Arizona State University

Identifying Strategies for a Cooler Scottsdale

A comprehensive report prepared for

City of Scottsdale

June 2022

This report was created in partnership between the Urban Climate Research Center and the Rob and Melani Walton Sustainability Solutions Service

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Executive Summary

Scottsdale, Arizona is situated in the hottest large metropolitan area in the United States. The City is well-recognized for its high quality of life and scenic desert and mountain landscapes. However, like its neighbors in the greater Phoenix area, Scottsdale faces long and hot summers each year that pose threats to human health, quality of life, and economic vitality. **Summers across the region are projected to become longer and more intense** in the coming decades, adding urgency to calls for more action to combat urban heat. This report summarizes a one-year partnership between the City and Arizona State University to help the City gain a better understanding of current patterns in environmental conditions and possible strategies to reduce environmental heat while supporting other sustainability, economic, and public health goals.

The project team used satellite and aerial imagery, along with LiDAR data, to assess current patterns in land cover, tree cover, and land surface temperature in Scottsdale. Surface characteristics and temperatures were highly variable across the City. The three growth areas identified in the 2035 General Plan, Airpark, Old Town, and South Scottsdale, had much higher land cover fractions for asphalt and buildings than the surrounding areas, and lower land cover fractions for trees and shrubs (Table E1). As such, they were the locations with some of the highest surface temperatures observed citywide. **On average, Scottsdale's growth areas have land surface temperatures that are 6-7°F higher than the rest of the City.**

Key environmental metrics	Scottsdale	Metro Scottsdale	Airpark Growth Area	Old Town Growth Area	South Scottsdale Growth Area
Land cover % Asphalt & buildings	17%	20%	27%	35%	48%
Land cover % Trees and shrubs	13%	14%	8%	10%	6%
Tree density	n/a	3366/mi^2	2377/mi^2	3232/mi^2	2459/mi^2
Summer land surface temperature	122.5°F	123.3°F	129.0°F	129.5°F	131.4°F

Table E1. Key environmental metrics for Scottsdale and Growth Areas identified in the 2035 Scottsdale General Plan. Methodological details regarding the metrics are available in the full technical report.

A cluster of census block groups in southern Scottsdale exhibited disproportionately high surface temperatures and disproportionately low tree coverage (Figure E1). **Of the 20 hottest census block groups in metropolitan Scottsdale, 19 were located in southern Scottsdale.** 18 of those 20 were in a spatially continuous, largely residential 4.2 square-mile area south of McDowell Road and west of Hayden Road. Tree density was approximately 50% lower in this part of the City than in the most vegetated neighborhoods. The high temperatures and low canopy cover in southern Scottsdale contributed to a broader pattern across the City where **census block groups with higher average incomes had lower land surface temperatures.** Land surface temperature decreased by more than 1°F for each $10,000 increase in mean per capita income.

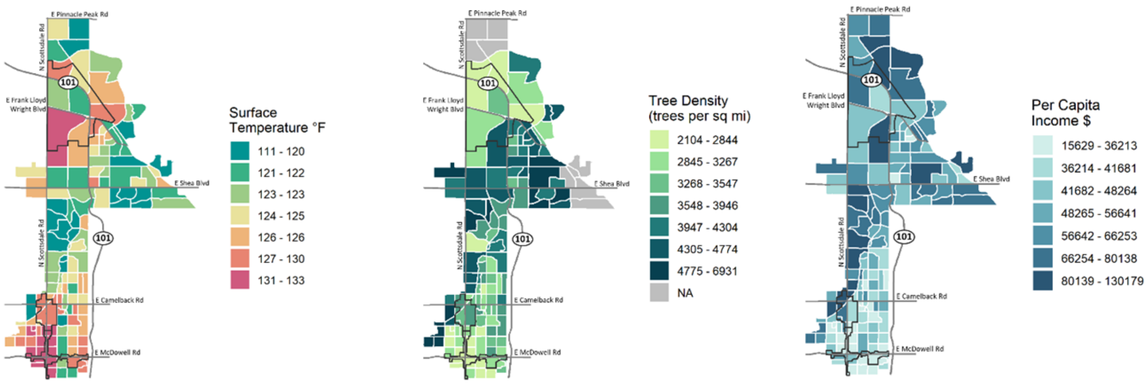


Figure E1. Average surface temperature (left), tree density (middle) and per capita income (right) for census block groups in Metro Scottsdale. Methodological details regarding each metric are available in the full report.

The mobile biometeorological cart "MaRTy" was deployed to capture high-resolution, detailed information about the thermal environment in four areas with diverse urban infrastructure: SkySong, Historic Old Town, Waterfront, and the Promenade Shopping Center in the Greater Airpark area. The data collected by MaRTy enabled comprehensive assessment of the thermal performance of different urban features, including trees, shade structures, and different surface materials, examples of which are shown in this report. These data were complemented by thermal photographs taken on the ground and from helicopter flights, to help researchers and city staff pinpoint specific design features that are influencing the urban climate. Key findings from these analysis included r**eductions in mean radiant temperature of approximately 55°F under mature, fully-leafed trees compared to fully exposed areas** in Old Town and along the Waterfront, **reductions in mean radiant temperature of approximately 30°F under mature, desert-adapted trees,** and **reductions in surface temperature of up to 50°F under bus stops with full, wide shade structures.**

Scottsdale's existing planning documents and design guidelines already provide abundant language in support of a wide range of urban heat mitigation strategies. Reducing urban heat and creating comfortable environments for pedestrians in a desert climate are clearly important goals for the City as articulated in those documents. However, the environmental conditions observed and measured in this project suggested that **the vision articulated in City plans with respect to heat mitigation and thermal comfort has yet to be realized** in many locations. Attention to heat mitigation in previously developed parts of Scottsdale, in addition to guidelines for new development, was identified as a priority. Furthermore, cooling investments in southern Scottsdale are needed to change a trajectory of historical development that has left residents there experiencing more heat, with less access to shade, compared to their neighbors elsewhere in the City.

Three recommended goals for heat mitigation emerged from this project:

1. Increase tree canopy, particularly along frequently traveled pedestrian walkways and along the south and west facades of buildings;
2. Reduce the land area of exposed dark asphalt, dark roofs, and other hot surfaces;
3. Improve and increase pedestrian shade amenities through building-integrated and free-standing shade structures, particularly along frequently traveled walkways and in locations that support public transportation.

The full report contains 29 specific strategies that could support the recommended goals in reducing temperatures in the City and making it more comfortable for residents and visitors.

SUPPORTING DOCUMENTS

An interactive StoryMap that accompanies this report, as well as the supporting data sets and technical documentation, can be found online by visiting Scottsdaleaz.gov and searching for "cooler Scottsdale."

Introduction

Background

Municipal governments across the United States are critical stakeholders in ongoing efforts to reduce the adverse effects of environmental heat on the health and well-being of their residents. In Arizona, high temperatures led to more than 500 premature deaths associated with heat exposure in 2020, and there were more than 3,000 additional cases of heat-related illness that required hospitalization or emergency department visits. Beyond those acute health events, many more residents and visitors experience negative impacts on their well-being and quality of life, including stress and anxiety associated with high summer energy bills. Heat also impacts the performance and longevity of many critical infrastructure systems, and has been perceived as a long-term threat to the economic vitality of the hot cities of the American Southwest.

Fortunately, municipal governments are well-positioned to help tackle the multifaceted challenges posed by environmental heat because of the many services and programs they provide that can impact thermal conditions in the City and protect residents and visitors from hot weather when it occurs. Historically, municipal governments have had limited and/or ad-hoc roles with respect to heat mitigation and adaptation. However, with increasing recognition of the risks of heat to health, well-being, and economic growth, as well as concerns about how those risks may grow in the future as a consequence of climate change, municipalities are increasing their attention to and investment in programs that address heat.

Scottsdale, Arizona is situated in the hottest large metropolitan area in the United States and is home to 250,000 residents. Scottsdale is well-recognized for its high quality of life and scenic desert and mountain landscapes, and parts of the City offer a slight respite from the Sonoran Desert's characteristic extreme heat as a consequence of higher elevation. However, like its neighbors in the Phoenix metropolitan area, Scottsdale faces long and hot summers each year that pose threats to human health, quality of life, and economic vitality. In 2020, the Scottsdale Airport reported numerous heat-related meteorological records (Table 1). Summers across the region are projected to become longer and more intense in the coming decades, adding urgency to calls for more action to combat urban heat.

Metric	Average (2001-2020)	Maximum (year observed)
Number of Days 110+	9.8	28 (2020)
Number of Days 100+	92.7	129 (2020)
Number of Nights 90+	2.9	9 (2020)
Number of Nights 80+	60.4	75 (2015)
Average Daily Max. Temperature (June-Aug.)	103.4°F	106.3°F (2020)
Average Daily Min. Temperature (June-Aug.)	80.4°F	82.4°F (2020)

Table 1. Summary statistics for hot days, hot nights, and summer temperatures at Scottsdale Airport. The maximum average daily temperatures reported in the right-most column refer to the average maximum or minimum temperature for the entirety of the hottest summer (June-August) available in station records, and not the temperature of an individually hot day. The Scottsdale Airport is located at a higher elevation than other parts of the City and, as such, does not reflect the highest air temperatures that could be observed within the City limits.

This report summarizes a one-year partnership between the City of Scottsdale, and Arizona State University to help the City develop and implement a comprehensive set of heat mitigation and adaptation strategies that would ultimately result in a cooler, safer, and more comfortable city for residents and visitors.

Project Purpose and Objectives

The overall objective for the partnership between ASU and the City of Scottsdale for heat planning was to conduct a series of assessments that will aid the City in prioritizing programs and policies. It is the project team's intention that the assessment contained in this report and other deliverables will provide City staff and residents with a better understanding of current patterns in environmental conditions in Scottsdale and possible strategies to reduce environmental heat while supporting other sustainability, economic, and public health goals.

The project activities included: (1) assessment of current microclimate conditions in the City using on-the-ground observations and remotely sensed data; (2) modeling of statistical relationships between land cover types and land surface temperature; (3) generation of recommendations for heat mitigation strategies for consideration by staff, council, and the public; (4) production of a public-facing online educational and engagement resource concerning urban heat; and (5) periodic presentations to City staff, the Scottsdale Environmental Advisory Commission (SEAC), City Council, and other stakeholder groups. Project deliverables include this technical report and the accompanying executive summary, a publicly-accessible to be hosted on the Sustainable Scottsdale website, and a public-facing StoryMap.

Project Personnel and Key Technical Notes

This project was completed over the time period September 2020–April 2022. Data sets used in the report were the most recently available at the time of production. Field measurements for components of this report were collected in summer 2021. The project team included three faculty members from Arizona State University's Urban Climate Research Center: Professor David Sailor, Associate Professor David Hondula, and Assistant Professor Jennifer Vanos. Graduate student researchers Mary Wright, Florian Schneider, and Aaron Mehner led various components of the project. Bill Campbell served as project manager, from ASU's Rob and Melani Walton Sustainability Solutions Service. The ASU team was supported by numerous City staff members, led by Environmental Initiatives Manager Tim Conner, and Brent Stockwell, Assistant City Manager. An interactive StoryMap that accompanies this report, as well as the supporting data sets and technical documentation, can be found online by visiting Scottsdaleaz.gov and searching for "cooler Scottsdale."

Many of the project activities focused on the three Growth Areas identified in the City of Scottsdale 2035 General Plan. According to the 2035 General Plan, the Growth Areas are "specific locations within the community that are most appropriate for development focus, and will best accommodate future growth, new development, revitalization, and redevelopment. Scottsdale's Growth Areas focus higher intensity development, a planned concentration of land uses, and enhanced transportation and infrastructure in designated areas." Accordingly, the project was focused on these areas to help staff identify opportunities for mitigating heat in parts of the City that are currently developed and/or expected to see additional development in the coming years. Urban heat and associated impacts are closely tied to the intensity of urban development; prioritizing the Growth Areas for heat mitigation actions will likely offer the best opportunities for targeted and substantial temperature reductions and increases in thermal comfort.

Spatial boundaries for the growth areas were provided to the project team by City staff (as aligned with the 2035 General Plan) and are illustrated in Figure 1. The three Growth Areas are: South Scottsdale (yellow in Figure 1, a t-shaped area that closely follows McDowell and Scottsdale Roads; this area is referred to as the "McDowell Road/Scottsdale Road Growth Area" in the 2035 General Plan), Old Town Scottsdale (blue in Figure 1, following the boundaries described in the 2018 Old Town Scottsdale Character Area Plan), and the Airpark area (red in Figure 1, following the boundaries described in the 2010 Greater Airpark Character Area Plan). A new measurement campaign focusing on Indian Bend Wash was conceived during the project period and bounded by 74th Street, Hayden Road, McDowell Road, and McKellips Road.

The City of Scottsdale 2035 General Plan Growth Areas Element describes each of the three Growth Areas as follows:

- South Scottsdale (McDowell Road/Scottsdale Road Growth Area): "consists of long-standing commercial properties…the majority of properties in this Growth Area are in land use or development transition…building heights general range between two and six stories."
- Old Town: "the commercial, cultural, civic, and symbolic center of the community…includes a collection of interconnected, mixed-use districts… some of the greatest development intensity within the community…the small-lot development pattern, active ground level land uses, and pedestrian focus of the Downtown Core are some of the primary elements that give Old Town its most identifiable character."
- Greater Airpark: "one of the largest employment centers in the State of Arizona…headquarters for a multitude of national and regional corporations…. largest employment and industrial-zoned area within Scottsdale…home to the Scottsdale Airport."

To facilitate comparison between the growth areas and other parts of the City, the project team conducted several analyses for an area that is called "Metro Scottsdale" in this report (green area in Figure 1, in addition to the three growth areas). Metro Scottsdale is

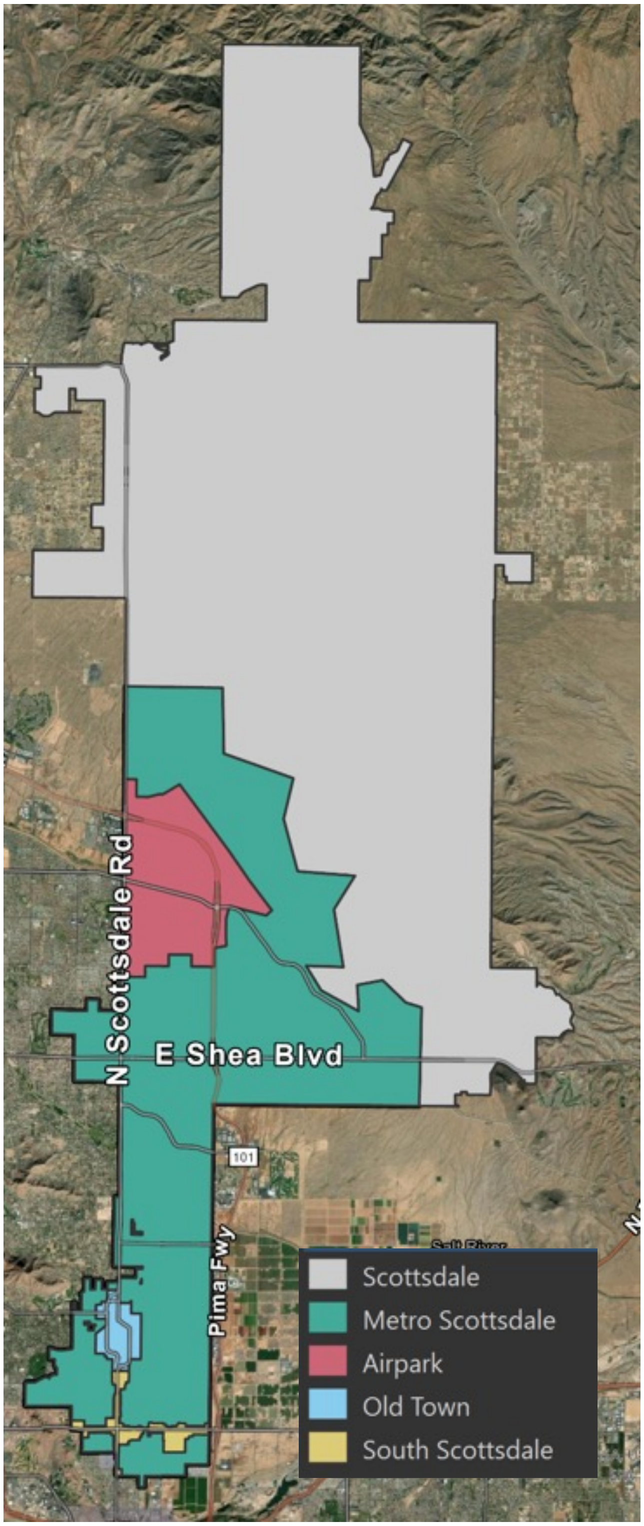


Figure 1. City of Scottsdale map indicating the boundaries of areas used for analysis of environmental data sets in the Cooler Scottsdale project.

not an officially recognized unit or area by the City of Scottsdale, and was established for the purposes of this report to provide a more appropriate set of comparisons and benchmarks between the more developed parts of the City and those that remain relatively or completely undeveloped. Some analyses were conducted at the spatial scale of census block groups; only those census block groups whose boundaries fell completely within the Metro Scottsdale boundary were included. The northernmost extent of the City's jurisdiction fell outside of the spatial range of available data and was therefore excluded.

The most recently available data were used for all components of this report, and most data sets were constrained to the summer season, defined as June, July, and August. However, the most recent high-resolution land cover data set was from 2015, requiring certain analyses to use other data sets from that time period as well. Due to rapid growth and redevelopment in certain parts of the City, analysis based on 2015 data will not be a completely accurate representation of contemporary conditions.

The project team consulted a number of City plans and guidance documents to help craft recommended heat mitigation actions, with guidance from City staff. The primary documents reviewed were the City's 2035 and 2001 General Plans (including subsequent amendments and revisions to the latter), the respective Character Area Plans for Southern Scottsdale, Old Town, and Greater Airpark, the City's 2018 Design Standards & Policies Manual, the Old Town Urban Design and Architectural Guidelines, and the City's Shading Guidelines. These documents are all publicly available through the City of Scottsdale's website. Additional valued input on project direction and priorities was provided by members of Scottsdale's Environmental Advisory Commission.

Land Cover and Surface Temperature Assessment

Land cover analysis

Land cover in Scottsdale was analyzed using a remote sensing-based classification developed by researchers at ASU's Central Arizona-Phoenix Long-Term Ecological Research (CAP LTER) Program. The underlying data for the classification were collected in 2015 from aerial imagery as part of the National Agricultural Imaging Program (NAIP); the resulting classification is the most up-to-date information available at a high (1 meter) spatial resolution and has been evaluated to have accuracy of at least 94%. Six land cover types were examined for this project: Building, Asphalt, Bare Soil & Concrete, Tree & Shrub, Grass, and Water. More details on the source data are available via the CAP LTER data portal (Zhang and Turner 2020). A sample of the classification scheme, along with maps for each growth area, are shown below as Figures 2-5.

