviously does not look like traditional grey pavement.

Glare (also see the above discussion on glare) was another key factor examined during the walking experiments. Participants rated glare levels similarly regardless of pavement type, with some in Group 1 reporting higher glare on traditional pavements. This suggests that glare was a more prominent issue for residents than for study participants, possibly due to the timing of the study during peak irradiance. Conducting similar research in the morning or evening may yield different findings. Participants were also asked about perceptions of reflective pavement costs and cooling effectiveness. Regarding cost, responses were more consistent than those from residents, with approximately 57% estimating that reflective pavements cost $16 or more per square foot. When asked about the minimum temperature reduction required for heat mitigation techniques to be considered effective, 42% of respondents indicated 2–5°F, 23% said 5–10°F, 15% said 1–3°F, and 7.6% said more than 10°F. Some respondents were unsure or did not answer. These expectations significantly exceed the observed impact of reflective pavements and other mitigation strategies on ambient temperatures, suggesting a disconnect between public perceptions and scientific realities. This discrepancy underscores potential challenges in defining "success" for heat mitigation projects. Regarding the spatial extent of reflective pavement effects, the walking group was more evenly split than residents. Among respondents, 34.6% believed the effects should reach 1–5 feet, 38.4% expected 6 feet or higher, 7.6% believed the effects should be less than a foot, and 19.2% were unsure. When asked about future municipal investments, 76.9% supported a combination of greening and novel cooling infrastructures, 19% favored urban greening alone, and 3.8% preferred investments solely in novel infrastructure. These findings echo what was discussed earlier suggesting that while respondents lack consensus on specific details regarding reflective pavements, they broadly agree that urban greening alone is insufficient for addressing urban heat challenges. Continued investments in pilot programs like this one are essential for informing future policy and implementation strategies.

5. Conclusions and Suggestionsfor the City

This section synthesizes the findings from the Austin pilot project, and the three projects conducted by other cities as a means to develop strategies regarding reflective pavements for the future.

1. Impact on Surface Temperature

A consistent finding across all studies on reflective pavements is the significant reduction in surface temperatures particularly around midday, compared to traditional pavements. This impact has been confirmed by using multiple sensor types across different temporal scales for each different city. From a city planning perspective, this cooling of the road's surface is important as it is often considered beneficial for extending the lifespan of asphalt by reducing thermal wear and tear. This cooling effect also appears to extend into the subsurface, suggesting potential benefits for preserving the base pavement layer.

These benefits depend heavily on how quickly the road surface degrades and the albedo decreases. Reflective pavement coatings darken over time, while traditional sealcoats lighten, often converging toward a similar albedo. Although reflective pavements reach this equilibrium faster, this is not necessarily a disadvantage, as fresh traditional sealcoats remain darker for longer. Overall, reflective pavements may still offer a net benefit in terms of reduced surface temperature and therefore pavement longevity. A major outstanding question is the full lifecycle impact of albedo degradation, which requires further field-based research. Additionally, albedo decreases as road grime, tire marks, oil stains, and other pollutants accumulate on reflective pavements. To maintain effectiveness, municipalities may need to budget for regular street cleaning, introducing potential operational costs that should be considered in installation decisions.

2. Impact on Air Temperature

Air temperature results have generally also been consistent between studies, showing a modest decrease in air temperature, especially in the evening. The Austin study shows the average diurnal pattern of the reflective pavements, as an increase in air temperature in the afternoons and a subsequent cooling during the evening. It is critical to note that these changes are less than a degree Celsius, with the most dramatic changes being (on average) around 0.3°C cooler. Other studies have reported similar or smaller differences through continuous and non-continuous monitoring. Thus, reflective pavements by themselves do not appear to be a robust city cooling solution if the metric used is changes in ambient air temperature.

This conclusion is important in that it is likely that ambient air temperature is not the right metric for studying the impact of reflective pavements alone. Additional potential co-benefits and more sophisticated meteorological or radiative variables likely need to be monitored to make informed decisions.

3. Impact on Thermal Comfort and MRT

Studies on other pilots examined thermal comfort directly through measurements, either using a Kestrel Heat Stress Tracker or a biometeorological cart. The Kestrel sensors from the data in other cities seemed to have difficulties recording significant differences between reflective and traditional pavements. The biometeorological carts however, detected significantly raised MRT measurements over reflected pavement during peak solar hours as a result of more shortwave (solar) radiation being reflected back into them. This means that people's thermal comfort should decrease walking over reflective pavements during this time. The carts did see a similar pattern with air temperature, where MRT decreased slightly during the afternoon leading to a slight cooling effect. The magnitude of this increase however, is modest and a large majority of people only spend a limited amount of time outside during peak solar hours (especially in the summer), this is not expected to drastically effect individuals walking experience. Since this difference is moderate, and the majority people only spend a limited amount of time outside during peak solar hours (especially in the summer) and it is likely not a cause for concern for a large portion of the population. However, it is an important trade off that must be considered when choosing the locations to install reflective pavement within a city. This trade off becomes more critical when one considers that while the majority of people do not stay outside, there are subsets of the population (the unhoused, individuals without cars, outdoor workers, etc) who do and who may be directly affected by this trade off. Another important note is that even though MRT (and therefore the amount of shortwave solar radiation) increases, UV radiation does not seem to increase (per the Phoenix pilot) indicating there is not a danger of increased sunburn or skin cancer risks. Studies are needed to see if the presence of trees in conjunction with reflective pavements can help offset some of the negative impacts, or if the effect is negligible.

4. Resident Survey Conclusions: City to Resident Communication

While reviewing the survey data from Los Angeles and Phoenix, two recurring themes emerged. First, residents generally expressed satisfaction with the introduction of reflective pavements in their neighborhoods. Second, the most common dissatisfaction communicated was the aesthetic appeal of the pavements. Austin's study built on these findings to evaluate the overall resident experience from start to finish.

The city’s communication efforts were relatively successful in notifying residents about the installation of reflective pavement. The City’s communication efforts need to be revised and improved in explaining the installation process in the neighborhood and coordinating/ scheduling as noted in the residents’ comments. The disruption caused by the installation, which affected residents' daily routines, was a point of concern. As the city continues to invest in reflective pavements in residential areas it will be beneficial to explore alternative communication methods and installation schedules. For example, installation occurred mid-week, beginning in the morning and continuing into midday, when many residents were trying to commute to work. To minimize disruptions, alternative installation times or improved communication efforts may be necessary.

Similarly, the research team learnt that they needed to communicate information on the project with more info sheets and signage while starting the study. Had there been earlier engagement with the HOA, it is likely that the first seven HOBO sensors would not have been destroyed. This highlights the importance of establishing clear and consistent communication channels between the city, research team, and residents to ensure positive and effective research in future projects.