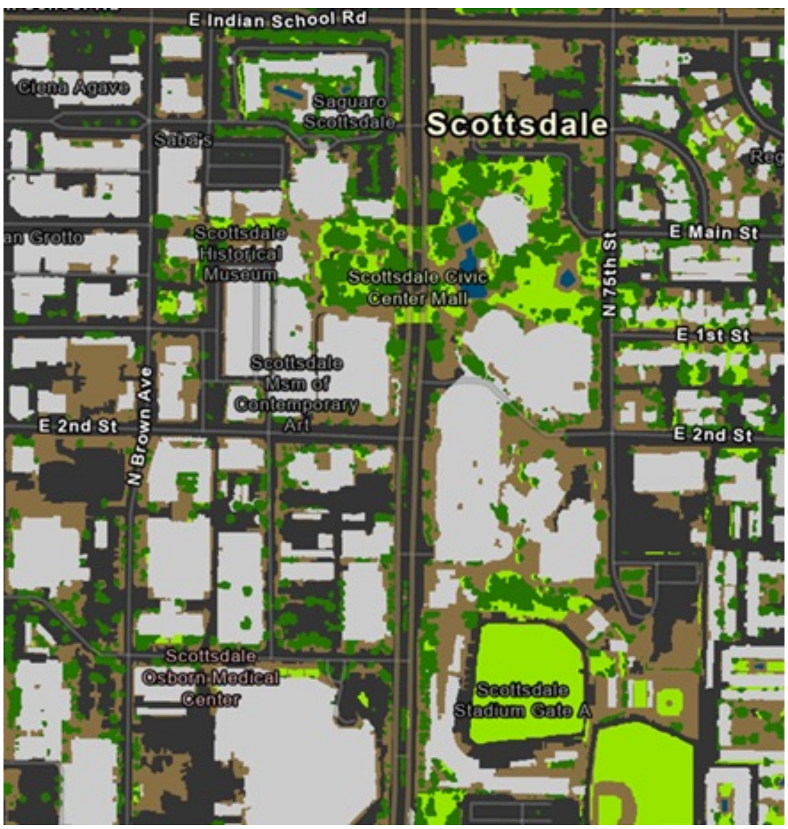


Figure 2. 2015 land cover classification for a section of Old Town Scottsdale.

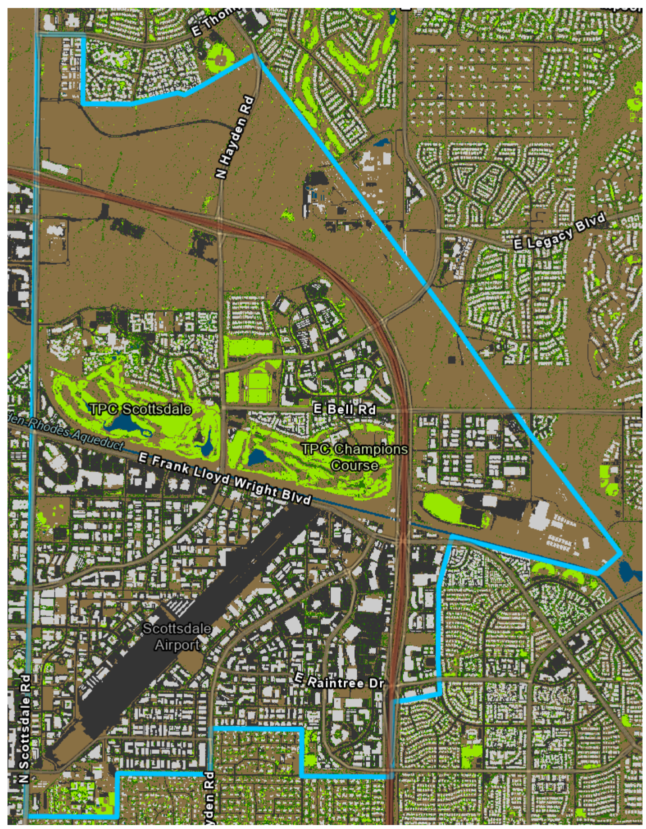


Figure 3. 2015 land cover classification for the Airpark growth area. The growth area boundary is shown in blue.

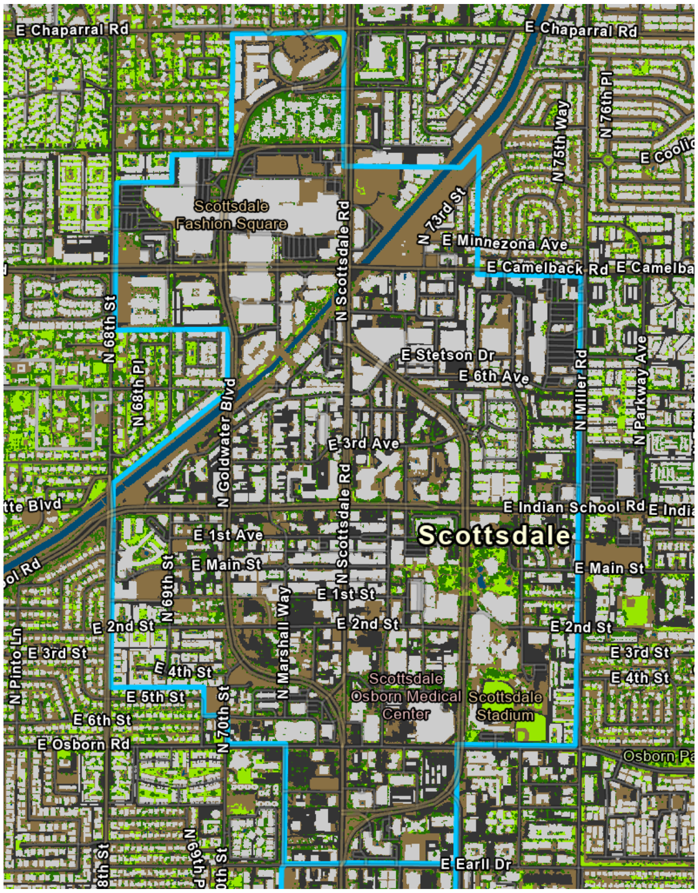


Figure 4. 2015 land cover classification for the Old Town growth area. The growth area boundary is shown in blue.

Figure 5. 2015 land cover classification for the South Scottsdale growth area. The growth area boundary is shown in blue.

Concrete and bare soil, buildings, and asphalt accounted for a high percentage of land cover in each of the areas examined. Buildings and asphalt accounted for at least 40% of total land area in each of the three Growth Areas, with a maximum of 69% in South Scottsdale. Green land cover types, including trees, shrubs, and grass, accounted for approximately 20% of land cover for the entire City, and 22% in Metro Scottsdale. However, green land cover types accounted for a much lower percentage of the total area in the three Growth Areas, with a minimum of 7% observed for South Scottsdale. Overall, trees and shrubs accounted for approximately twice as much land area as grass, although this ratio varied considerably between growth areas. The distribution of land cover types for each of the five areas examined in this project are shown in Figure 6 (next page).

Land cover was also assessed at the census block group scale, for all census block groups that were completely contained within the boundaries of Metro Scottsdale (see Figure 7). The census block group analysis was conducted to provide a broader perspective on how land cover varied spatially across the City, given the distinctive geographic boundaries of the three prioritized growth areas (e.g., the South Scottsdale growth area boundaries closely follow the major road network and include very few residential parcels). The census block group scale analysis focused on four land cover types: Tree & Shrub, Grass, Asphalt, and Building.

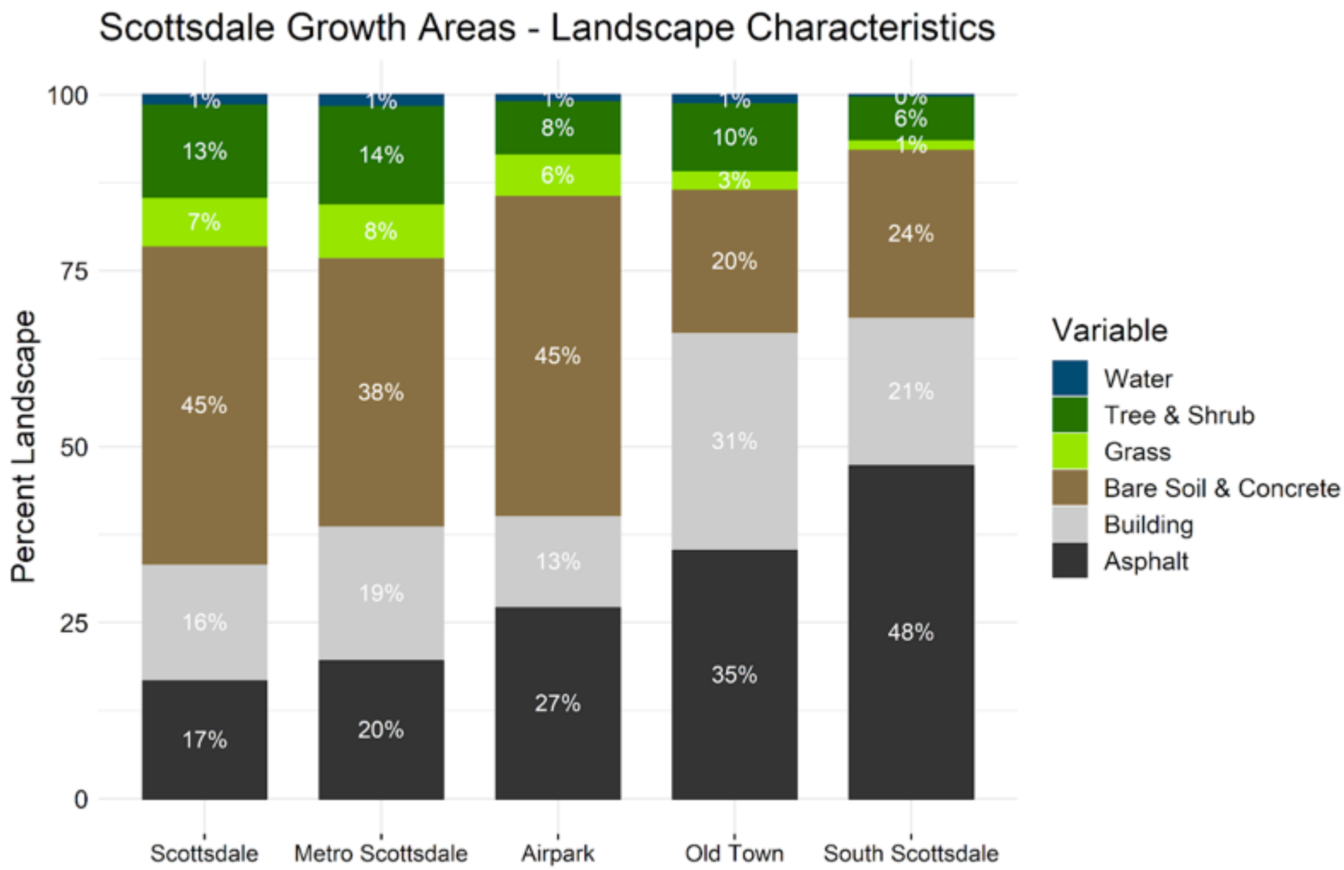


Figure 6. Land cover fractions for different regions in the City of Scottsdale based on 2015 classification data. Refer to Figure 1 for boundaries of each region.

There were clear and large spatial differences in land cover types across the 135 census block groups examined in this project:

- Tree & Shrub coverage varied from 6.5% to 25.0%. Tree & Shrub coverage was generally higher in Central Scottsdale, along the Shea Boulevard Corridor, and along the western boundary of the City bordering Paradise Valley and Phoenix. Tree & Shrub coverage was lower in Southern Scottsdale, and in several census block groups including and surrounding the Airpark growth area.
- Grass coverage varied from nearly 0 to more than 36%. Many of the census block groups with the highest grass coverage were along the Greenbelt corridor, especially between McDowell Road to the south and Shea Boulevard to the north. The lowest grass coverage was found in census block groups east of Highway 101 near Shea and Frank Lloyd Wright Boulevards.
- Asphalt coverage varied from a low of 5.1% to more than 42%. Block groups including and near Old Town were among those with the highest asphalt coverage; other areas with high asphalt coverage included the airport and immediate surrounds, the area to the southeast of Hayden and McDowell Roads, and the shopping complex at McCormick Ranch. The least asphalt was found in census block groups in the northernmost extent of Metro Scottsdale.
- Building coverage varied between 7.4% and 37.8%. The highest building coverage was evident to the northeast of Old Town Scottsdale, bounded by Hayden and Miller Roads on the east and west, and Indian School and Jackrabbit Roads to the north and south. Census block groups between the airport and Central Arizona Project Canal also had high building density. The lowest building density was observed in census block groups flanking the north and south of Highway 101 as it curves to the west, but portions of these areas have started to be developed since the land cover data were collected.

Finally, land cover fractions were calculated for each of the 128,439 parcels available from City of Scottsdale public records. The complete land cover assessment for all parcels is available in the data package; summary results below are presented for 95,676 parcels located within Metro Scottsdale.

- Approximately 53% of parcels in Metro Scottsdale (50,939 of 95,676 individual parcels) had at least 50% of their land area classified as building or asphalt as of 2015.
- Approximately 32% of parcels larger than one acre in size in Metro Scottsdale (1,345 of 4,192 parcels) had at least 50% of their land area classified as building or asphalt as of 2015.
- There were 45 individual parcels in Metro Scottsdale that had 10 or more acres of building or asphalt land cover as of 2015. Because of the relatively strong relationship between building and asphalt land cover types and land surface temperature, parcels with larger building and asphalt land areas could be prioritized for future heat mitigation efforts. Examples of these parcels are shown in figure 8 below; the complete set of parcel calculations is available in the data package on the City of Scottsdale website (scottsdaleaz.gov, search for “cooler Scottsdale”).

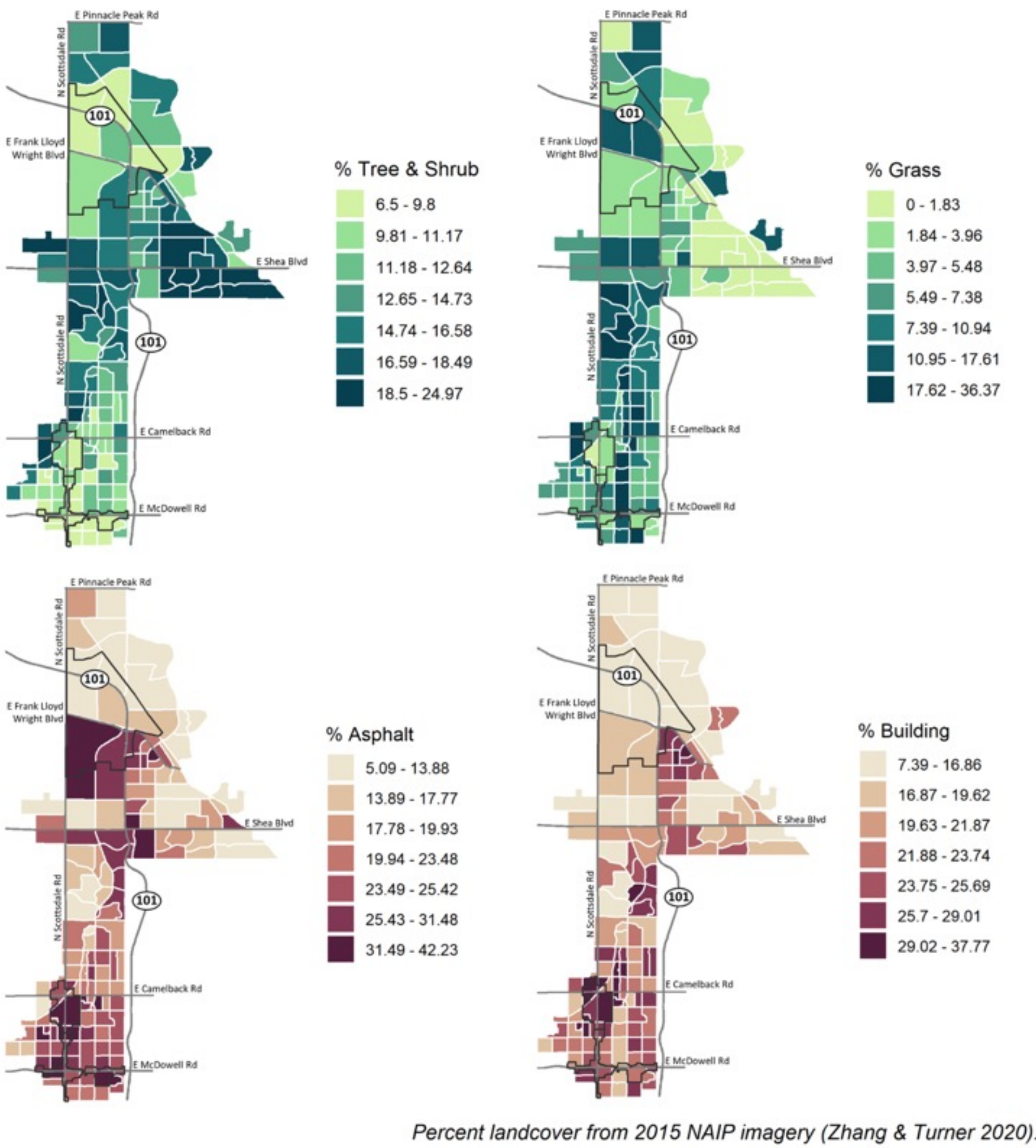


Figure 7. Land cover fractions for census block groups in Metro Scottsdale based on 2015 classification data.

Sample parcels in Metro Scottsdale with high building and asphalt land area

15255 N Hayden Road
Building+asphalt fraction: 78.3%
Building+asphalt area: 15.4 acres
Warehouse-type store (1153)

8201 E McDowell Road
Building+asphalt fraction: 68.0%
Building+asphalt area: 85.9 acres
Industrial (3099)

601 N Hayden Road
Building+asphalt fraction: 74.5%
Building+asphalt area: 12.7 acres
Manufactured home park (0840, 0802)

4300-4400 block, west side of Miller Road
Building+asphalt fraction: 84.8%
Building+asphalt area: 11.3 acres
Community shopping center, open air (1430)

7014 E Camelback Road
Building+asphalt fraction: 90.3%
Building+asphalt area: 19.8 acres
Super regional shopping center, enclosed mall (1460)

8764 E Shea Blvd
Building+asphalt fraction: 85.2%
Building+asphalt area: 13.3 acres
Neighborhood shopping center (1410)

Figure 8. Sample parcels with at least 10 acres of building or asphalt land cover. Land cover data as of 2015, imagery as of July 2020. Property use (and codes) derived from Arizona Department of Revenue Property Use Code Manual. *Note: Some of the land cover in these parcels may be designated as "Soil or concrete," which is not well differentiated in the original classification scheme. Building and asphalt fractions should be considered as an indicator for, but not necessarily precise measurements of, the actual amount of building, asphalt, or other impervious surface coverage on each parcel.*

Data package contents relevant to the land cover analysis are accessible on the City of Scottsdale website (scottsdaleaz.gov, search for “cooler Scottsdale”) and include:

1. The complete map of 2015 land cover for the City of Scottsdale
2. Land cover shape files and data tables for prioritized growth areas
3. Land cover shape files and data tables for Metro Scottsdale census block groups
4. Land cover shape file and data tables for all parcels within City boundaries

Land surface temperature analysis

Land surface temperature in Scottsdale was analyzed using imagery from NASA’s Landsat 8 satellite. Composites of land surface temperature images from all cloud-free summer (June, July, August) days in 2015 and 2020 were created for this report; most results presented are reflective of 2020 conditions with the exception of modeling results, where 2015 data were used for alignment with land cover data (which are only available for 2015). Landsat images are taken approximately every two weeks, resulting in approximately five images included in each composite. These images are only available for late morning hours. Satellite-derived land surface temperature reflects the temperature of the highest vertical surface as viewed from overhead.

For interpreting results, it is important to note that land surface temperatures are not equivalent to near surface air temperatures; many urban materials including roads and roofs often have surface temperatures much higher than air temperatures during the daytime hours. Land surface temperature is an important variable to examine in the context of urban heat island mitigation because surface characteristics are key drivers of elevated urban air temperatures (Hart and Sailor 2009). However, because different surfaces heat and cool at different rates throughout the course of the day, these results (based exclusively on late morning imagery) should be interpreted as providing a partial perspective on how surface temperatures vary across the City.