5. Resident Survey Conclusions: Thermal Comfort

Residents indicated they detected a noticeable improvement in their thermal comfort after the reflective pavements were laid down. This perception that was communicated to the research team interestingly, contrasts the sensor-based data that was collected, which indicated the changes in thermal comfort and ambient air temperature are modest and vary throughout the day. There are two possible explanations for this discrepancy: first, a placebo effect may have been triggered by the city’s messaging about “cool pavements,” and second, because the sample consisted of upper middle class residents, many of whom have 9-to-5 jobs, their outdoor activity likely occurred in the evening, when the reflective pavements are somewhat cooling the area. While the difference in air temperature is small, recent research suggests that humans can detect temperature differences as small as 0.3°C, making it plausible (but not conclusive) that this is what residents were reporting (Battistel et al., 2023).

Recognizing the possibility of a placebo effect, the research team conducted a “blind” study to determine whether a measurable difference existed between reflective and traditional pavements. Given that the study was held in the afternoon, participants walking on reflective pavements were expected to feel warmer due to an increase in (MRT). However, residents reported the opposite. Although the difference was only marginally significant (at the 0.1 level), it lends further support to the possibility of a placebo effect. Because of the distinct visual difference (*Figure 12*) it is likely participants were aware of walking on reflective pavements due to the noticeable changes in appearance. Future studies should investigate this placebo effect, as it may allow cities to implement small changes that make residents feel cooler, even if the physiological effects are minimal.

6. Resident Survey Conclusions: Appearance and Aesthetics

Austin residents expressed dissatisfaction with the aesthetics and glare of reflective pavements, echoing complaints from residents in LA and Phoenix. This issue is likely to be a recurring challenge for other reflective pavement pilot programs unless advancements in technology can increase albedo without significantly affecting the pavement's appearance. Phase II of the Phoenix study used a new "Phoenix Gray" CoolSeal product, developed in response to negative feedback about the appearance in the first phase, though it remains unclear whether this new product alleviated aesthetic complaints.

The glare from the surface can likely be alleviated with the installation of trees and shrubs and likely needs to be studied further.

7. Survey and Experiment Conclusions: Future Investments

It was widely demonstrated that both samples for the walking survey and the residential survey want Austin to continue to invest in a mix of urban greening and infrastructure-based policies to combat extreme heat. It is worth noting that these two strategies deal with the publicly controlled right of way. Comprehensive urban heat mitigation would likely require both public and private investments such as reflective and green roofs on private properties.

8. Key Unknowns

There are still many unknowns about reflective pavements that need to be evaluated. The first is that none of these pilot studies have evaluated runoff from reflective pavements to understand what elements or materials might be entering the surrounding ecosystem. While the proprietors have stated that the material is free of PAHs (polycyclic aromatic hydrocarbons) and other harmful chemicals, it remains to be evaluated in pilot studies.

This could be documented in a full lifecycle analysis of these pavement types as the coating deteriorates over time through wear and tear.

The real-world impacts on residential energy and water use remain largely unknown. Though simulations have been conducted they have tended to unrealistically simulate entire cities having the reflective pavement installed rather than singular neighborhoods. These simulations however, have yielded significant results meaning that questions of scale may also be important to consider when evaluating reflective pavements as a mitigation tool. Other simulations have modeled reflective pavements in conjunction with reflective roofing or other materials and have yielded much more significant results than examining reflective pavements alone.

Another question raised in San Antonio is whether the orientation of streets affects the performance of reflective pavements. Streets oriented north-south may reflect solar radiation differently than those oriented east-west, potentially influencing the thermal effects of reflective pavements. This needs to be studied further either in more simulations or field studies.

One of the published-benefits of using reflective pavements that include titanium dioxide is the potential cleaning up of pollutants emitted from vehicles. While there have been promising results shown in laboratory and modeling studies, no pilot study has evaluated this co-benefit meaning that its effectiveness in the real world is still in question. This may be important to consider as it may deliver benefits to cities looking to reduce air pollutants.

Another unknown regarding the pilot is how reflective pavements act in winter conditions. As of now this infrastructure has been tested in southwestern cities where winter weather is rarely an issue. However, cities that experience extremes in summer and winter time such as Chicago and New York have begun to discuss placing reflective pavements in their city, which makes answering this question more critical.

9. Considerations for Future Reflective Pavement Placements and Final Conclusion

Reflective pavements are not a one-size-fits-all solution. The changes that can occur in the ambient environment and the thermal comfort experienced are likely subtle with various pros and cons. The impacts are likely heavily influenced by a variety of factors such as shading, road orientation, pedestrian usage, weather and climate patterns, land use, traffic, and even the neighborhood urban geometry. More thorough evaluation using data and models will be necessary before implementing reflective pavements as a city's heat mitigation solution.

It is important to emphasize that this report does not discourage the use of reflective pavements, rather it highlights that their implementation requires careful consideration and strategic planning.

To be effective, reflective pavements likely need to be placed in areas that already have large percentages of impervious surfaces and not a lot of established shading infrastructure. Some examples may be in newer neighborhoods (such as Austin's study site) or large parking lots. This means reflective pavements would be most effective in car-centric American cities that have wide roads and low shading. It is also likely that the effective placement of reflective pavements are in places where there is less human pedestrian traffic in the afternoons relative to evenings to early morning.

While not considered directly in Austin, studies in Phoenix and LA also indicate that reflective pavements should NOT be implemented in splash pads and parks as it will decrease thermal comfort. Additionally, reflective pavements will not be effective in dense urban areas with high-rises or high shading elements as reflective pavement works by reflecting solar radiation. Areas that have high pedestrian foot traffic should also be avoided due to the increase in MRT and thermal load in the afternoon hours. This could decrease thermal comfort for those individuals (especially the unhoused, outdoor workers, and tourists). Discussions of installing reflective materials in splash pads, playgrounds, and parks should cease as it likely will have the opposite effect of increasing thermal comfort.

One of the major obstacles in installing reflective pavements in an area, other than the monetary costs, is the high likelihood of pushbacks from HOA's and businesses on the aesthetics and glare issues. This issue needs careful consideration as a city plans its reflective pavement strategy.

There is still much that is unknown about the values and or the negative impacts of large-scale implementation of reflective pavements. Return on public investment is crucial to justify the expenses of reflective pavements, as they currently cost about twice as much as traditional coatings. More studies on their feedback and cascading effects are needed.

Disclaimer: This report was not generated by artificial intelligence. However, AI software was used to assist in editing the text for clarity, flow, and style. All content and conclusions within the report are the result of human research and analysis.

6. References

Anupam, B. R., Sahoo, U. C., Chandrappa, A. K., & Rath, P. (2021). Emerging technologies in cool pavements: A review. Construction and Building Materials, 299, 123892.