Surface temperatures are highly variable across Scottsdale on summer days. In 2020, surface temperatures across the entire City ranged between 95.1 and 165.5°F, although 50% of the City had surface temperatures between 119.0 and 125.0°F. A similar range was observed for Metro Scottsdale. The average land surface temperature for the entire City was 122.5°F and for Metro Scottsdale, 123.3°F. Distributions of the land surfaces temperatures for each growth area are shown in Figure 9, and the map of 2020 land surface temperatures across the City is available as Figure 10.

Key summary statistics from the land surface temperature analysis for the growth areas:

- All three of the growth areas had average land surface temperatures that were at least 5.5°F warmer than the citywide average.
- Airpark and Old Town had average land surface temperatures of 129.0°F and 129.5°F, respectively.
- South Scottsdale was the hottest of the three growth areas with respect to land surface temperature, averaging 131.4°F.
- Both Old Town and South Scottsdale were notably characterized by an absence of locations with particularly low land surface temperatures, when compared to the Airpark growth area and the City as a whole (see Figure 9).

The project team extracted locations with anomalously high or low land surface temperatures to help staff prioritize different places in the City for future heat mitigation initiatives. Maps of urban “hot spots” and “cool spots” appear below as Figures 11-14. The blue and red colors in these maps represent relatively

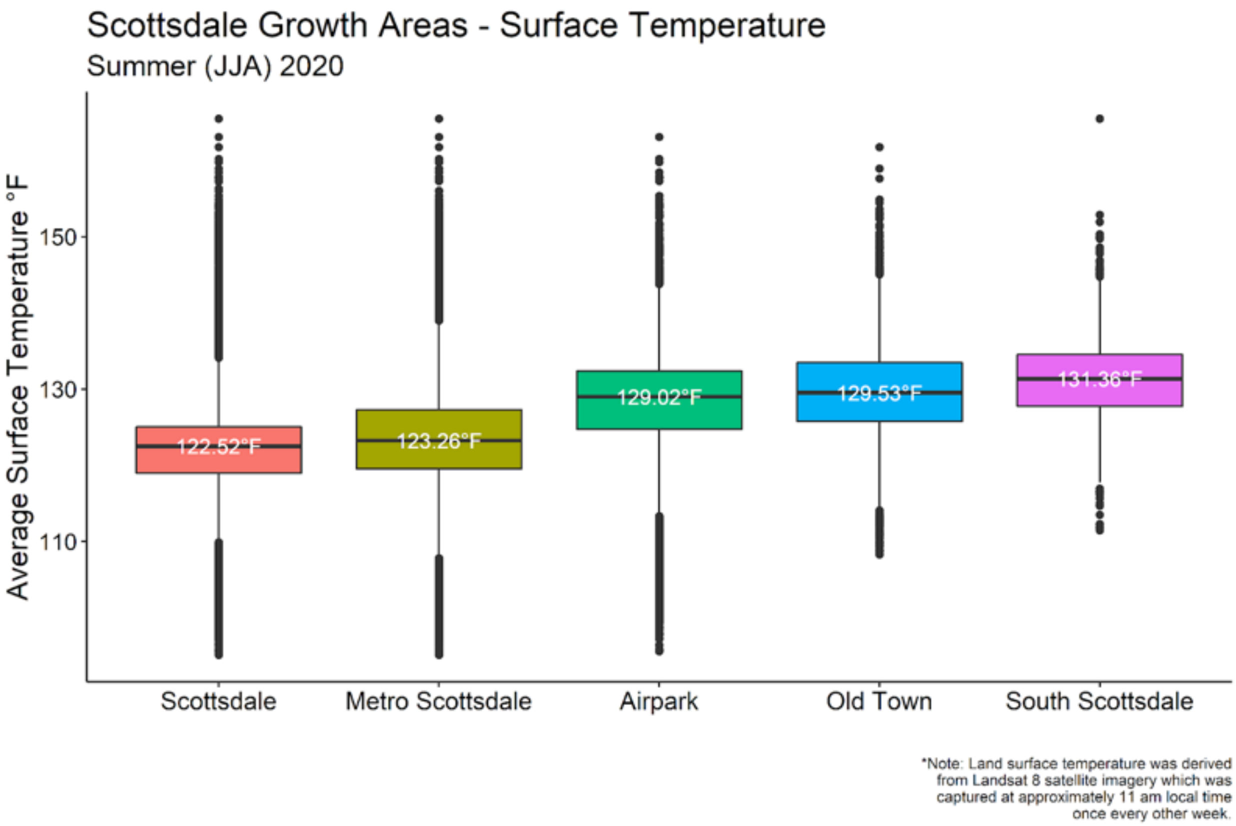


Figure 9. Distribution of land surface temperatures observed from NASA Landsat imagery for Scottsdale, Metro Scottsdale, and three growth areas in summer 2020. For each region, the colored box shows the range of the middle 50% of observed values, and the horizontal line represents the median value. The vertical lines span approximately 95% of observed values; each dot represents a statistical outlier. Landsat imagery is collected at approximately 11am local time.

cool spots and hot spots respectively, defined by standard deviations from the mean surface temperature within Metro Scottsdale (based on summer 2020 data):

- The darkest blue represents surfaces that are two standard deviations below the mean, or cooler (less than 109.2°F).
- Light blue represents surfaces that are warmer than the dark blue surface, but still one standard deviation cooler than the mean surface temperature (less than 116.1°F).
- The darkest red represents surfaces that are two standard deviations above the mean, or hotter (greater than 137.1°F).
- Light red represents surfaces that are cooler than the dark red surface, but still one standard deviation hotter than the mean surface temperature (greater than 130.1°F).
- Any surfaces within one standard deviation from the mean are not colored in these maps (between 116.1 and 130.1°F)

The hot spot and cool spot maps reveal some striking patterns in land surface temperatures in Scottsdale. Notably, the three growth areas prioritized for this project account for the vast majority of the hot spots in Metro Scottsdale. Despite only accounting for 17.6% of the land area of Metro Scottsdale, these three locations collectively contain 58.0% of the pixels designated as hot spots (light and dark red on the map/ temperatures greater than one standard deviation above the mean). Additionally, 74.9% of the hottest locations (dark red on the map/temperatures greater than two standard deviations above the mean) in Metro Scottsdale fall within the three growth areas. Many individual features stand out on the growth area hot spot and cool spot maps (Figures 12-14), including the Scottsdale Airport runway, Fashion Square Mall, and commercial development on the northeastern and northwestern corners of the intersection of Scottsdale Road and McDowell Road.

With respect to cool spots, the connected chain of parks, golf courses, and green space that comprise Indian Bend Wash stands out as a “blue ribbon” in southern Scottsdale. Farther north, cool spots are largely dominated by golf courses and their surrounding developments, especially in cases where those developments include larger surface water features. The most prominent cool spot within any of the three growth areas is the TPC Scottsdale golf complex (two golf courses) in the Airpark growth area. Adjacent properties including the Scottsdale Sports Complex and polo field at Westworld also stand out as cool spots. In the Old Town growth area, Scottsdale Stadium’s two baseball fields, and the Scottsdale Civic Center’s extensive green space, represent the two most notable cool spots. There were no significant cool spots in the South Scottsdale growth area.

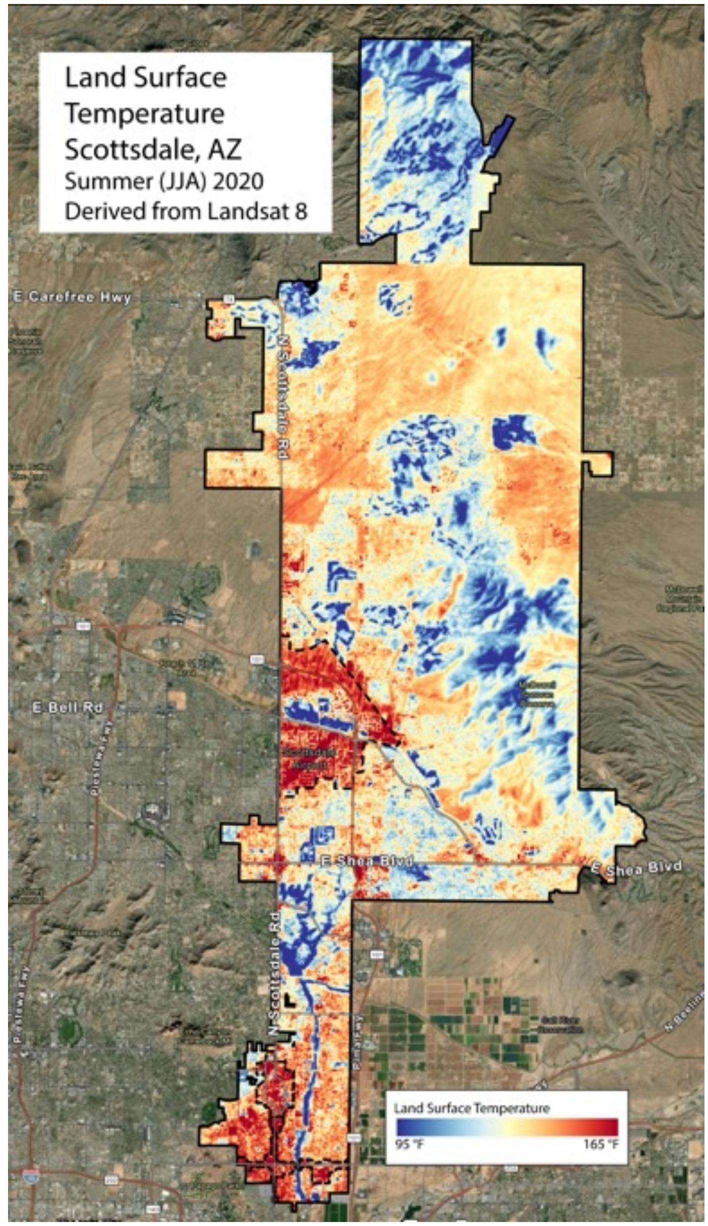


Figure 10. Map of land surface temperatures observed from NASA Landsat imagery for Scottsdale in summer 2020. Landsat imagery is collected at approximately 11am local time.

Analysis of summer 2020 satellite-derived land surface temperatures at the census block group scale also revealed a clear and large spatial difference across Metro Scottsdale (Figures 15 and 16). Southern Scottsdale (below Camelback Road), and in particular, the western half of southern Scottsdale (west of Miller Road), which is home to 18 of the 20 hottest census block groups in Metro Scottsdale. Of the other two of the 20 hottest census block groups, one is also located in southern Scottsdale to the south of McDowell Road and west of Hayden Road. The other contains the Scottsdale Airport. The average land surface temperature of the 18 census block groups in this 4.2 square-mile south Scottsdale “hot zone” was 130.0°F in 2020, compared to an average of 122.6°F for the census block groups in the remainder of Metro Scottsdale. Attributes for the census block groups that had the five highest and five lowest average land surface temperatures are shown below in Table 2; the full list of census block group land surface temperatures is available in the data package that accompanies this report.

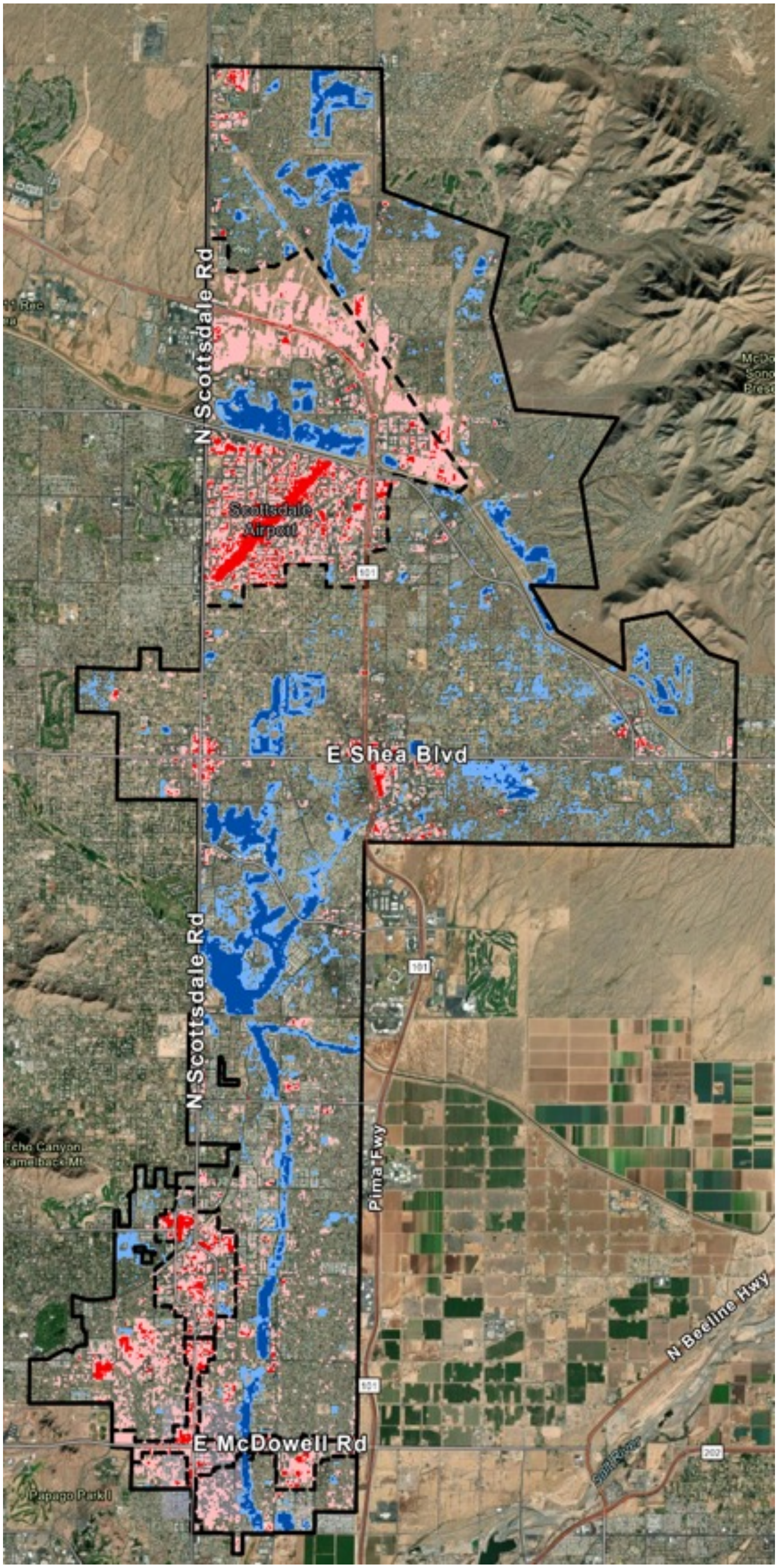


Figure 11. Hot spots and cool spots in Metro Scottsdale, extracted from land surface temperatures observed in summer 2020. Landsat imagery is collected at approximately 11am local time. The blue and red colors in these maps represent relatively cool spots and hot spots respectively, defined by standard deviations from the mean surface temperature within Metro Scottsdale (based on summer 2020 data). Locations without color were not classified as cool spots or hot spots.

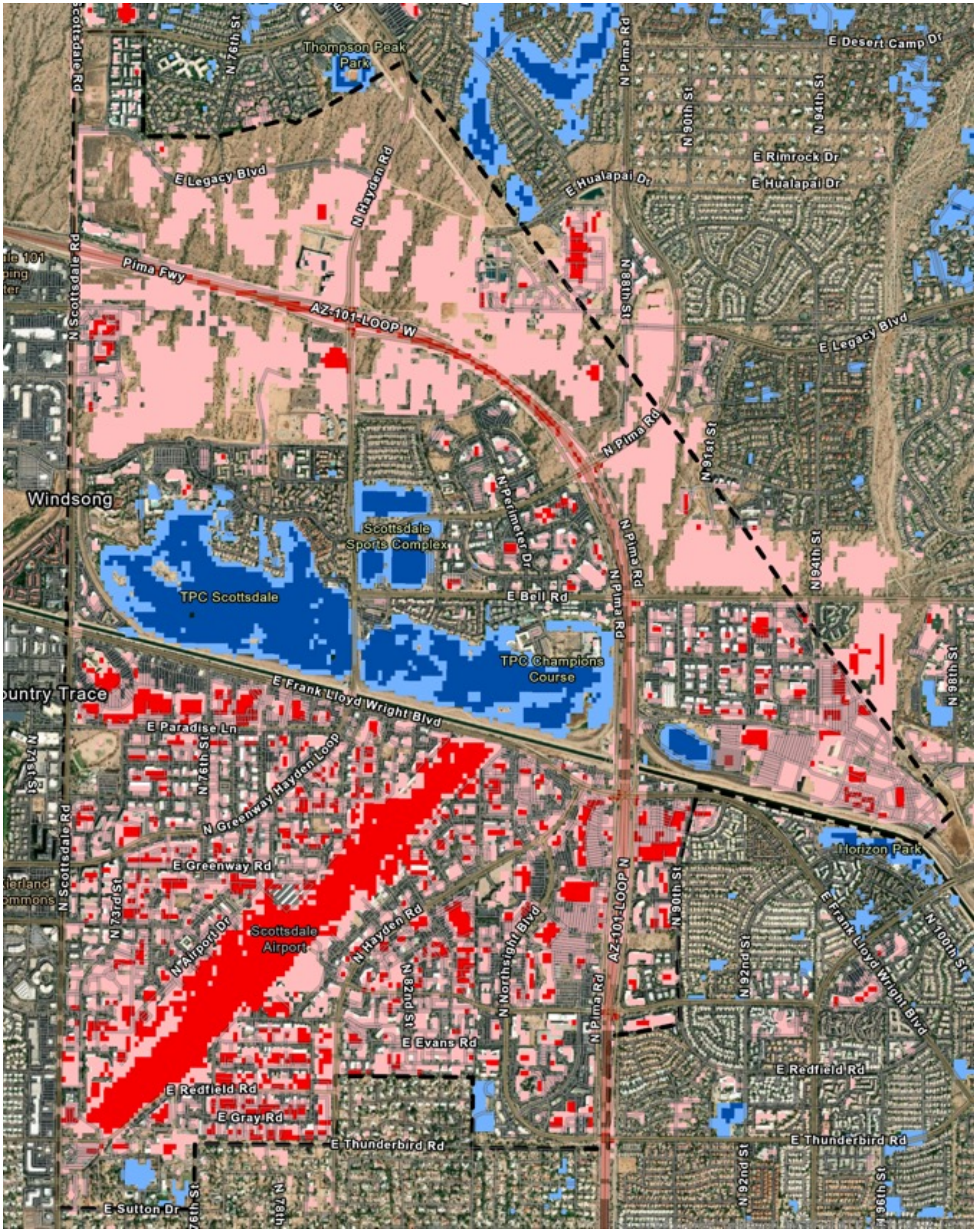


Figure 12. Hot spots and cool spots in the Airpark growth area, extracted from a land surface temperatures observed in summer 2020. Landsat imagery is collected at approximately 11am local time. The blue and red colors in these maps represent relatively cool spots and hot spots respectively, defined by standard deviations from the mean surface temperature within Metro Scottsdale (based on summer 2020 data). Locations without color were not classified as cool spots or hot spots.

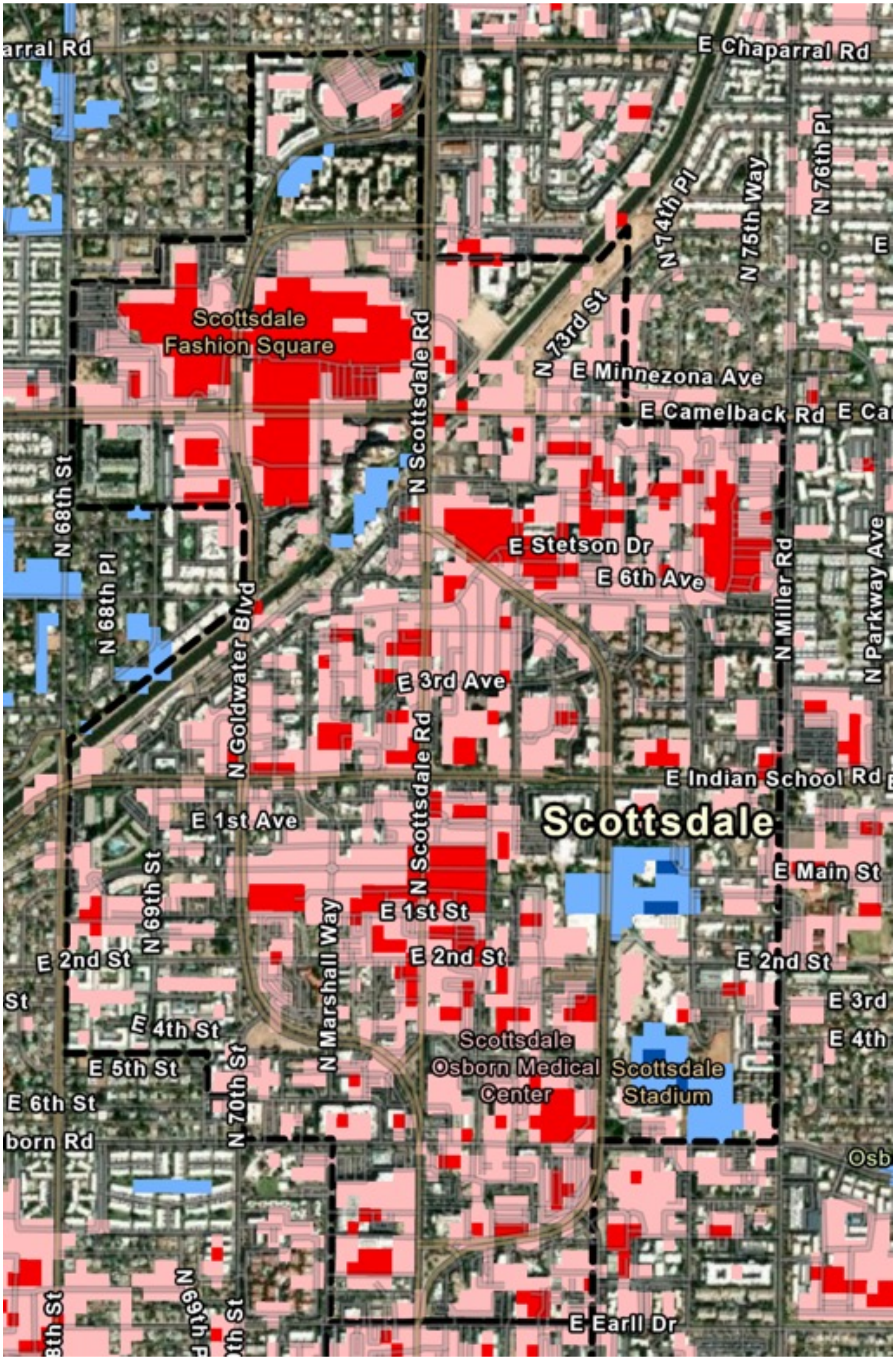


Figure 13. Hot spots and cool spots in the Old Town growth area, extracted from land surface temperatures observed in summer 2020. Landsat imagery is collected at approximately 11am local time. The blue and red colors in these maps represent relatively cool spots and hot spots respectively, defined by standard deviations from the mean surface temperature within Metro Scottsdale (based on summer 2020 data). Locations without color were not classified as cool spots or hot spots.

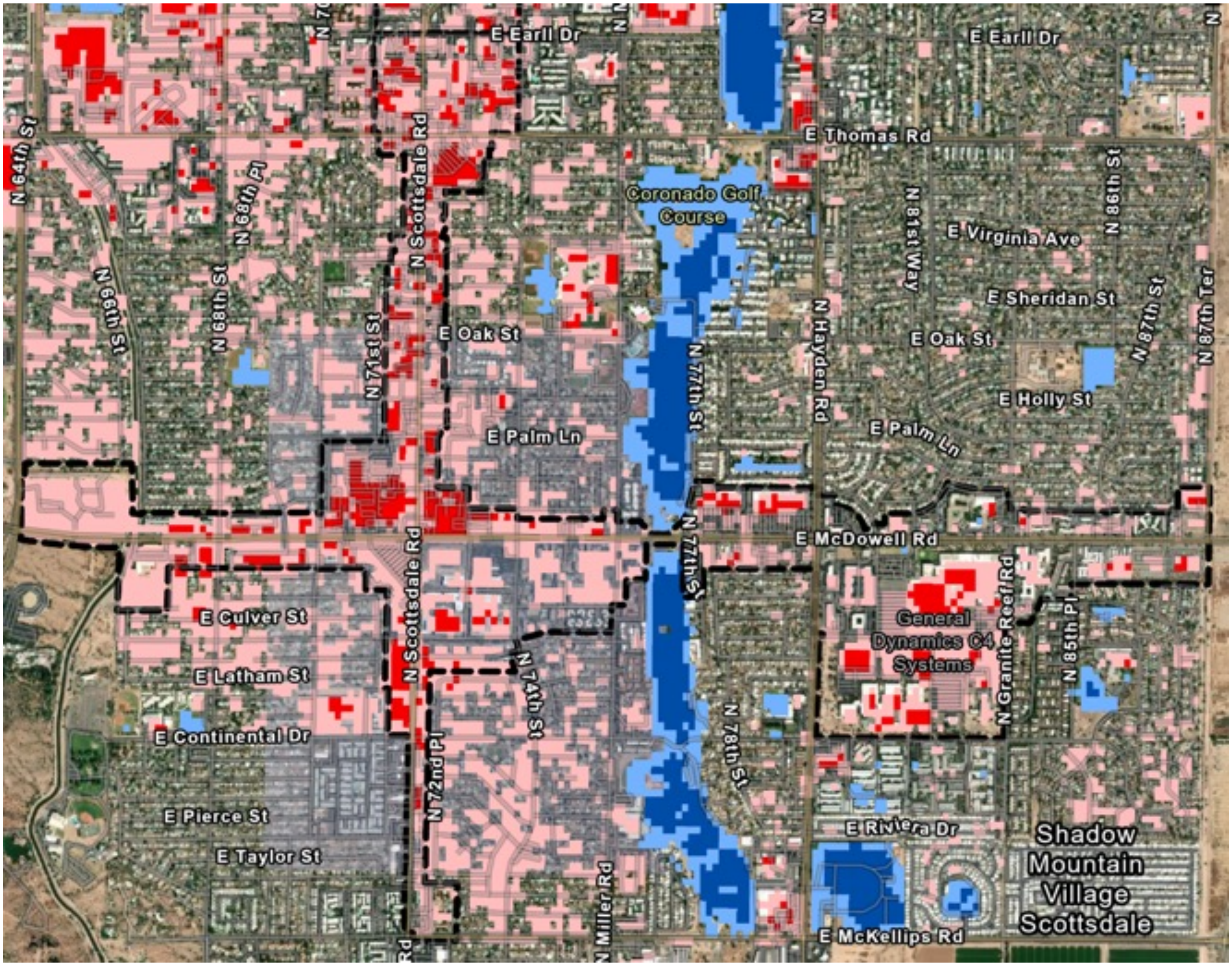


Figure 14. Hot spots and cool spots in the South Scottsdale growth area, extracted from land surface temperatures observed in summer 2020. Landsat imagery is collected at approximately 11am local time. The blue and red colors in these maps represent relatively cool spots and hot spots respectively, defined by standard deviations from the mean surface temperature within Metro Scottsdale (based on summer 2020 data). Locations without color were not classified as cool spots or hot spots.

Metro Scottsdale Land Surface Temperature by Census Block Group

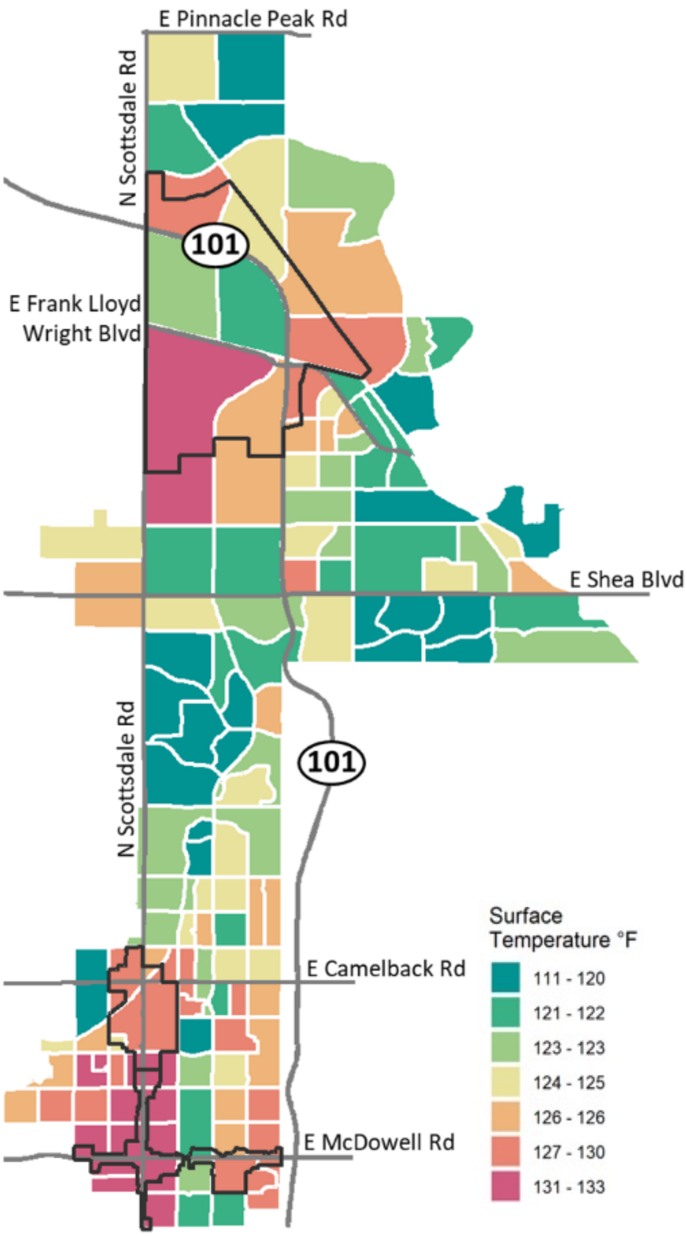


Figure 15. Average summer 2020 land surface temperatures by census block group in Metro Scottsdale. Surface temperatures are based on NASA Landsat imagery collected at approximately 11am local time.

Metro Scottsdale Census Block Groups with Highest and Lowest Land Surface Temperature

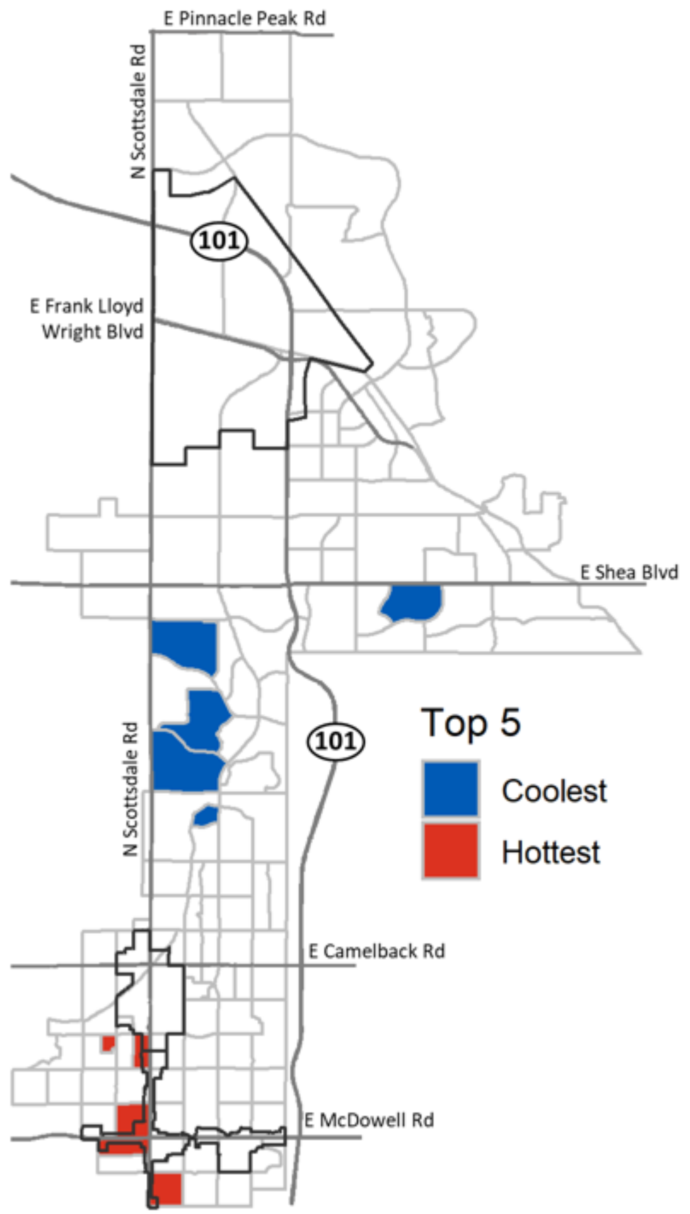


Figure 16. The five census block groups with the highest (red) and lowest (blue) land surface temperatures in Metro Scottsdale, based on average summer 2020 land surface temperatures derived from NASA Landsat imagery collected at approximately 11am local time.

Metro Scottsdale's Five Hottest Census Block Groups (based on 2020 land surface temperature imagery)				& Five Coolest Census Block Groups (based on 2020 land surface temperature imagery)			
Rank	Census Tract, Block Group	Approximate Location	2020 LST (mean block group in City = 123.6°F)	Rank	Census Tract, Block Group	Approximate Location	2020 LST (mean block group in City = 123.6°F)
1	7501, 2	SW of Osborn Road and 68th Street	133.2°F	1	6835, 2	McCormick Ranch (including parts of golf course)	111.3°F
2	8100, 1	S of McDowell Road, between 66th Street and Scottsdale Road	131.4°F	2	6834, 2	McCormick Ranch (including parts of golf course)	112.6°F
3	7502, 3	W of Scottsdale Road, between Thomas Road and Obsorn Road	130.5°F	3	6813, 2	Gainey Ranch (including parts of golf course)	112.9°F
4	8000, 2	NE of McDowell Road and Scottsdale Road	130.4°F	4	6901, 3	W of Hayden Road, parts of Silverado Golf Club	114.9°F
5	8200, 3	SW of Scottsdale Road and Roosevelt Street	130.3°F	5	6832, 2	S of Shea Boulevard, between 100th Street and Via Linda	115.4°F

Table 2. Attributes for the five census block groups in Metro Scottsdale with the highest and lowest average land surface temperatures in summer 2020 Landsat imagery. Landsat imagery is collected at approximately 11am local time.

Land surface temperatures were estimated for all parcels in the City based on 2020 summertime imagery. The complete land surface temperature assessment for all parcels is available in the data package on the City of Scottsdale website; summary results below are presented for 95,676 parcels located within Metro Scottsdale, including results for the parcels specifically contained in the three prioritized growth areas. In interpreting these results it is important to note that the spatial resolution of the land surface temperature imagery is coarser than many individual land parcels; estimates for individual parcels are often influenced by adjacent parcels, street segments, and other features.

- The mean summer 2020 land surface temperature of the 95,635 parcels in Metro Scottsdale with available data was 123.7°F; parcel temperatures ranged between 99.4°F and 147.7°F.
- In Metro Scottsdale, the average land surface temperature of vacant (126.7°F) and commercial (126.6°F) parcels was higher than the average of residential parcels (123.4°F).
- There was no relationship between parcel size and parcel land surface temperature.
- Following the growth area results presented previously, the parcel land surface temperatures were higher for those located in the three growth areas than in other parts of Metro Scottsdale. Of the three growth areas, the average parcel land surface temperature was highest for South Scottsdale (130.9°F). The average parcel in Old Town was 128.2°F, and Airpark, 127.2°F.
- Residential parcels had lower land surface temperatures than commercial parcels in all three growth areas (Figure 17). However, the difference between residential and commercial parcels varied considerably between the three. The difference was, on average, 7.6°F in Airpark, whereas in South Scottsdale, residential parcels were only 1.4°F cooler than commercial parcels. Old Town was an intermediate case with a difference of 4.6°F between the two property types.
- Sample parcels with lower land surface temperatures from Scottsdale's growth areas are shown below in Figure 18. Replicating certain landscape and design features from these parcels in other locations could help reduce citywide land surface temperatures and urban heat. The complete set of parcel calculations for the entire City is available in the data package on the City of Scottsdale website (scottsdaleaz.gov, search for "cooler Scottsdale").

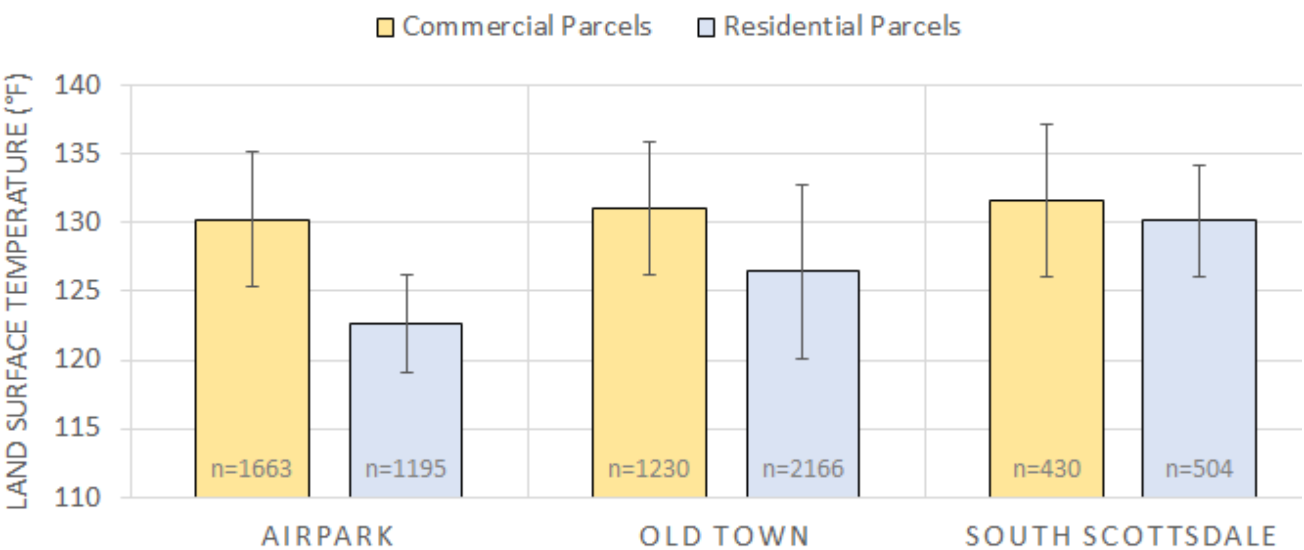


Figure 17. Mean land surface temperatures for commercial and residential parcels in each growth area, based on summer 2020 Landsat imagery. The bar height represents the mean for each parcel type and growth area and the error bars indicate one standard deviation around the mean. The number of parcels in each category is shown at the base of each bar. Please note that the bottom of the minimum axis only extends to 110°F to emphasize contrasts between different property types. Landsat imagery is collected at approximately 11am local time.