Battistel, L., Vilardi, A., Zampini, M., & Parin, R. (n.d.). *An investigation on humans' sensitivity to environmental temperature | Scientific Reports*. Retrieved February 2, 2025, from https://www.nature.com/articles/s41598-023-47880-5

City of Austin Office of Resilience. (2024). Heat Resilience Playbook. https://www.austintexas.gov/sites/default/files/files/Resilience/Austin-heat-resilience-playbook.pdf?

Crank, P. J., Middel, A., Coseo, P., & Sailor, D. J. (2023). Microclimate impacts of neighborhood redesign in a desert community using ENVI-met and MaRTy. Urban Climate, 52, 101702.

Debbage, N., Zhai, W., Ochoa, E. L., Lee, R. J., Pineda, A., Clearwater, T., Rueda, S., Pursch, T., Renteria, J., & Kenney, M. (2024). *Evaluating the Urban Heat Mitigation Potential of the San Antonio Cool Pavement Pilot Program*.

Envi-met. (2019). ENVI-met Model Architecture [A holistic microclimate model]. Envi-Met.info. https://envi-met.info/doku.php?id=intro:modelconcept

Fluke. (2025). High Temperature Thermometer | Fluke 572-2 Handheld Infrared. Www.fluke.com. https://www.fluke.com/en-us/product/temperature-measurement/ir-thermometers/fluke-572-2

Guard Top. (2023, May). Phoenix Gray Cool Seal by Guard Top Spec Sheet. Cool Seal.com; Guard Top. https://cdn.prod.website-files.com/65c568b49d53c6eea442c742/65ceec96a47e6e9312d6cc3e_2023%20CoolSeal%20RTU%20Phoenix%20Gray%20Specification%20Sheet.pdf

HOBO. (2025). Solar Radiation Shield RS3-B | Onset's HOBO Data Loggers. Onsetcomp.com; LI-COR. https://www.onsetcomp.com/products/mounting/rs3-b#specifications

HOBO Onset. (2025). MX2300 Data Logger Data Sheet | Onset's HOBO Data Loggers. Onsetcomp.com; LI-COR. https://www.onsetcomp.com/resources/documentation/mx2300-data-sheet

Huang, T. (2022). Assessment of human thermal comfort during short-term exposure in hot and humid urban outdoor areas. Hong Kong Polytechnic Institute.

Hughes, S., Yordi, S., & Besco, L. (2020). The role of pilot projects in urban climate change policy innovation. Policy Studies Journal, 48(2), 271-297.

Hukseflux Thermal Sensors. (2025). NR01 net radiometer. Hukseflux. https://www.hukseflux.com/products/pyranometers-solar-radiation-sensors/net-radiometers/nr01-net-radiometer

iButtonLink Technologies. (2021). iButtons. IButtonLink. https://www.ibuttonlink.com/collections/ibuttons

Kestrel Instruments. (2025b). Kestrel 5400 HST Heat Stress Tracker, Weather & WBGT Meter. Kestrel Instruments. https://kestrelinstruments.com/kestrel-5400-heat-stress-tracker

Kestrel Instruments. (2025a). Kestrel Heat Stress Monitoring System. Kestrelinstruments.com. https://kestrelinstruments.com/heat-stress-monitoring-system

Kipp & Zonen. (2016). SMP 6 spectrally flat Class B pyranometer with digital interface - Kipp & Zonen. Kippzonen.com; HydroMet. https://www.kippzonen.com/Product/358/SMP6-Pyranometer

Ko, J., Schlaerth, H., Bruce, A., Sanders, K., & Ban-Weiss, G. (2022). Measuring the impacts of a real-world neighborhood-scale cool pavement deployment on albedo and temperatures in Los Angeles. *Environmental Research Letters*.

Kyriakodis, G. E., & Santamouris, M. J. U. C. (2018). Using reflective pavements to mitigate urban heat island in warm climates-Results from a large scale urban mitigation project. Urban Climate, 24, 326-339.

Middel, A., Hondula, D. M., Vanos, J., Kaloush, K., Medina, J., Sailor, D., Schneider, F. A., Ortiz, J. C., & Campbell, B. (2021). *Cool Pavement Pilot Program Joint Study between the City of Phoenix and Arizona State University*. https://www.phoenix.gov/streetssite/Documents/Phoenix%20Cool%20Pavement%20Exec%20Summary_091420213.pdf

Middel, A., Vanos, J., Kaloush, K., Sailor, D., Medina, J., Campbell, B., Van Tol, Z., Karam, J., Napogbong, L., Lartey, P., Alhozaimy, M., Alhazmi, M., Guzmen, G., & Epel, E. (2024, October). *Cool Pavement Pilot Program A report prepared for the City of Phoenix*. https://www.phoenix.gov/streetssite/Documents/COP-CoolPavement-Phase2-ExecSum-FINAL-Oct2024.pdf

Mohammad, L., Hassan, M., & Cooper, S., III. (2012). Mechanical Characteristics of Asphaltic Mixtures Containing Titanium-Dioxide Photocatalyst. *Journal of Testing and Evaluation*, *40*(6), 998–1005. https://doi.org/10.1520/JTE104607

Santamouris, M. (2013). Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. Renewable and Sustainable Energy Reviews, 26, 224-240.

Teledyne FLIR. (2014, May 31). FLIR E4 TECHNICAL DATA MANUAL Pdf Download. ManualsLib. https://www.manualslib.com/manual/698356/Flir-E4.html

US Department of Commerce, N. (n.d.). *Weather Related Fatality and Injury Statistics*. NOAA's National Weather Service. Retrieved June 19, 2024, from https://www.weather.gov/hazstat/

Wang, Y., He, B. J., Kang, C., Yan, L., Chen, X., Yin, M., ... & Zhou, T. (2022). Assessment of walkability and walkable routes of a 15-min city for heat adaptation: Development of a dynamic attenuation model of heat stress. Frontiers in public health, 10, 1011391.

Witter, A. E. (2024). Acute toxicity of petroleum asphalt seal coat leachates to Ceriodaphnia dubia is linked to polymer preservatives. *Science of The Total Environment*, *935*, 173123.

Zaidi, F. F. (2020). *Cool Pavement Evaluation—Sun Valley, Los Angeles*. https://doi.org/10.17610/T6Q88C

7. Appendix

Appendix A: Air Temperature

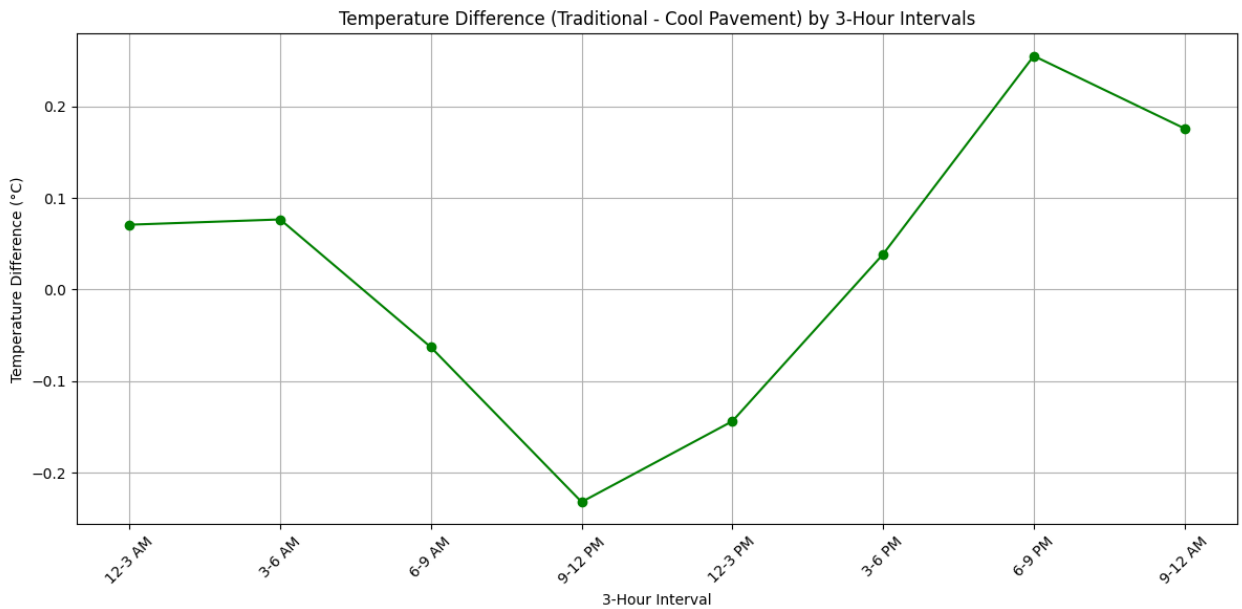

Figure 1A The air temperature results averaged for 3 hr intervals rather than given in hourly intervals. The general pattern is still evident though in this case the scale is flipped (Traditional – Reflective pavements rather than Reflective – Traditional). Meaning that when the number is negative the reflective pavement is warming the area up and vice versa.

Figure 2A Poster installed below air temperature sensor to deter vandalism and inform the neighborhood/residents.

Figure 3A Researchers installing HOBO air temperature sensors before the treatment was applied

Appendix B: Surface Temperature

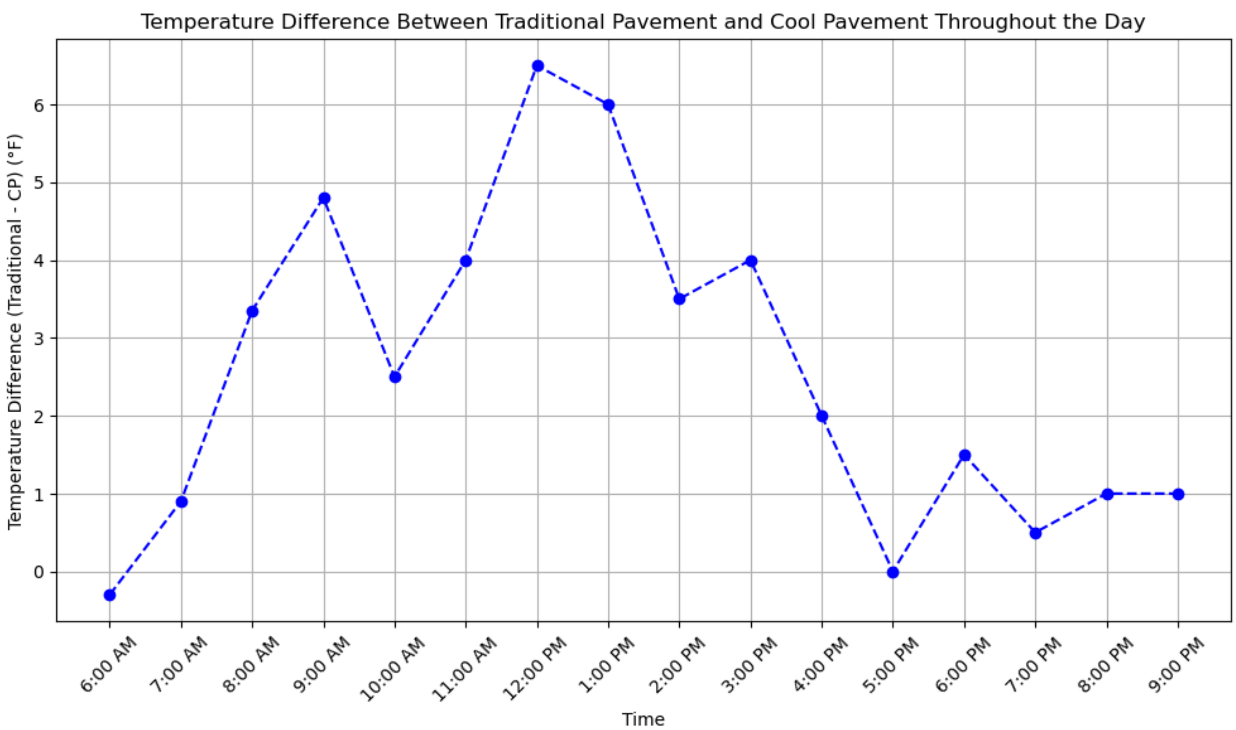

Figure B1. Average surface temperature differences plotted out during 17-hour survey

Figure B2 Picture showing the area where reflective pavement, traditional pavement, and new asphalt meet. Image of where reflective pavements, new asphalt, and worn-out asphalt meet.

Figure B3 An example of a thermal image taken from the FLIR during the 17-hour surface temperature profile at the study site