Sample parcels in Metro Scottsdale with lower land surface temperatures

7523 E Culver Street *South Scottsdale*
Use: Multiple residential, fourplex (PUC 0345)
Land surface temperature: 122.9°F
Key features: Grass and tree coverage, lighter-colored roofs

8101 E McDowell Road *South Scottsdale*
Use: Industrial warehousing (PUC 3710)
Land surface temperature: 125.0°F
Key features: Tree coverage, lighter-colored roof

6875 E Camelback Road *Old Town*
Use: Multiple residential, 100+ apartments (PUC 0377)
Land surface temperature: 121.4°F
Key features: Vegetation on and surrounding building, interior shading, no surface parking

7153 E Thornwood Drive *Old Town*
Use: Condominiums and townhouses (PUC 0780)
Land surface temperature: 119.8°F
Key features: Vegetation on and surrounding building, interior shading, no surface parking

8750 E Raintree Drive *Airpark*
Use: Bank (PUC 1610)
Land surface temperature: 123.2°F
Key features: Tree coverage, lighter-colored roof

17700 N Pacesetter Way *Airpark*
Use: One-story office building (PUC 1511)
Land surface temperature: 121.7°F
Key features: Tree coverage, desert landscaping, lighter-colored surface materials, lighter-colored shade structures for parking

Figure 18 (previous page). Google Street View images from a sample of low land surface temperature parcels in Scottsdale's three growth areas. The land surface temperature data were from summer 2020, and Google imagery was dated July 2020. PUC refers to Property Use Code, as detailed in the Arizona Department of Revenue Property Use Code Manual.

Note: Land surface temperature data are at relatively coarse resolution compared to individual parcels and parcel boundaries; surface temperature estimates are also influenced by the reflectivity of ground and building materials and certain materials may introduce significant error into the estimates. Additional measurements are recommended to verify microclimate conditions on and near these parcels. The parcels shown below fell in the coolest 10% of all parcels in the three growth areas with at least 25% building/asphalt land cover and an area of at least 0.1 acres. Many larger commercial properties were difficult to evaluate because of the manner in which parcels are allocated on the property; the full set of parcel and land surface temperature data are available for further analysis and investigation.

Data package contents relevant to the land surface temperature analysis on the City of Scottsdale website (scottsdaleaz.gov, search for "cooler Scottsdale") include:

- The complete map of 2015 and 2020 land surface temperature for the City of Scottsdale
- Land surface temperature shape files and data tables for prioritized growth areas
- Land surface temperature shape files and data tables for Metro Scottsdale census block groups
- Land surface temperature shape file and data tables for all parcels within City boundaries

Land surface temperature modeling

There are clear and strong relationships between the prevalence of different land cover types across the City of Scottsdale and land surface temperature. Consistent with findings reported in the scientific literature, places in Scottsdale with higher fractions of land cover with buildings and asphalt had higher land surface temperatures, whereas places with more trees, shrubs, and grass had lower land surface temperatures. There is also an inverse relationship between income and land surface temperature, with lower surface temperatures observed in higher income neighborhoods. (Note: these relationships are based on 2015 land cover and land surface temperature, the most recent year for which high-resolution land cover data are available). Details for linear regression models for four land cover types calculated at the census block group scale are presented below, along with imagery of exemplar census block groups with high and low amounts of each land cover class (Figures 19-22). For reference, census block group average land surface temperature (from 2015 imagery) varied between 103.4°F and 126.8°F.

Tree & Shrub Land Cover

- Each 1% increase in tree & shrub land cover in a census block group was associated with a 0.59°F reduction in land surface temperature.
- Approximately 200 trees or shrubs per square mile are required to increase tree and shrub land cover by 1%.
- Tree & shrub land cover explained 24.7% of the variance in land surface temperature

High tree cover, low land surface temperature

Tract 7300, Block Group 2
Arcadia area
SE of Camelback Road and 68th Street
23.8% Tree and Shrub coverage
Metro Scottsdale average = 13.8%
106.9°F average LST
Metro Scottsdale average = 118.3°F

Low tree cover, high land surface temperature

Tract 7501, Block Group 2
Holiday Park area
SE of Osborn Road and 66th Street
8.8% Tree and Shrub coverage
Metro Scottsdale average = 13.8%
122.3°F average LST
Metro Scottsdale average = 118.3°F

Figure 19. Representative cases demonstrating the relationship between tree and shrub land cover and land surface temperature (visible imagery from July 2020; statistics from summer 2015).

Grass Land Cover

- Each 1% increase in grass land cover in a census block group was associated with a 0.39°F reduction in land surface temperature.
- Grass land cover explained 36.5% of the variance in land surface temperature

High tree cover, low land surface temperature

Tract 6901, Block Group 1
Vicinity of Silverado Golf Course
SE of Lincoln Drive and Arizona Canal
26.3% Grass coverage
Metro Scottsdale average = 8.1%
111.8°F average LST
Metro Scottsdale average = 118.3°F

Low tree cover, high land surface temperature

Tract 6837, Block Group 3
Mountainside Plaza area, SE of Via Linda and Frank Lloyd Wright Boulevard
0% Grass coverage
Metro Scottsdale average = 8.1%
122.3°F average LST
Metro Scottsdale average = 118.3°F

Figure 20. Representative cases demonstrating the relationship between grass land cover and land surface temperature (visible imagery from July 2020; statistics from summer 2015).

Asphalt Land Cover

- Each 1% increase in asphalt land cover in a census block group was associated with a 0.31°F increase in land surface temperature.
- Asphalt land cover explained 25.0% of the variance in land surface temperature

High asphalt cover, high land surface temperature

Tract 8300, Block Group 2
Southern Scottsdale area
SE of McDowell Road and Hayden Road
42.0% Asphalt coverage
Metro Scottsdale average = 21.5%
126.8°F average LST
Metro Scottsdale average = 118.3°F

Low asphalt cover, low land surface temperature

Tract 6831, Block Group 1
Vicinity of Orange Tree Golf Course
SE of Cactus Road and 60th Street
10.3% Asphalt coverage
Metro Scottsdale average = 21.5%
114.1°F average LST
Metro Scottsdale average = 118.3°F

Figure 21. Representative cases demonstrating the relationship between asphalt land cover and land surface temperature (visible imagery from July 2020; statistics from summer 2015).

Building Land Cover

- Each 1% increase in building land cover in a census block group was associated with a 0.25°F **increase** in land surface temperature.
- Building land cover explained 10.7% of the variance in land surface temperature.

High building cover, high land surface temperature

Tract 7204, Block Group 2
Holiday Park area
SE of Osborn Road and 66th Street
33.4% Building coverage
Metro Scottsdale average = 22.3%
122.3°F average LST
Metro Scottsdale average = 118.3°F

Low building cover, low land surface temperature

Tract 6845, Block Group 1
Northeastern ‘corner’ of Loop 101 Highway
SE of Loop 101 and Hayden Road
10.8% Building coverage
Metro Scottsdale average = 22.3%
111.9°F average LST
Metro Scottsdale average = 118.3°F

Figure 22. Representative cases demonstrating the relationship between building land cover and land surface temperature (visible imagery from July 2020; statistics from summer 2015).

Income

- Several research studies published in the past two decades have demonstrated statistical relationships between income and land surface temperature; more recent studies have connected these patterns to legacy effects of historical land use and zoning practices. Contemporary attention to environmental justice and equity motivated the project team to add an additional model exploring the association between income and land surface temperature in Scottsdale.
- Each $10,000 increase in census block group average per capita income was associated with a 1.13°F **reduction** in land surface temperature. Census block group average per capita income ranges from $15,629 to $130,179 in Metro Scottsdale (Figure 24).
- Income explained 23.2% of the variance in land surface temperature.

High income, low land surface temperature

Tract 7300, Block Group 2
Arcadia area
SE of Camelback Road and 68th Street
$100,814 mean per capita income
Metro Scottsdale average = $54,575
106.9°F average LST
Metro Scottsdale average = 118.3°F

Low income, high land surface temperature

Tract 7600, Block Group 3
SE of Old Town Scottsdale
SE of Osborn Road and Scottsdale Road
$20,924 mean per capita income
Metro Scottsdale average = $54,575
124.6°F average LST
Metro Scottsdale average = 118.3°F

Figure 23. Representative cases demonstrating the relationship between income and land surface temperature (visible imagery from July 2020; statistics from summer 2015).

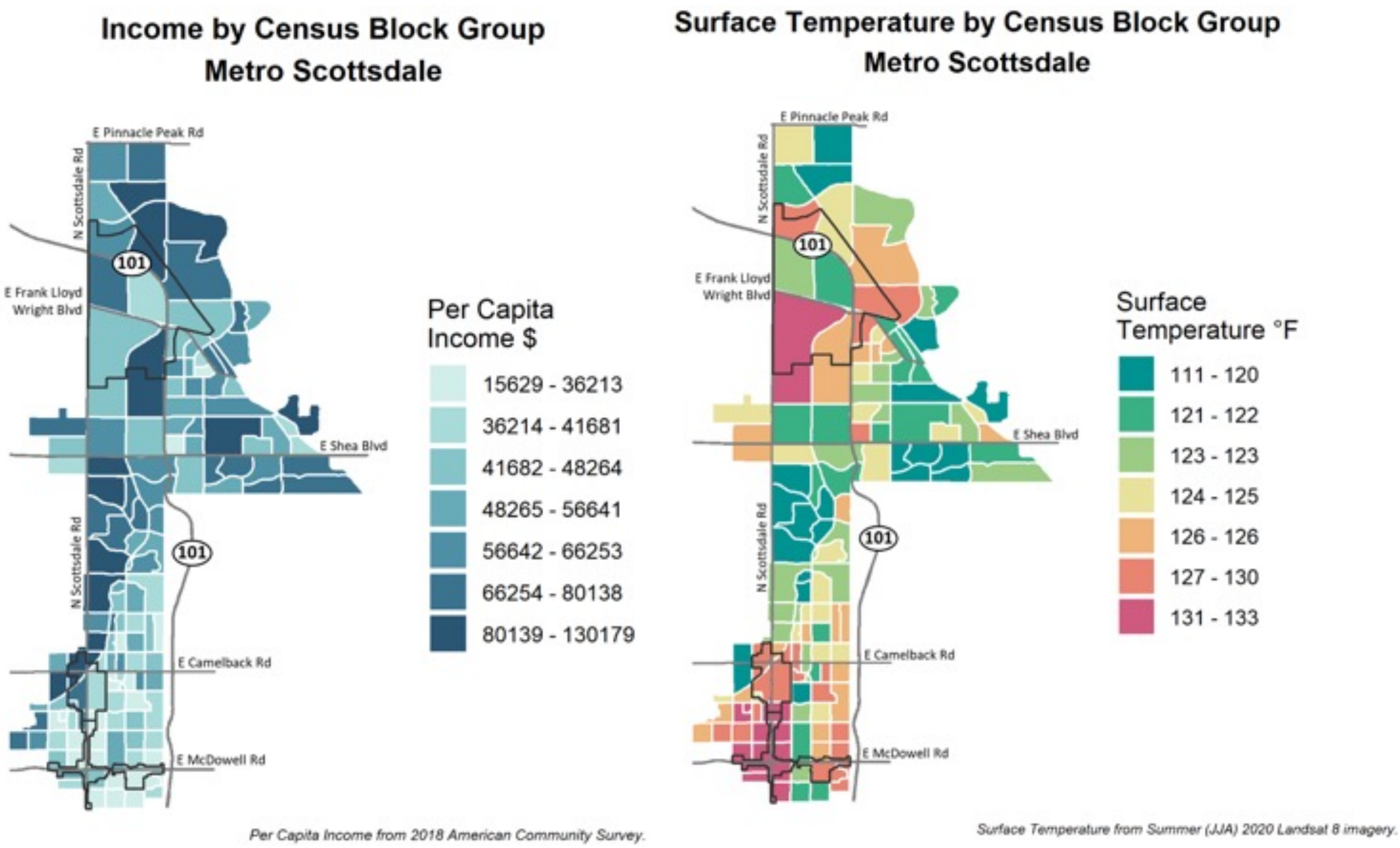


Figure 24. (left) Mean per capita income at the census block group scale for Metro Scottsdale, as reported in the 2018 American Community Survey. (right) Average summer 2020 land surface temperatures by census block group in Metro Scottsdale, as in Figure 15a.

Tree analysis

The number of trees in Metro Scottsdale was estimated from Light Detection And Ranging (LiDAR) data produced by the United States Geological Survey (USGS). The LiDAR data were collected in 2014 and include algorithmically-derived tree point data as part of the processed and value-added products.

According to LiDAR data, there were 299,905 trees in Metro Scottsdale as of 2014, with an average density of 3,736 trees per square mile. As seen in the land cover analysis, however, tree density varied considerably across the City, with the places with the most trees having more than three times the tree density of those with the fewest (Figure 25). Tree density was lower in the three growth areas than in the remainder of Metro Scottsdale, with approximately 2,400 trees per square mile in both the South Scottsdale and Airpark growth areas. Old Town had approximately 3,200 trees per square mile. For reference, tree and shrub land cover was estimated as 14% for Metro Scottsdale, 6% for South Scottsdale, 8% for Airpark, and 10% for old Town. Direct estimates of tree canopy coverage (excluding shrubs, accounting for varying tree crown diameters) are not directly available from either the LiDAR or land cover classification data. Across all of Metro Scottsdale, tree density was highest along the western border of the City near Arcadia and Paradise Valley, as well as through much of central Scottsdale along the Shea, Cactus, and Thunderbird corridors. Tree density was lowest in several census block groups in southern Scottsdale.

Average tree height in the City followed a different pattern than tree density, with maximum average tree heights in the McCormick Ranch area and along parts of Indian Bend Wash. Tree heights were lower in parts of southern Scottsdale, as well as through much of the northernmost extent of Metro Scottsdale.

Data package contents relevant to the tree analysis accessible on the City of Scottsdale website (scottsdaleaz.gov, search for “cooler Scottsdale”) include:

1. Tree point locations from 2014 LiDAR
2. Tree count, density, and height shape files and data tables for prioritized growth areas
3. Tree count, density, and height shape files and data tables for Metro Scottsdale census block groups
4. Tree count, density, and height shape file and data tables for all parcels within City boundaries

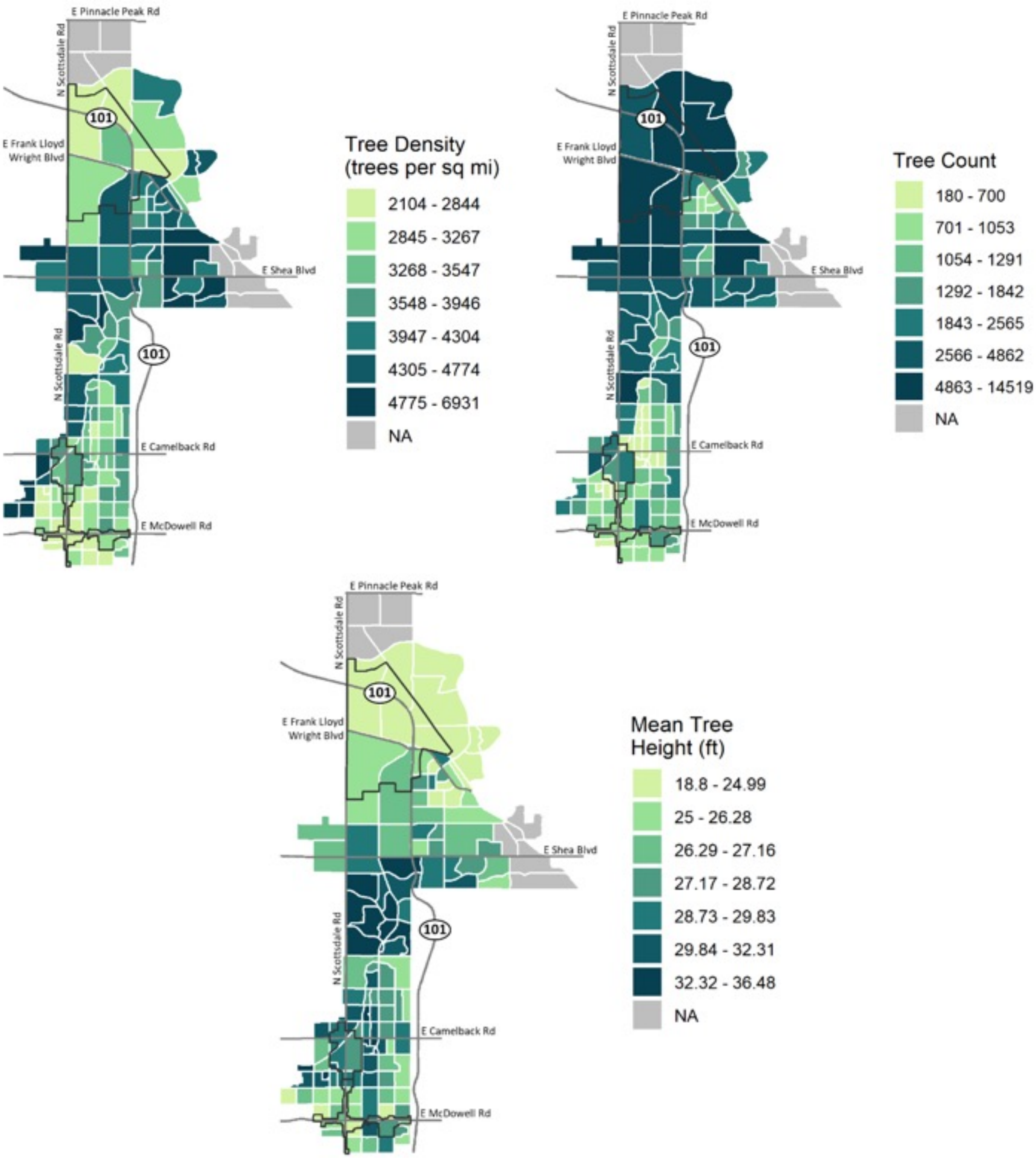


Figure 25. LiDAR-derived tree parameters for Metro Scottsdale at the census block group scale, including tree density (top-left), tree count (top-right), and tree height (bottom). LiDAR data were collected in 2014.

Detailed Microclimate Assessment for Four Sites

Introduction to methods and key metrics

Data were collected with a mobile human-biometeorological platform (MaRTy, Figure 26, Middel and Krayenhoff 2019) that measures the total environmental experience felt by a human in a small, localized environment (or microclimate). In addition to wind speed and humidity, the cart measures three important temperature parameters affecting a human's experience to heat:

Air Temperature (Tair): A measure of how hot or cold the air is. Air temperature changes minimally across an area compared to surface temperature and mean radiant temperatures. It drives building energy use for cooling/heating of buildings and is a key metric to define the UHI magnitude (difference between Tair in a city compared to Tair in the rural surroundings).

Mean Radiant Temperature (MRT): A measure of the total heat load on the human body due to the exposure to shortwave and longwave radiation from all directions (sky plus all horizontal and vertical surfaces) at a given time and location. This exposure includes the longwave radiation emitted from hot surfaces, such as an asphalt parking lot in the summer, and the shortwave radiation from the sun and reflected from surfaces in unshaded places. In the figure, the MRT is determined using the net radiometers in a 3D set up to gain radiation from all directions experienced by a human. The MRT can vary substantially across an area due to surface type and temperature (e.g., water, grass, dirt), building orientation and presence, and shade presence (more shade = lower MRT).