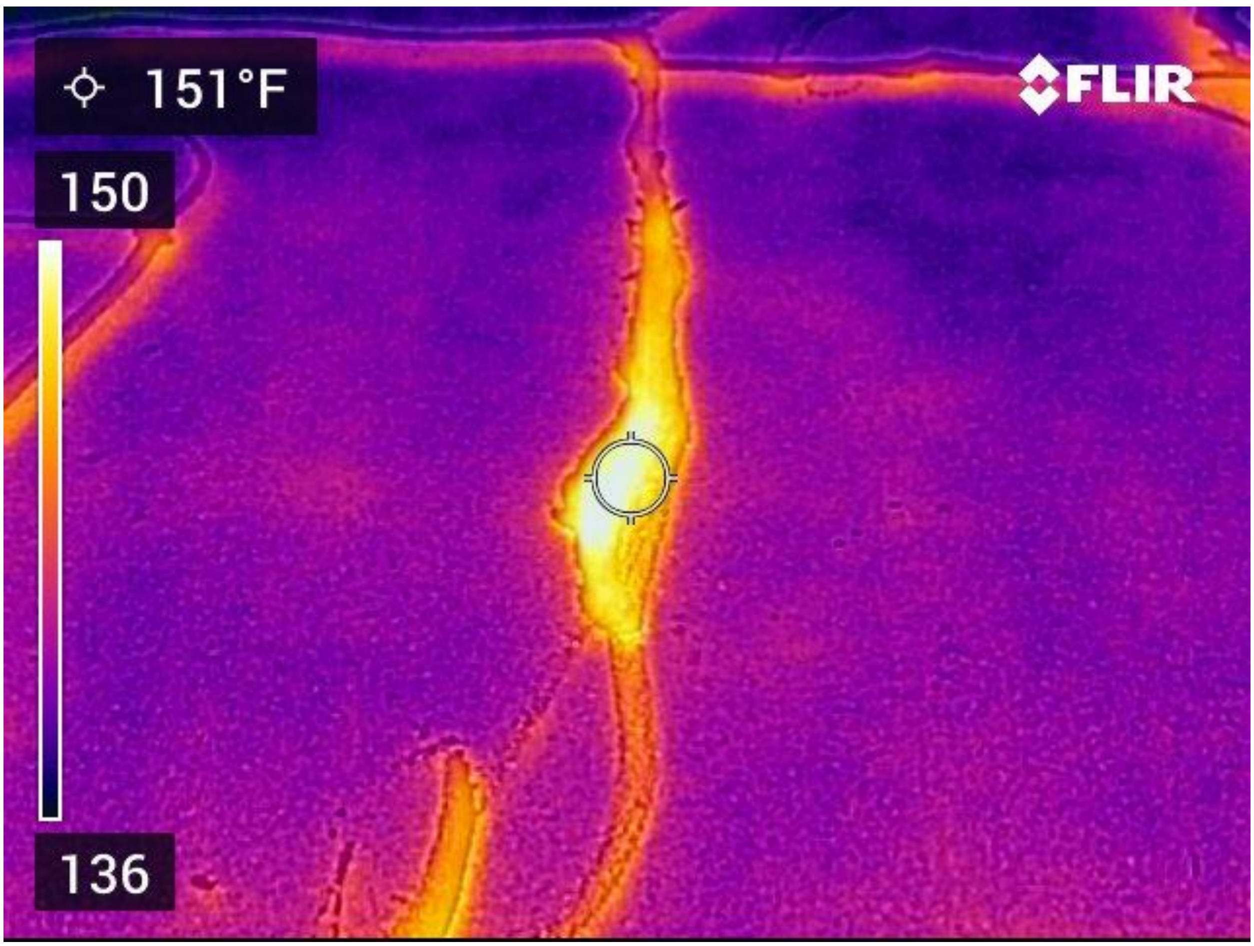

Figure B4 An example of the albedo effects different on surface temperature.. This vein was black sealed compared to worn out asphalt. (GO INTO MORE DESCRIPTION).

Appendix C: Residential Survey

Figure C1 An image trying to capture the glare that residents reported

Survey Forms

1. By typing your name below, you affirm that you have read the above information and agree to participate in this study *

2. If you are interested in entering the drawing for the $50, please enter your email below.

Questions about reflective pavements

Thank you for choosing to participate in or survey! To begin we are going to ask you a few questions about your awareness and opinions on the reflective pavements laid down in your neighborhood.

3. Were you aware that the city has laid down reflective pavement in your neighborhood?

   Mark only one oval.

   - Yes
   - No

4. If you answered yes, how did you hear about the reflective pavement?

5. Reflective pavement was laid down in your neighborhood in June 2024. Since then, have you noticed any change in your comfort level in regard to heat?

Mark only one oval.

- ◯ No change at all: I have not noticed a difference in my thermal comfort
- ◯ Slight change; I've noticed minor differences in my thermal comfort, but they haven't been significant
- ◯ Moderate change; there have been noticeable differences in my thermal comfort, but they haven't been substantial
- ◯ Significant change; my thermal comfort has varied noticeably, and the differences have been pronounced
- ◯ Extreme change; there have been drastic differences in my thermal comfort, with noticeable increases or decreases in comfort compared to before the installation of the reflective pavement

6. If you noticed a change in your overall thermal comfort, was the change positive (you felt cooler) or negative (you felt warmer)?

Mark only one oval.

- ◯ Positive (Cooler)
- ◯ Negative (Warmer)

7. Since the reflective pavement has been laid down have you noticed a change in the glare given off by the road?

Mark only one oval.

- ◯ No noticeable change; the glare remains the same as before the installation
- ◯ Slight change; there have been minor differences in glare, but they haven't been significant
- ◯ Moderate change; there have been noticeable differences in glare, but they haven't been substantial
- ◯ Significant change; glare has varied noticeably, and the differences have been pronounced
- ◯ Extreme change; there have been drastic differences in glare, with noticeable increases or decreases compared to before the installation of the reflective pavement

8. How do you feel about the reflective pavement in your neighborhood?

Mark only one oval.

- ◯ Extremely negative
- ◯ Somewhat negative
- ◯ Neutral
- ◯ Somewhat positive
- ◯ Extremely positive
- ◯ I need more information about reflective pavements to have an opinion.

9. Before this study, were you familiar with reflective pavement as a way to reduce heat in urban areas?

Mark only one oval.

- ◯ Familiar – I know about reflective pavement and how they work
- ◯ Somewhat familiar – I've heard about reflective pavement but I don't know how it works
- ◯ Not at all familiar – I don't know about reflective pavement

10. Please describe what you know (if anything) about reflective pavements.

11. Please share your comments and thoughts about the reflective pavement in your neighborhood. You might consider listing any questions you have about reflective pavement, or any reasons why you are satisfied or dissatisfied with it being in your neighborhood.

Questions about your relationship to heat and your neighborhood

Here we are going to ask you a few questions about your relationship to heat in your neighborhood.

12. How long have you lived in the neighborhood?

13. How often do you go outside and walk around your neighborhood?

Mark only one oval.

- Multiple times a day
- Once a day
- Several times a week
- Once a week
- Less than once a week
- Never

14. How would you rate your tolerance for heat?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
No T	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	Highly Tolerant

15. When it is hot outside do you find yourself becoming irritated more or less frequently?

Mark only one oval.

- More Frequently
- Less Frequently
- Neither More or Less Frequently

16. On a scale of 1-10 how much do you think extreme heat threatens your personal health and safety?

Mark only one oval.

1	2	3	4	5	6	7	8	9	10
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

Current Knowledge and Future Preferences

These are some general questions we wish to ask regarding your current understanding and preferences of climate change adaptation infrastructure.

17. Are you aware of what the term albedo means?

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Unsure

18. As a measure to cool down the city, would you rather the city invest in urban greening (increasing the number of trees planted) or invest in various building materials (such as reflective pavements)?

Mark only one oval.