Surface Temperature: Quantifies the "touch" temperature of a surface, such as roads, benches, buildings, and roofs. It is important in areas where people or animals directly touch a hot surface without the protection of clothing. High surface temperatures result in a higher infrared (longwave) radiation from a surface, which

Figure 26: MaRTy biometeorological platform collecting data in Historic Old Town Scottsdale. The platform is mobile (moved by researchers) and microclimate information total environmental experience felt by a human in a small, localized environment. These values include air temperature, relative humidity, windspeed, surface temperature, and mean radiation temperature (MRT) via 3D net radiometers. The MRT is the most important factors affecting human thermal comfort in hot & dry climates and can vary dramatically (up to 40°F) across a small area.

we feel as heat, and thus it also impacts Tair above the surface. Surface temperature can vary substantially across and area due to surface type, color, shading, and time of day, as shown in infrared photos on subsequent pages. Some surfaces heat up and cool down faster than others (such as metal benches), while others heat slowly during the day and release their heat slowly at night (asphalt, brick), the latter being an important factor in the UHI effect.

MaRTy data were collected in four different parts of the City, illustrated on Figure 27. Results from the select MaRTy transects across four locations within the growth areas are presented on subsequent pages. Selected visible and thermal photos demonstrating lower (most comfortable) and higher (least comfortable) MRTs are provided, along with explanations of certain design features that are contributing to lower and higher MRTs.

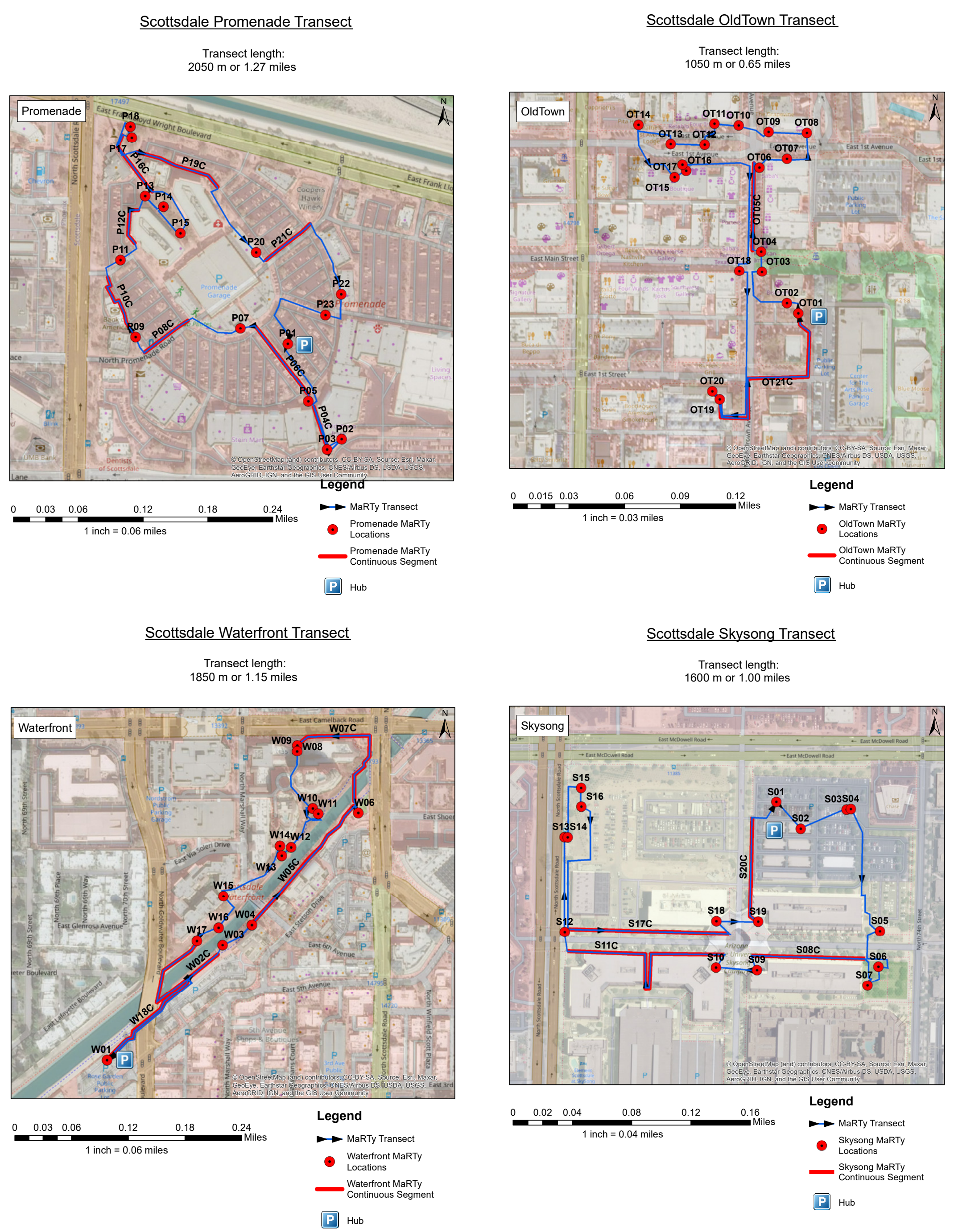


Figure 27: Maps of transects performed in four locations within Scottsdale growth areas. One-minute stops (indicated by red circles) were made at ~18–22 times/ location, selecting various design types, orientations, shading patterns, etc. for these stops. Transects occurred four times of day (8-9am, 12-1pm, 4-5pm, and 8-9pm) to represent times when people may be out in the late spring or early summer. Results include visual representations of surface temperature via on-site thermal photography.

Site Evaluation: Scottsdale Promenade

Site evaluation overview

The MaRTy transect at Scottsdale Promenade consisted of a 1.27 mile loop on the northwest corner of the property near the intersection of North Scottsdale Road and East Frank Lloyd Wright Boulevard. The transect followed a clockwise route around the main parking structure and included a mixture of open and landscaped parking lot areas, shaded storefront areas with awnings and covered walkways, and gathering places and plazas. Measurements were made at 15 different point locations and along 8 individual transects during which data were logged continuously. Of the 15 point locations, four were shaded (partially or fully) during the 8:30am measurement period, ten were shaded for the 12:30pm measurement period, and seven were shaded during the 4:30pm measurement period. There was an approximately 70°F range in mean radiant temperature between the hottest (~160°F) and coolest (~90°F) location at the Scottsdale Promenade during the 4:30pm measurement period, during which air temperatures at each location were approximately 95°F.

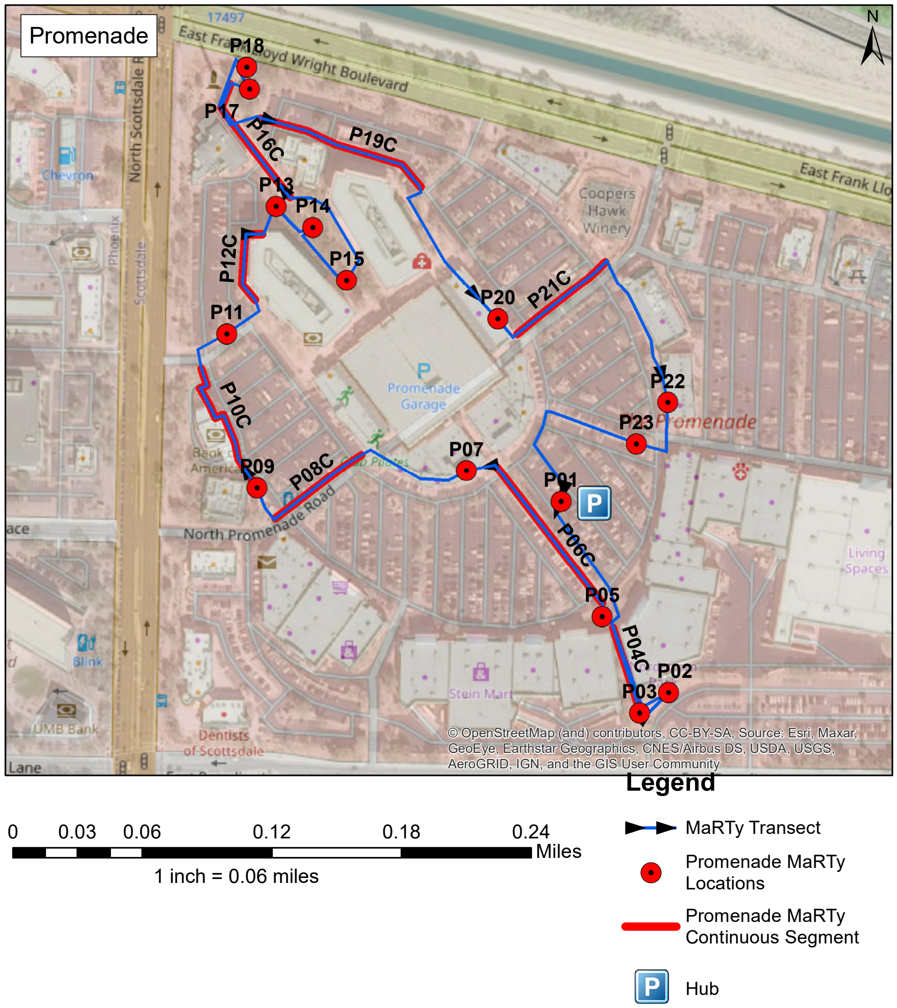


Figure 28: Transect map for Scottsdale Promenade (Greater Airpark Growth Area).

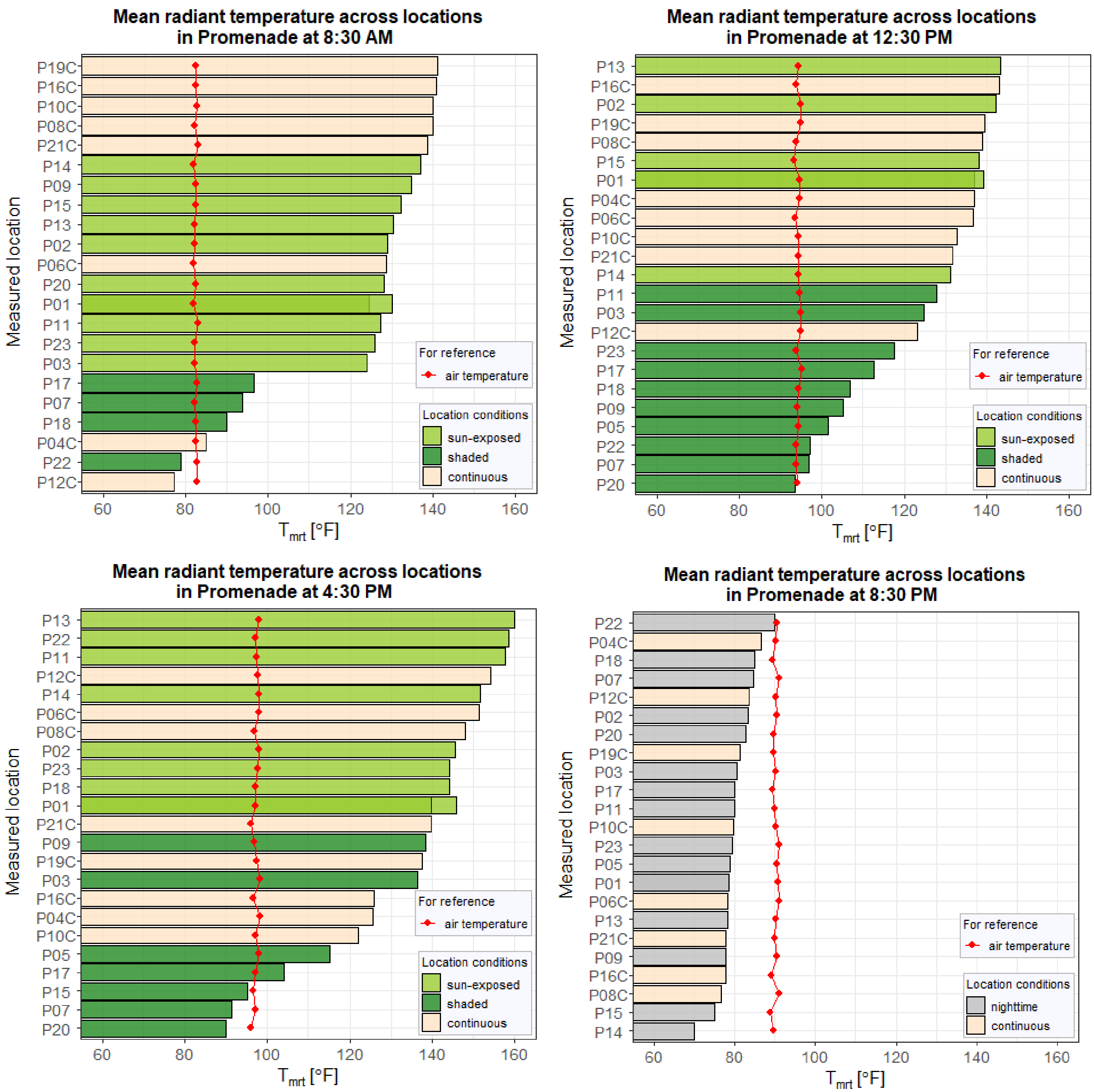


Figure 29. Scottsdale Promenade (Greater Airpark area) MRT Results. Variation in mean radiant temperature (colored bars) and air temperature (red line) across stops, indicated by numbers on left hand side. Sun-exposed stops during the daytime transects are shown in light green, with shaded stops in dark green. Continuous transects, where measurements were taken across a pedestrian path, are shown in yellow. Grey indicates nighttime conditions. As is the case across all locations, the MRT values varied significantly more than the air temperature. The most uncomfortable time of day at the Scottsdale Promenade was 4-5pm. Generally, the locations with the lowest MRT are those with full built shade (building overhangs) or shaded grass (P5 – also shown in thermal images below). The more uncomfortable areas with the highest MRT were open lots and the ride share stop (see thermal image below – P2). The Promenade features many desert trees that are not yet fully mature, which help provide small areas of shade, and will hopefully continue to enhance the shaded area in the future.

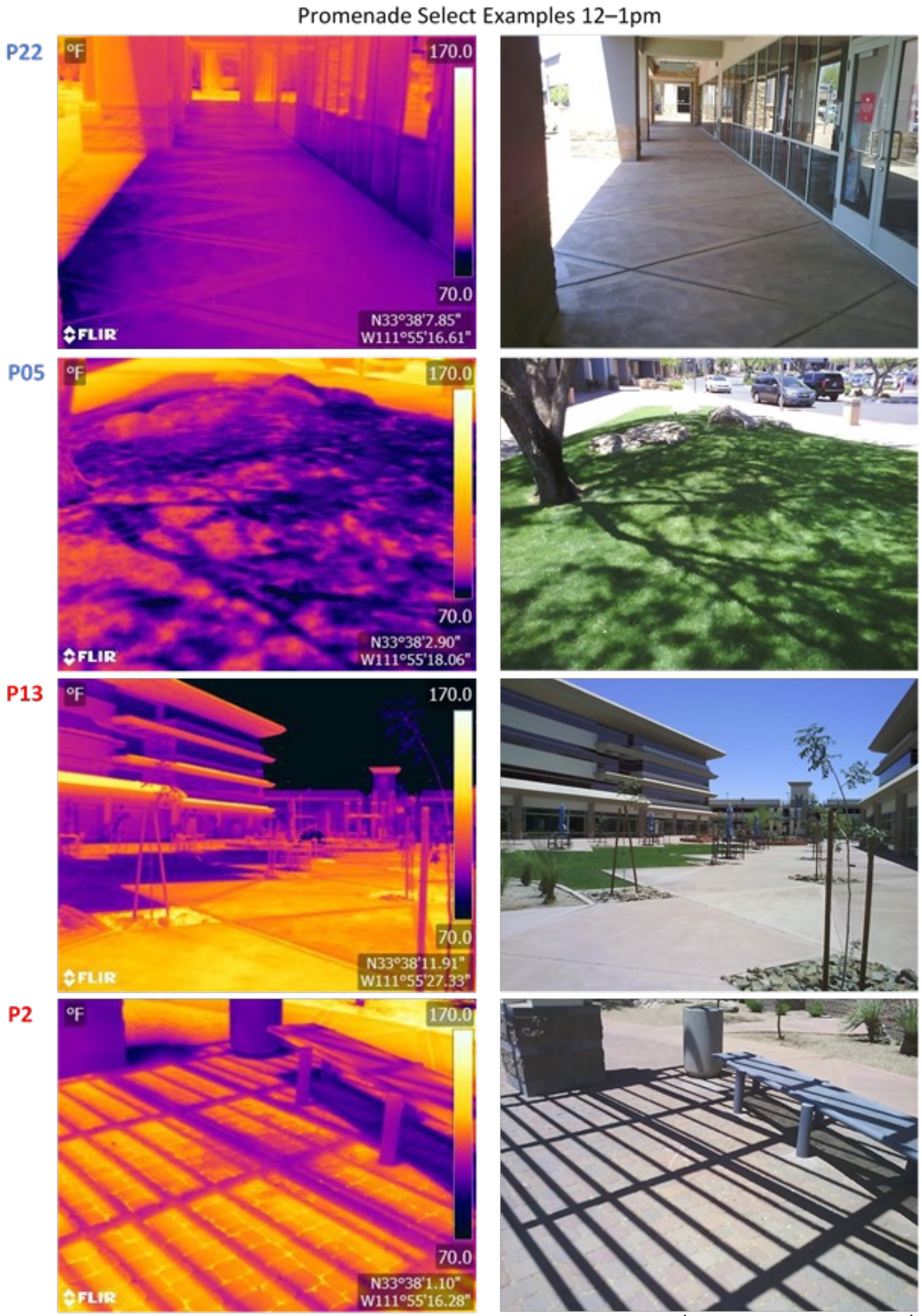


Figure 30. Thermal photographs from Scottsdale Promenade (Greater Airpark area).

Thermal comfort best practices

Wide overhang: Promenade stop P7 had the lowest average mean radiant temperature measurements across the three daytime measurement periods. Although the site is fully characterized by hardscape with a concrete ground surface and an immediately adjacent storefront, the wide overhang at this site provided shade at all sun angles. Site P20, which has similar design features but a north-east facing, had the lowest mean radiant temperature measurements during the two afternoon time periods.

Mature tree with irrigated grass: The combination of a mature mesquite tree and an irrigated grass landscape at site P5 also produced one of the most thermally comfortable environments at the Promenade, particularly during the two afternoon measurement periods.

Shade sail over seating area: Promenade stop P17 had consistently low mean radiant temperature measurements across the three daytime periods. The key design feature at this stop is a high-quality shade sail that covers a high fraction of a seating and gathering space with an artificial turf ground cover, even during different sun angles.

Wide roof on bus stop shade structure: The bus stop shade structure on the southeast corner of the intersection North Scottsdale Road and East Frank Lloyd Wright Boulevard (P18) produced some of the lowest mean radiant temperature observations during the morning and midday transects. However, the orientation of the structure presented shading challenges with a low sun to the west, which significantly elevated mean radiant temperature at this stop during the 4:30 transect.

Thermal comfort challenges

Sun-exposed hardscape: Promenade stop P13 was characterized by a wide area of sun-exposed concrete with recently planted trees that provided minimal shade. This location had the highest mean radiant temperature during both afternoon measurement periods, in part due to the reflective nature of the concrete surface. However, the more reflective surface and open exposure helped the location cool quickly at night, and it had among the lowest mean radiant temperatures during the evening transect.