- ◯ Increase urban greening
- ◯ Increase investments into different building materials
- ◯ A mixture of these two options
- ◯ Some other option
- ◯ The city should not be investing in measures to cool down the city

19. Would you like to see water sprayers (water misters, foggers, spray heads, etc) implemented in key areas to increase thermal comfort?

Mark only one oval.

- Yes
- No
- Unsure

20. What do you think happens at night when reflective pavements are laid down? Do you think they would cool down faster or slower than traditional pavements?

Mark only one oval.

- Reflective pavements would cool an area down faster than traditional pavements
- Reflective pavements would cool an area down slower than traditional pavements
- Reflective pavements would cool an area down at the same rate as traditional pavements

21. How far do you think the effects of a reflective pavement may reach?

Mark only one oval.

- 0-6 inches away from the pavement
- 1-2 feet away from the pavement
- 3-5 feet away from the pavement
- 6-8 feet away from the pavement
- 9-10 feet away from the pavement
- Greater than 10 feet away from the pavement

22. How much do you think reflective pavements may cost per square foot? For reference, traditional pavement costs about 7-13$ per sq/ft

____

23. How many degrees do you think cooling infrastructure should lower the temperature in order to be deemed effective?

____

Demographics

We are now going to ask a little bit about your demographics. If any of these questions, make you feel uncomfortable feel free to skip them.

24. Please enter your age

____

25. Which of the following best describes the gender you identify with?

Mark only one oval.

- Male
- Female
- Transgender
- Non-Binary
- A gender not listed
- Prefer not to say

26. Which category best describes you?

Mark only one oval.

- ( ) American Indian or Alaska Native (Eg: Navajo nation, Blackfeet tribe, Mayan, Aztec, Native Village or Barrow Inupiat Traditional Government, Nome Eskimo Community, etc)
- ( ) Asian (Eg: Chinese, Filipino, Asian Indian, Vietnamese, Korean, Japanese, etc)
- ( ) Black or African American (Eg: African American, Jamaican, Haitian, Nigerian, Ethiopian, Somalian, etc)
- ( ) Hispanic, Latino or Spanish origin (Eg: Mexican or Mexican American, Puerto Rican, Cuban, Salvadoran, Dominican, Colombian, etc)
- ( ) Middle Eastern or North African (Eg: Lebanese, Iranian, Egyptian, Syrian, Moroccan, Algerian, etc)
- ( ) Native Hawaiian or Other Pacific Islander (Eg: Native Hawaiian, Samoan, Chamorro, Tongan, Fijian, etc)
- ( ) White (Eg: German, Irish, English, Italian, Polish, French, etc)
- ( ) Some other race, ethnicity or origin

27. What is the highest level of education you have completed

Mark only one oval.

- ( ) Less than high school diploma
- ( ) High school diploma or equivalent (e.g., GED)
- ( ) Some college, but no degree
- ( ) Associate degree (e.g., AA, AS)
- ( ) Bachelor's degree (e.g., BA, BS)
- ( ) Graduate or professional degree (e.g., MA, PhD, MD)

28. On a scale of 1 to 10, how much do you think climate change threatens your personal health and safety?

Mark only one oval.

	1	2	3	4	5	6	7	8	9	10	
	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	

29. How many people live in your household?

Mark only one oval.

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6 or more

30. Is anyone in your household at a higher risk for heat? (For example, young children, those 65 and older, and those with chronic health conditions)

Mark only one oval.

- ◯ Yes
- ◯ No
- ◯ Unsure

31. If you are comfortable, please elaborate on the number of those who are at risk to heat and their age.

32. Please check yes if you are interested in receiving the results of this study once it is available.

Check all that apply.

- [ ] Yes
- [ ] No

Thank you

Thank you for participating in our survey!