Unshaded walking path: Several walking paths at Promenade, including transect P8c, had little to no shade cover and were thus among the locations with the highest mean radiant temperature observations during the daytime.

Metal overhang at rideshare stop: The metal overhang at the rideshare stop (Promenade stop P2) provides partial shade that did help keep ground temperatures lower than at fully sun-exposed locations. However, the partial shade did not reduce mean radiant temperature by a significant margin relative to fully sun-exposed locations.

Site Evaluation: Old Town

Site evaluation overview

The MaRTy transect in Old Town Scottsdale consisted of a 0.65 mile loop to the east of Scottsdale Road. The route covered approximately two blocks in the north-south direction along North Brown Avenue, and approximately one block in the east-west direction along East 1st Avenue. All measurements were made in commercial areas, including along streetscapes and at storefronts. Measurements were made at 19 different point locations and along 2 individual transects during which data were logged continuously. Of the 19 point locations, 12 were shaded during the 8:30am measurement period, 7 were shaded during the 12:30pm measurement period, and 10 were shaded during the 4:30pm measurement period. There was an approximately 60°F range in mean radiant temperature between the hottest (~155°F) and coolest (~95°F) location in Old Town during the 4:30pm measurement period, during which air temperatures at each location were in the vicinity of 95°F.

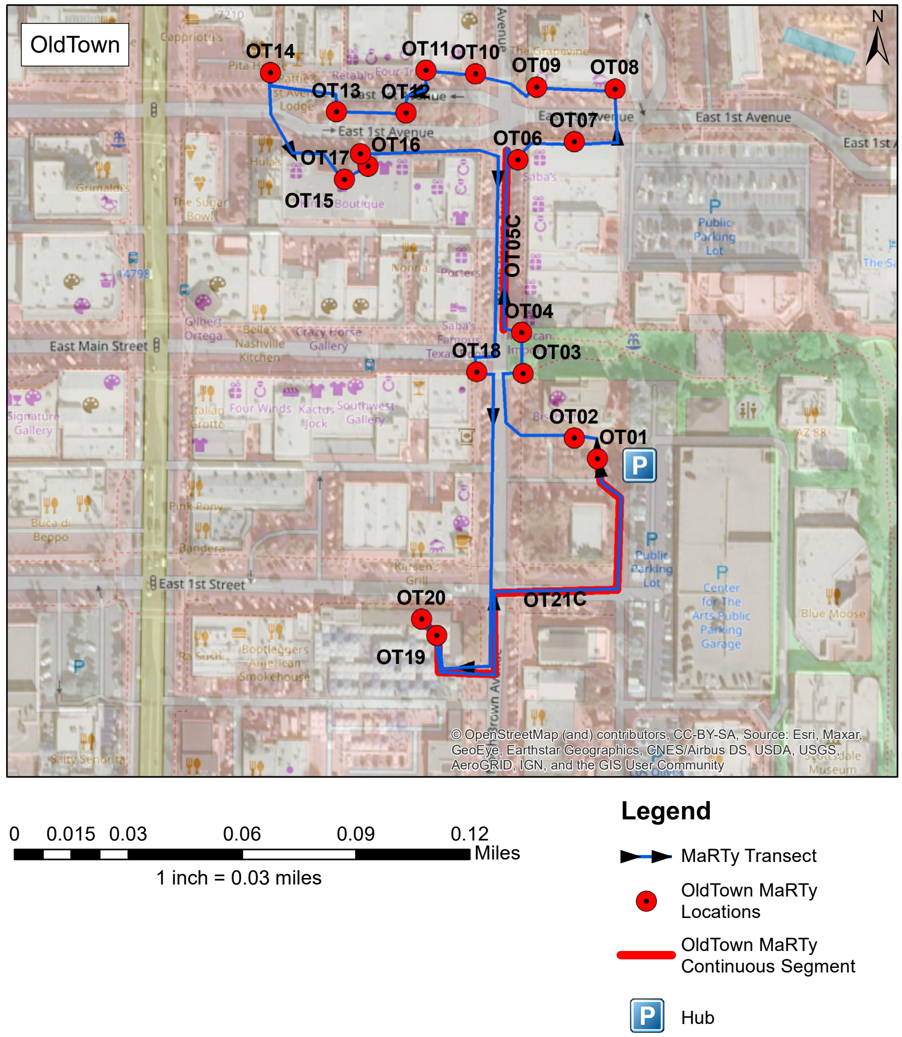


Figure 31: Transect map for Old Town Scottsdale (Old Town Growth Area).

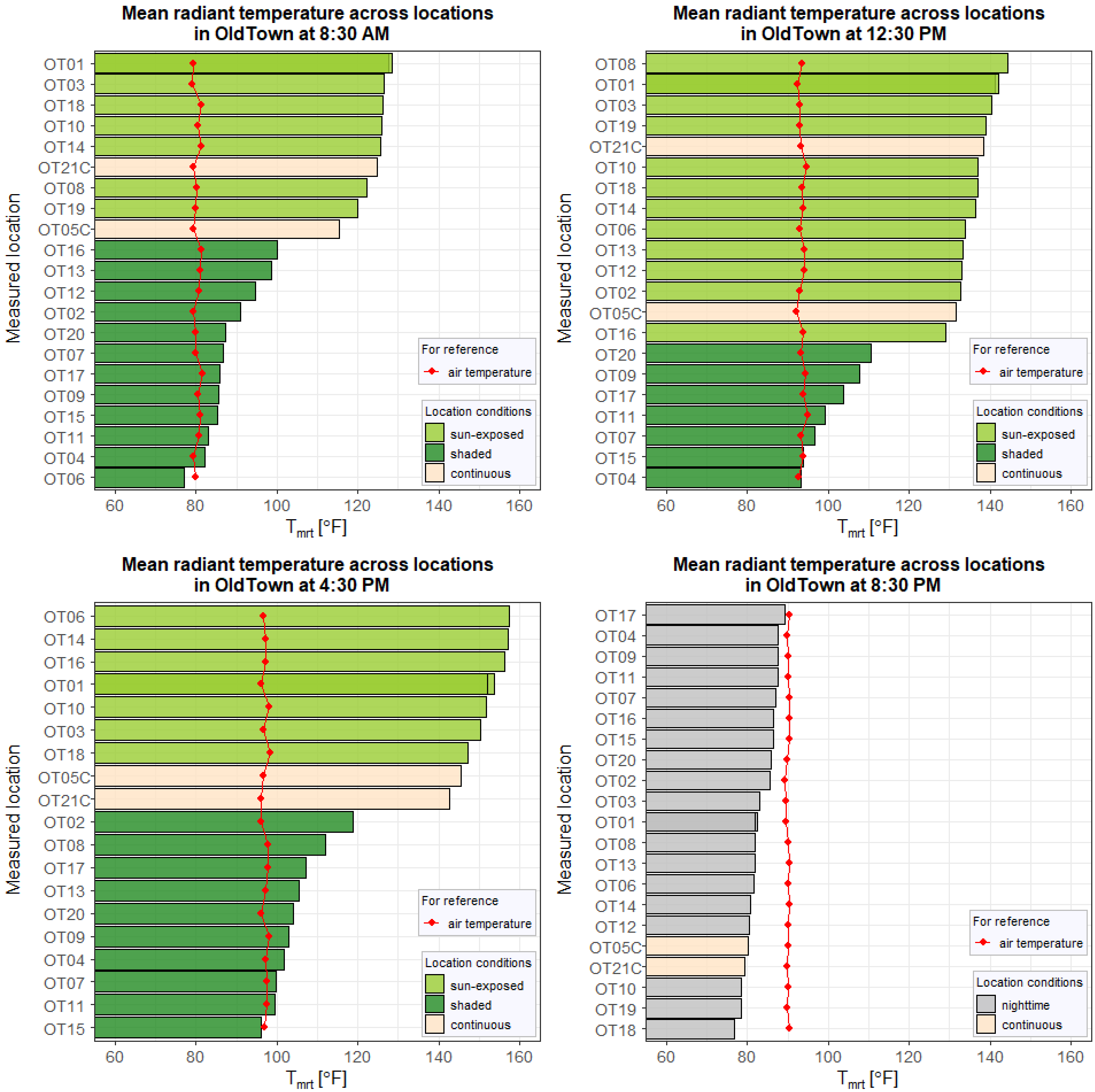


Figure 32: Old Town Growth Area: Old Town – MRT Results. Conventions in the figure are the same as in Figure 29.

Across all daytime transects in Old Town, shaded locations presented lower MRT values than sun-exposed conditions, with the most oppressive conditions at 4-5pm. The lowest MRTs in Old Town were generally found under full building overhang shade (OT7 (below), OT11, OT15, and OT9) as well as the large Banyan tree (OT4 below). Many of the overhangs along these streets provide shade for most of the day. The least comfortable locations were open asphalt or concrete lots, such as a parking lot beside an outdoor eatery (OT14 below).

Figure 33. Thermal photographs from Old Town.

Thermal comfort best practices

Mature trees: The lowest mean radiant temperature observed in Old Town during the 12:30pm transect was under the area's notable Banyan tree at the intersection of Brown Avenue and Main Street. This location also had the lowest average mean radiant temperatures across all daytime measurement periods. Native, drought-tolerant, and low water-use trees evident in Old Town also provided significant reductions in mean radiant temperature compared to fully sun-exposed locations, although they provided less shading than the Banyan tree or engineered overhangs. (Note: the Banyan tree shown here does not appear on recommended species lists from the Arizona Department of Water Resources or Maricopa County Department of Air Quality).

Overhangs and covered walkways: A defining feature of Old Town Scottsdale is the area's abundant covered walkways and overhangs that create shade for pedestrians. Mean radiant temperatures measured under these structures were among the lowest measured in Old Town. In particular, the overhangs at Old Town site OT11 and OT15 had the lowest mean radiant temperature measurements during the 4:30pm transect, and site OT15 had equally low mean radiant temperatures to those observed under the Banyan tree across all daytime measurement periods.

Thermal comfort challenges

Sun-exposed hardscapes: Areas with concrete, brick, or asphalt ground cover with no shade had the highest mean radiant temperatures observed in Old Town. In the afternoon transect, two of the locations with mean radiant temperatures equal to or exceeding those measured in an open parking lot were near storefronts (stops OT10 and OT14), including near an open-air seating area. The high mean radiant temperature observed near the small landscaping feature at site OT10 indicates that this particular configuration of vegetation, and species selection, provides little benefit to pedestrian thermal comfort (although it is likely considered aesthetically pleasing to many pedestrians, which can help create a more pleasant overall experience in the absence of thermal benefits). The highest mean radiant temperature observed during the 4:30pm transect was at stop OT6, which features two benches outside of a storefront. This location benefits from shade during the early morning hours; it had the lowest mean radiant temperature observed during the 8:30am transect. However, by midday the site becomes sun-exposed, and the direct sun exposure plus added heat from nearby radiating surfaces produces a particularly hot microclimate by late afternoon.

Reflective surface at pedestrian level: Reflective exterior building surfaces, including roofs and walls, can be advantageous from an energy conservation perspective, keeping summertime building energy demand lower. However, reflective surfaces can create challenges for pedestrians in urban environment. The light-colored vertical wall at Old Town stop OT8 was associated with the highest mean radiant temperature during the 12:30pm transect. The high mean radiant temperature at this location resulted from direct sun exposure, plus additional reflected solar radiation from the vertical surface. Given the available overhang in the immediate vicinity, it is unlikely that this location would be a pedestrian gathering point, but it is a useful illustration of the tradeoffs associated with reflective materials in the streetscape.

Site Evaluation: Waterfront

Site evaluation overview

The MaRTy transect at the Waterfront consisted of a 1.15 mile loop along the Arizona Canal between North Goldwater Boulevard and North Scottsdale Road. The transect largely flanked the canal, but included commercial and residential parcels, particularly along the north side of the canal and along East Camelback Road. Measurements were made at 14 different point locations and along 4 individual transects during which data were logged continuously. Of the 14 point locations, six were shaded (partially or fully) during the 8:30am measurement period, five were shaded for the 12:30pm measurement period, and eight were shaded during the 4:30pm measurement period. There was an approximately 70°F range in mean radiant temperature between the hottest (~155°F) and coolest (~85°F) location at the Waterfront during the 4:30pm measurement period, during which air temperatures at each location were in the vicinity of 95°F.

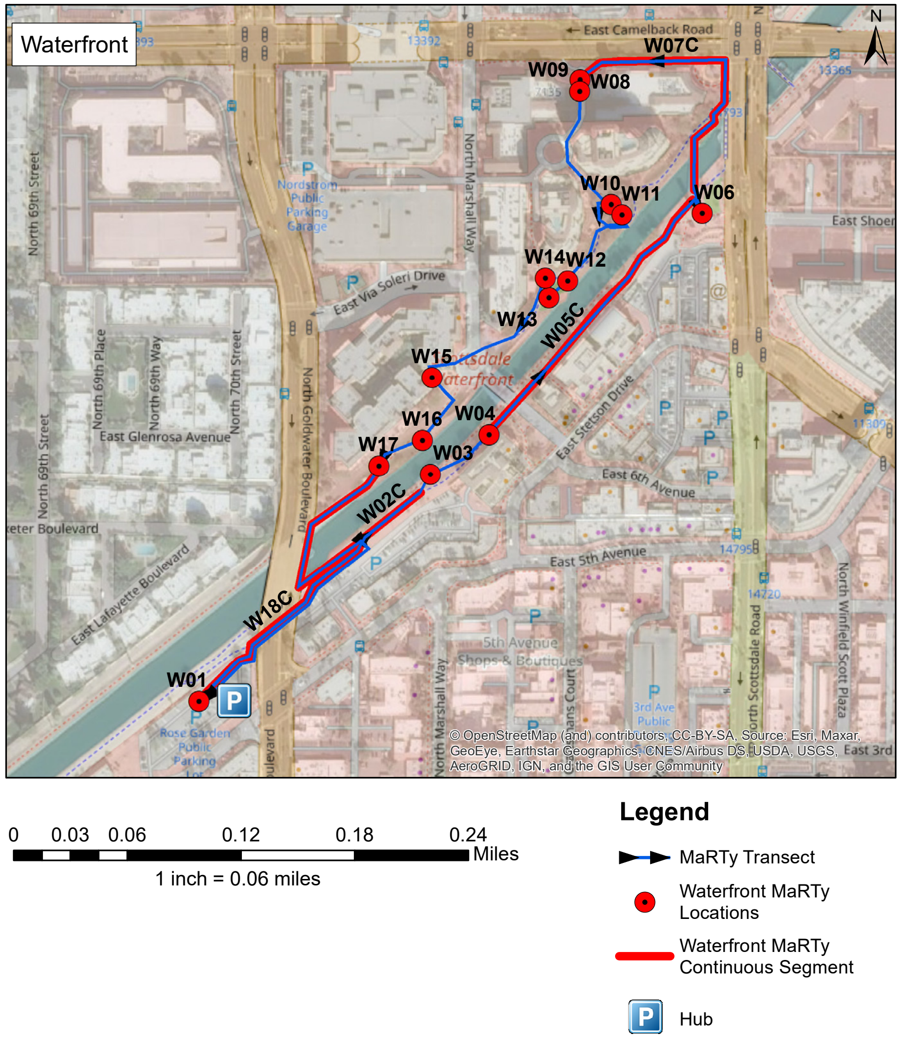


Figure 34: Transect map for Waterfront (Old Town Growth Area).

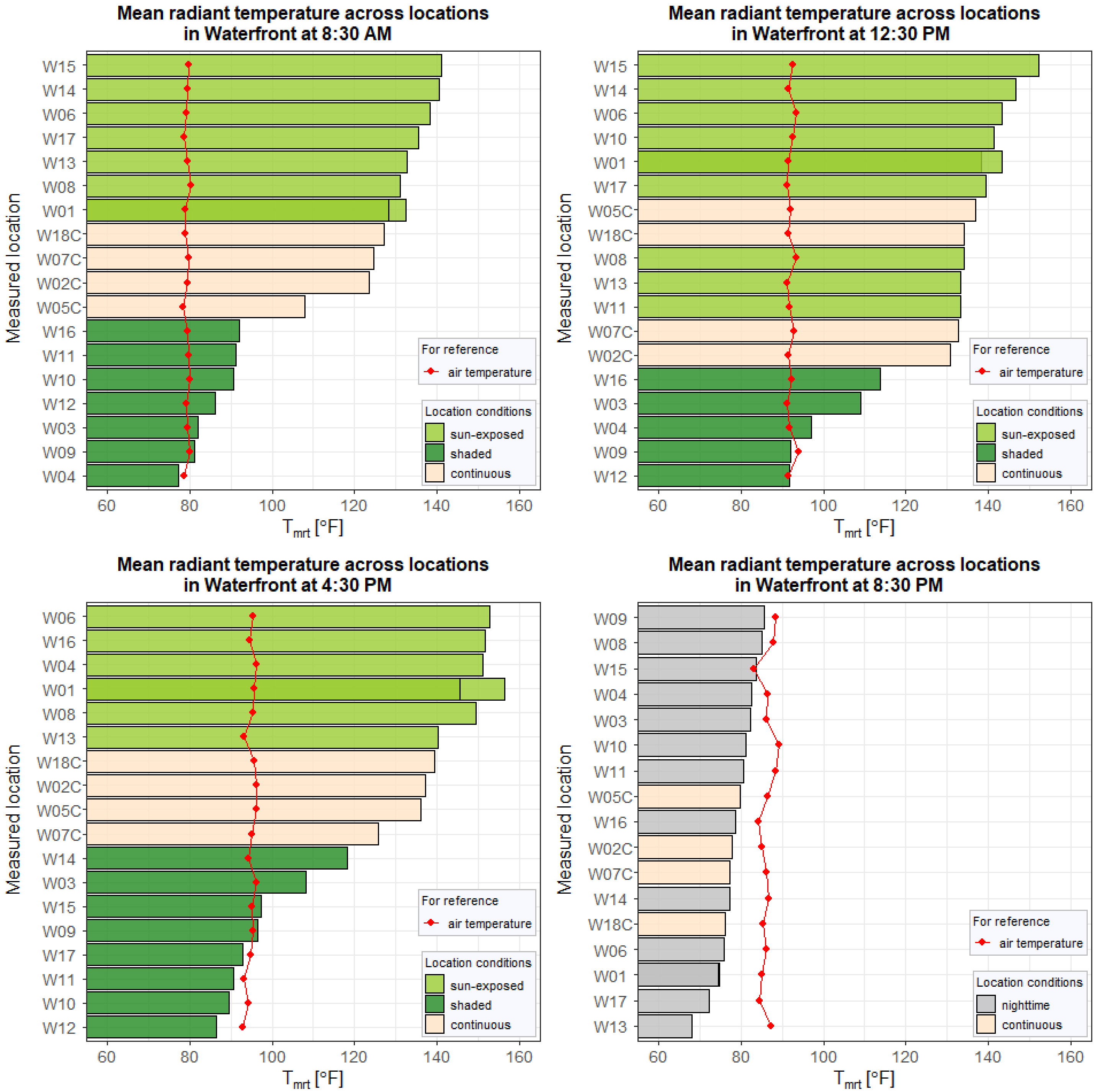


Figure 35: Old Town Growth Area: Waterfront – MRT Results. Conventions in the figure are the same as in Figure 29.

General observations from the Waterfront transect find the hottest location and surface temperature over a brick area with artificial turf (W15). The Waterfront provides a wide mixture of shade types, with trees (both desert-adapted and non) providing some of the lowest shaded MRT locations (W4 W12, W16). Open areas, particularly where people may want to sit or play (e.g., W14, and W17) could be prime candidates for shade midday, yet were shaded by 5pm.