Figure C2 The residential survey

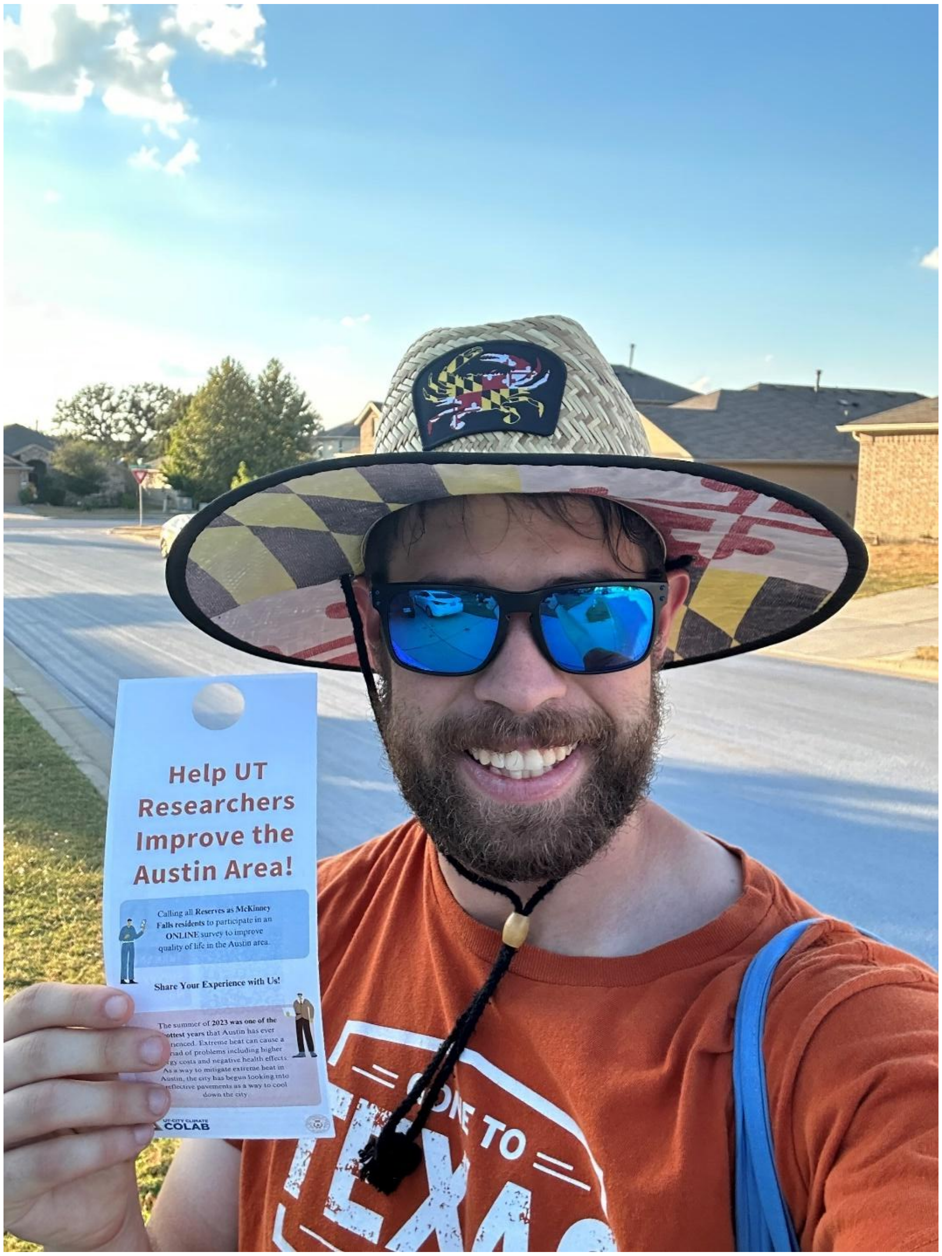

Figure C3 Researcher passing out door hangers advertising the residential survey

Appendix D: Walking Activity

The University of Texas at Austin
Jackson School of Geosciences

UT-CITY CLIMATE COLAB

TE(x)US Extreme Weather Lab

Walk the Way to Cool: Join Our Reflective Pavement Study

Feeling the Heat?

Take action by participating in an evaluation campaign of cool infrastructure!

We invite you to be a part of our research study examining how reflective pavements effect people's thermal comfort while walking in neighborhoods in southeast Austin.

Date: September 28th (Pending weather)

Requirements

- Relatively healthy
- Access to reliable transportation is preferred
- Ability to safely spend time outdoors for 30 minutes or more during the summer
- Must be 18 or older

What we would need from you

Participants will be asked to do the following:

1. Fill out the attached survey
2. Communicate with researchers
3. Travel to a neighborhood in southeast Austin and walk along various sites
4. Fill out one final survey

Important Notes

1. First 50 Participants will be compensated $20.00 in cash for completion of data collection
2. Light snacks will be provided on data collection day
3. The data collection will most likely take 2-3 hours

Registration

Please scan the QR code to the right or follow this link (https://forms.gle/RckH9aNV1dXjGot69) to register to volunteer!

Please reach out to Trevor Brooks: tbrooks4343@utexas.edu if you have any questions or concerns

Figure D1 The recruitment flyer distributed around the City of Austin

Reflective Pavement Field Survey

Welcome to the field portion of our project! To start we will begin with some preliminary questions that will help us set a baseline for the rest of the survey. We ask you to describe your clothes because what you are wearing may affect how you feel while you are outside. A linen shirt may make you feel cooler in general than a wool shirt.

1. Please provide your email address. We do NOT share your email with any other parties.

____

2. What color is the shirt you are wearing?

A) Red

B) Blue

C) Black

D) White

E) Green

F) Purple

G) Other __________________________

3. What color are the bottoms you are wearing?

A) Red

B) Blue

C) Black

D) White

E) Green

F) Purple

G) Khaki

F) Other ___________________________

4. What is the material of your shirt?

A) Cotton

B) Wool

C) Linen

D) Polyester

E) I am not sure

F) Other ____________________________

5. What is the material of your bottoms?

A) Cotton

B) Wool

C) Linen

D) Polyester

E) I am not sure

F) Other ____________________________

6. What is the length of your shirt sleeves?

A) Short Sleeves

B) Long Sleeves

C) Sleeveless

D) Other ____________________________

7. What is the length of your pants/bottoms?

A) Shorts

B) Capris

C) Full-Length Pants

D) Above Knee Skirt/Kilt

E) Below Knee Skirt/Kilt

F) Other ____________________________

8. Are you wearing a hat?

A) Yes

B) No

9. What type of hat are you wearing? (If applicable)

A) Baseball Cap

B) Sun Hat

C) Fedora

D) Beanie

E) Bucket Hat

F) Visor

G) Other ____________________________

10. What kind of shoes are you wearing?

A) Sneakers

B) Sandals

C) Boots

D) Flats

E) Other ____________________________

11. Are you wearing socks?

A) Yes

B) No

First Neighborhood

Now we're going to ask you about your experience at the first field site you just walked through

1. What pavement site did you visit first?

A) Site A

B) Site B

C) Site C

2. Please describe your thermal comfort while you were walking on the pavement. Please check one.

O +5 Intolerably hot

O +4 Very hot

O +3 Hot

O +2 Warm

O +1 Slightly warm

O 0 Neutral (comfortable)

O −1 Slightly cool

O −2 Cool

O −3 Cold

O −4 Very cold

O −5 Intolerably cold

3. Please provide a brief explanation for your answer to the previous question. Please include a brief description of how your thermal comfort changed over time.

____

____

____

____

____

____

____

____

4. While walking through the neighborhood, did you experience any of the following? Please select all that apply.

O Sweating

O General discomfort

O Dehydration

O Exhaustion

O Heat Rash

O Heat cramps

O Sunburn

O Worsening of existing health issues

O None of the above

O Other ___________________________

5. If you indicated that you experienced any of the issues in the question above, please describe the severity on a scale of 1-10 with 10 being the most severe and 1 being the least severe.

An example answer would be as follows:

Sweating - 5

Heat cramps- 3

Dehydration-8

____
____
____
____
____

6. Was there any wind while you were walking through the neighborhood?

A) Yes

B) No

7. Please rate the strength of this wind if applicable.

A) Calm: No noticeable wind

B) Light Breeze: Gentle breeze; leaves rustle and small flags begin to flutter. Slight movement of tree branches.

C) Moderate Breeze: Brisk breeze; small branches in motion. Walking against the wind is noticeable but not difficult

D) Strong breeze: larger branches sway. Unsecured objects may be blown around. Walking against the wind requires effort

8. Was there any noticeable glare from the pavement?

A) Yes

B) No

9. Please rate the extent to which you noticed a glare from the pavement

A) No glare

B) Noticeable but not distracting glare

C) Distracting but not uncomfortable glare

D) Uncomfortable glare

E) Intolerable

Second Neighborhood

Now we're going to ask you about your experience at the second field site you walked through

1. What pavement site did you visit second?

A) Site A

B) Site B

C) Site C

2. Please describe your thermal comfort while you were walking on the pavement. Please check one.

O +5 Intolerably hot

O +4 Very hot

O +3 Hot

O +2 Warm

O +1 Slightly warm

O 0 Neutral (comfortable)

O −1 Slightly cool

O −2 Cool

O −3 Cold

O −4 Very cold

O −5 Intolerably cold

3. Please provide a brief explanation for your answer to the previous question. Please include a brief description of how your thermal comfort changed over time.

4. While walking through the neighborhood, did you experience any of the following? Please select all that apply.

O Sweating

O General discomfort

O Dehydration

O Exhaustion

O Heat Rash

O Heat cramps

O Sunburn

O Worsening of existing health issues

O None of the above

O Other ___________________________

5. If you indicated that you experienced any of the issues in the question above, please describe the severity on a scale of 1-10 with 10 being the most severe and 1 being the least severe.

An example answer would be as follows:

Sweating - 5

Heat cramps- 3

Dehydration-8

____
____
____
____
____

6. Was there any wind while you were walking through the neighborhood?

A) Yes

B) No

7. Please rate the strength of this wind if applicable.

A) Calm: No noticeable wind

B) Light Breeze: Gentle breeze; leaves rustle and small flags begin to flutter. Slight movement of tree branches.

C) Moderate Breeze: Brisk breeze; small branches in motion. Walking against the wind is noticeable but not difficult

D) Strong breeze: larger branches sway. Unsecured objects may be blown around. Walking against the wind requires effort

8. Was there any noticeable glare from the pavement?

A) Yes

B) No

9. Please rate the extent to which you noticed a glare from the pavement

A) No glare

B) Noticeable but not distracting glare

C) Distracting but not uncomfortable glare

D) Uncomfortable glare

E) Intolerable

Comparison of both neighborhoods

1. Do you feel like there was a difference in your thermal comfort between the two neighborhoods you walked through?

A) Yes

B) No

2. Please rate how different, if at all, the two neighborhoods were from one another in terms of thermal comfort.

A) No difference at all; the two pavement sites felt very similar to each other.

B) Slight difference; there were minor differences between the two pavement sites, but they were not significant

C) Moderate difference; there were noticeable differences between the two pavement sites, but they were not extreme

D) Significant difference; the differences between the two pavement sites were quite pronounced and noticeable

3. If there was a difference in your thermal comfort, please indicate which site was warmer out of the two sites you visited.

A) Site A was warmer

B) Site B was warmer

C) Site C was warmer

D) Neither site was warmer than the other

4. Did you feel that the duration of time between your first and second site visits was adequate to allow for the recovery of your thermal comfort and overall well-being from your initial visit?

A) Yes

B) No

5. Please indicate whether or not you noticed changes in glare between the two neighborhood sites.

A) No noticeable changes; glare levels were consistent between the two site visits

B) Slight changes; there were minor differences in glare between the two site visits, but they were not significant

C) Moderate changes; there were noticeable differences in glare between the two site visits, but they were not substantial

D) Significant changes; glare levels varied noticeably between the two site visits and were pronounced

6. Did you or did you not enjoy walking through one neighborhood more than another?

A) Yes, I enjoyed the first neighborhood I went to more

B) Yes, I enjoyed the second neighborhood I went to

C) No, I did not enjoy walking in one neighborhood more than another

7. Do you have any comments, questions, or concerns you would like to share with us about this survey or your experience as a participant?

____
____
____
____
____
____
____
____
____
____

General Questions

These are some general questions we wish to ask regarding your knowledge and preferences of climate change adaptation infrastructure.

1. Are you aware of what the term albedo means?

A) Yes

B) No

C) Unsure

2. As a measure to cool down the city, would you rather the city invest in urban greening (increasing the number of trees planted) or invest in various building materials (such as reflective pavements)?

A) Increase urban greening

B) Increase investments into different building materials

C) A mixture of these two options

D) Other ____________________________

E) The city should not be investing in measures to cool down the city

3. Would you like to see water sprayers (water misters, foggers, spray heads, etc) implemented in key areas to increase thermal comfort?

A) Yes

B) No

C) Unsure

4. What do you think happens at night when reflective pavements are laid down? Do you think they would cool down faster or slower than traditional pavements?

A) Reflective pavements would cool an area down faster than traditional pavements

B) Reflective pavements would cool an area down slower than traditional pavements

C) Reflective pavements would cool an area down at the same rate as traditional pavements

D) I am unsure

5. How far do you think the effects of a reflective pavement may reach?

A) 0-6 inches away from the pavement

B) 1-2 feet away from the pavement

C) 3-5 feet away from the pavement

D) 6-8 feet away from the pavement

E) 9-10 feet away from the pavement

F) Greater than 10 feet away from the pavement

G) I am unsure

6. How much do you think reflective pavements may cost per square foot? For reference, traditional pavement costs about 7-13$ per sq/ft

____

7. How many degrees do you think cooling infrastructure should lower the temperature in order to be deemed effective? Please put your answer in degrees Fahrenheit.

____

8. On a scale of 1 to 10, how much do you think climate change threatens your personal health and safety?

1	2	3	4	5	6	7	8	9	10
○	○	○	○	○	○	○	○	○	○

9. Is anyone in your household at a higher risk for heat? (For example, young children, those 65 and older, and those with chronic health conditions)

A) Yes

B) No

C) Unsure

10. If you are comfortable, please elaborate on the number of those who are at risk to heat and their age.

____
____
____
____
____

Demographics

For the final section we are going to ask some questions about you. Please feel free to skip any of these questions if they make you uncomfortable. Please answer as truthfully as possible.

1. Which of the following best describes the gender you identify with?

O Male

O Female

O Transgender

O Non-Binary

O A gender not listed

O Prefer not to say

2. What category best describes you?

O American Indian or Alaska Native (Eg: Navajo nation, Blackfeet tribe, Mayan, Aztec, Native Village or Barrow Inupiat Traditional Government, Nome Eskimo Community, etc)

O Asian (Eg: Chinese, Filipino, Asian Indian, Vietnamese, Korean, Japanese, etc)

O Black or African American (Eg: African American, Jamaican, Haitian, Nigerian, Ethiopian, Somalian, etc)

O Hispanic, Latino or Spanish origin (Eg: Mexican or Mexican American, Puerto Rican, Cuban, Salvadoran, Dominican, Colombian, etc)

O Middle Eastern or North African (Eg: Lebanese, Iranian, Egyptian, Syrian, Moroccan, Algerian, etc)

O Native Hawaiian or Other Pacific Islander (Eg: Native Hawaiian, Samoan, Chamorro, Tongan, Fijian, etc)

O White (Eg: German, Irish, English, Italian, Polish, French, etc)

O Some other race, ethnicity or origin

O Prefer not to say

3. What is the highest level of education you have completed

O Less than high school diploma

O High school diploma or equivalent (e.g., GED)

O Some college, but no degree

O Associate degree (e.g., AA, AS)

O Bachelor's degree (e.g., BA, BS)

O Graduate or professional degree (e.g., MA, PhD, MD)

O I prefer not to say

4. What is your age?

____

5. Would you like to be contacted about the results of this study once it is completed?

O Yes

O No

R-Code

```
# Load the package
library(readxl)

# Read the Excel file
your_data <- read_excel("C:/Users/Trevor/OneDrive/Documents/CP_Mixed_Effects_Data.xlsx")

library(lme4)

library(lmerTest)

# Fit the mixed-effects model with RH included
model <- lmer(HeatPerception ~ PavementType + Scenario + (1 | ParticipantID), data =
your_data)

# View the summary of the model
summary(model)

library(car)
vif(model)

plot(model)
```