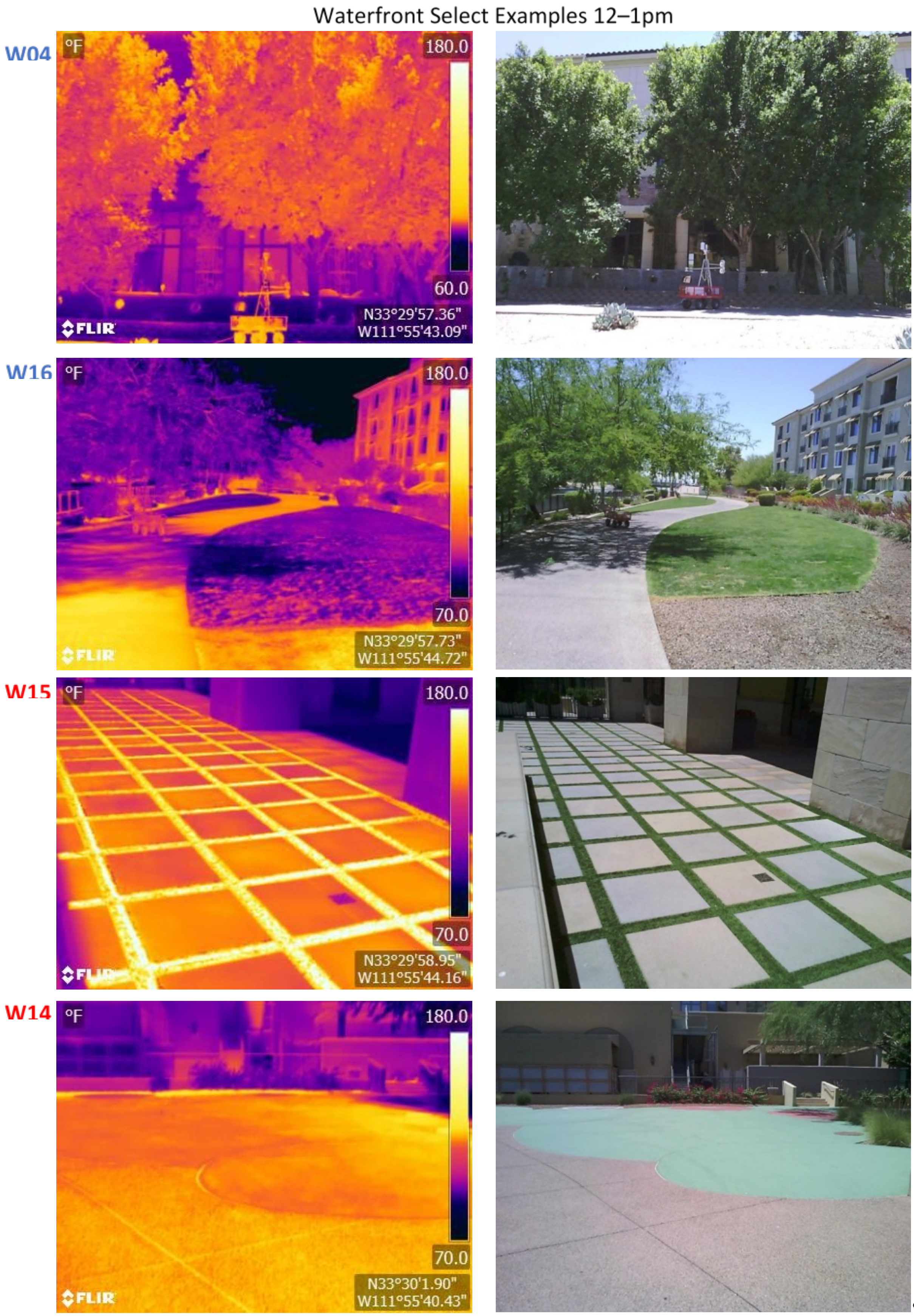


Figure 36. Thermal photographs from Waterfront.

Thermal comfort best practices

Dense tree shade: The Waterfront site with the lowest mean radiant temperature measurements during both afternoon transects was W12, which was characterized by a dense stand of palm trees and a grass sitting area. The close proximity of the palm trees to each other created a reasonably-sized shaded area, and the abundance of nearby vegetation and water limited opportunities for hot surfaces to adversely impact the human energy balance. Stop W11 had a generally similar landscape and mean radiant temperature, but measurements were made over a concrete surface instead of grass. The concrete in this location was shaded by a dense tree canopy, comprised of a mixture of mesquite and palm trees, during most of our measurement periods.

Shade structures and pedestrian underpasses: The shade structure along the canal at stop W3 and the pedestrian and vehicle underpass in the commercial shops along Camelback Road produced consistently low mean radiant temperature during the daytime measurement periods. Thermal comfort at the shade structure was also enhanced by surrounding trees and the canal, whereas thermal comfort at the underpass was aided by shade from surrounding buildings during certain sun angles.

Thermal comfort challenges

Sun-exposed hardscapes: The most common characteristic of locations at the Waterfront with the highest mean radiant temperature was a hardscaped surface with little to no shade. Multiple locations along the Waterfront path had higher mean radiant temperatures than those observed in the open asphalt parking lot at the start of the transect. These locations included site W6 with exposed concrete near the Soleri bridge, which had the highest mean radiant temperature during the 4:30pm transect and the highest average across all daytime measurements. The green-painted surface on the north side of the canal at site W14 had the second-highest mean radiant temperature during the morning and midday transects when it was sun-exposed.

Artificial turf: The Waterfront location with the highest mean radiant temperature during the morning and midday transects was stop W15, which was characterized by a patterned stone/tile hardscape separated by artificial turf. Surface temperatures for the artificial turf at this location were measured at 180°F, which was more than 35°F above the surface temperature of the adjacent stone and 40°F that the surface temperature of nearby sun-exposed asphalt. This artificial turf had the single highest surface temperature measurement recorded during the entire project. Once this location became shaded during the later afternoon, it had relatively low mean radiant temperature, although it still retained heat into the evening hours and had one of the highest mean radiant temperatures observed at 8:30pm.

Site Evaluation: SkySong

Site evaluation overview

The MaRTy transect in SkySong consisted of a 1.0 mile loop on the east side of Scottsdale Road and to the south of McDowell Road. The route traversed different parts of the SkySong campus, including the exteriors of commercial buildings, walkways, parking lots, landscapes areas, outdoor gathering spaces, and a nearby transit stop. All measurements were made to the north of the main parking garages and residential portions of the SkySong property. Measurements were made at 15 different point locations and along 6 individual transects during which data were logged continuously. Of the 15 point locations, 10 were shaded during the 8:30am measurement period, 7 were shaded during the 12:30pm measurement period, and 9 were shaded during the 4:30pm measurement period. There was an approximately 60°F range in mean radiant temperature between the hottest (~150°F) and coolest (~90°F) location in SkySong during the 4:30pm measurement period, during which air temperatures at each location were in the vicinity of 90°F.

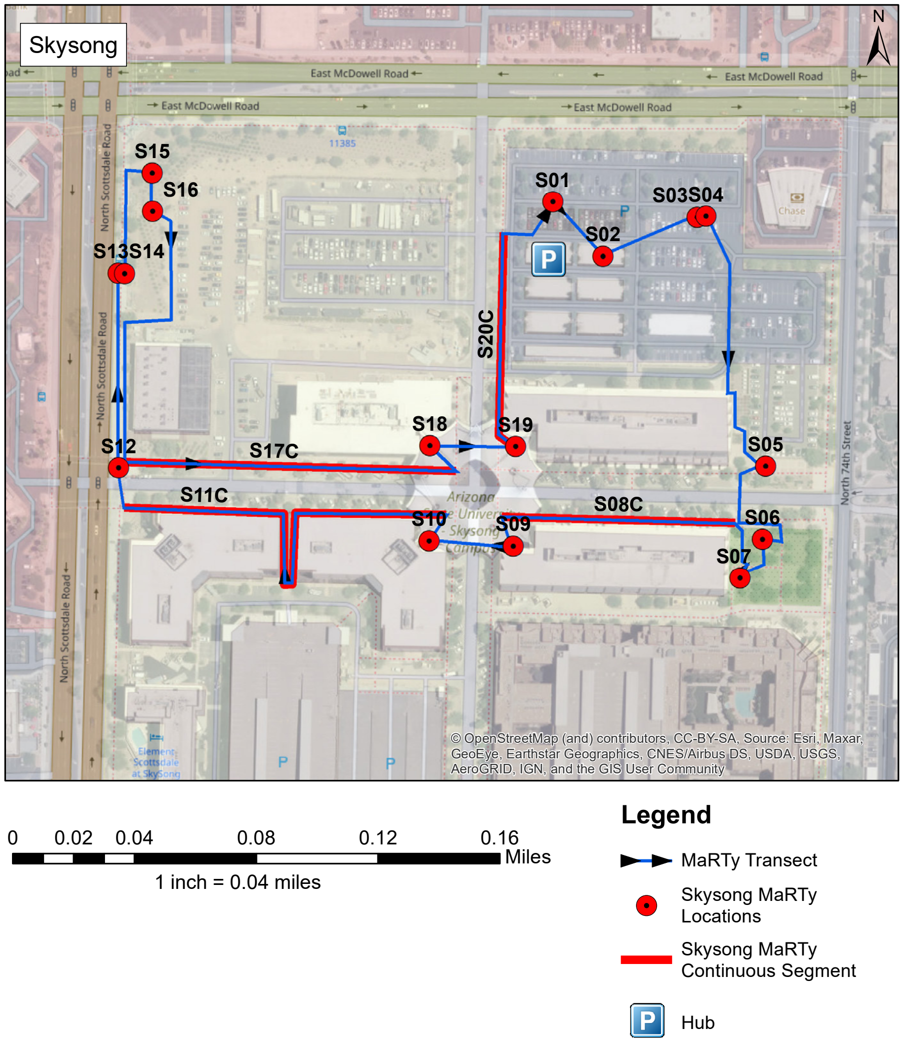


Figure 37: Transect map for SkySong (South Scottsdale Growth Area).

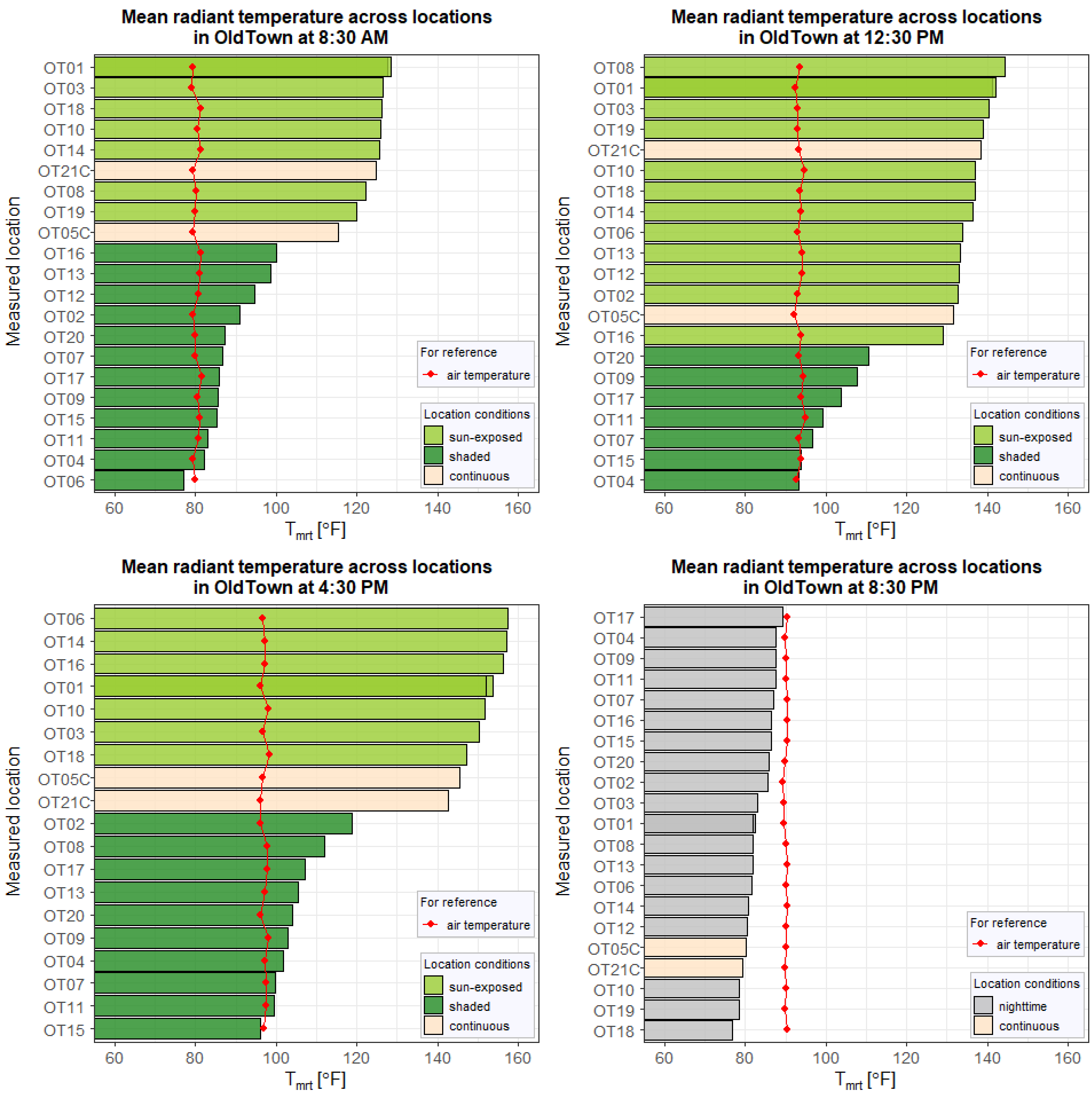


Figure 38: South Scottsdale, Skysong MRT results. Conventions in the figure are the same as in Figure 29. During midday and afternoon hours, all shaded locations at Skysong were more comfortable than sun-exposed. The highest MRTs at morning and noontime were found in areas purposed for human use, such as the bike rack (S5 below) and outdoor seating area (S6 below). Both locations would benefit from additional shade, as shown by S7 from a Palo Verde, which lowers the MRT dramatically. In addition to these locations, open asphalt and concrete locations (e.g., by stoplights) provided high MRTs. Some of the lowest MRTs were found at the bus stop on Scottsdale Road, in the desert landscaping beneath Palo Verdes (S15 below), as well as all stops under the white shade structure at the center. These areas provide comfortable locations for pedestrians and workers.

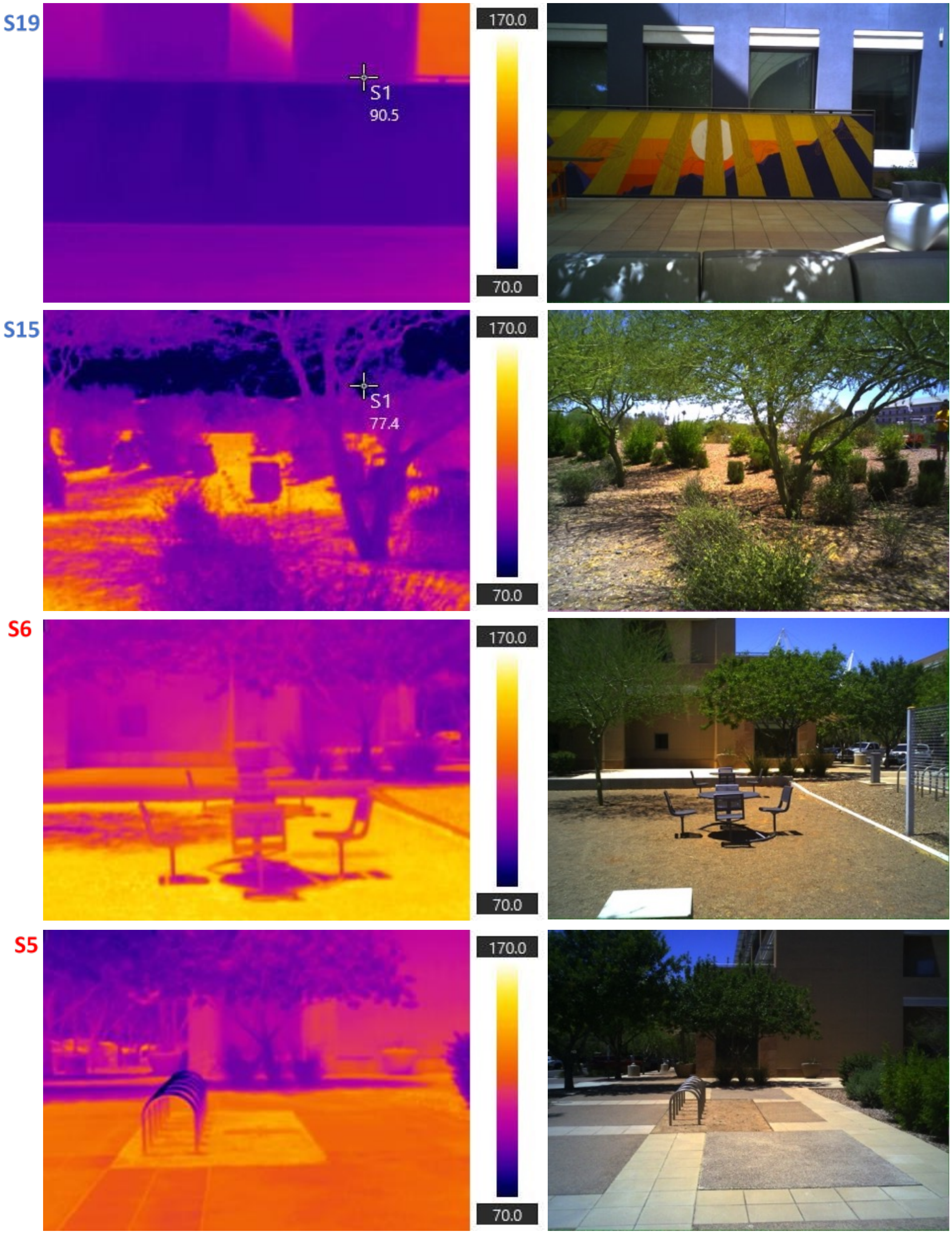
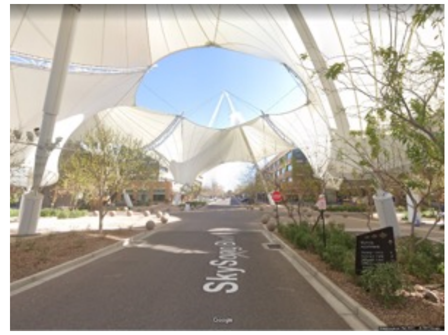


Figure 39. Thermal photographs from Skysong, select examples 12-1 p.m..

Thermal comfort best practices



Shade Structures: The large, white cable-and-membrane tensile shade structure that serves as the focal point of the SkySong complex created outdoor microclimates that were among those with the lowest mean radiant temperature on the property during all three daytime transects. The four specific measurement stops under the structure (S9, S10, S18, and S19) all consistently ranked among the six lowest with respect to mean radiant temperature during the 8:30am, 12:30pm, and 4:30pm transects. During the 4:30pm transects, two stops under the shade structure (S18 and S19) had mean radiant temperature observations below air temperature, suggesting that the shade structure also helped keep surrounding surfaces relatively cool compared to ambient air. The canopy over the parking lot on the northeast corner of the property (S2) led to similarly low mean radiant temperature during the morning and midday transects; mean radiant temperatures at 4:30pm under the parking lot shade structure were also relatively low but not as low as was observed under the tensile structure.

Multiple seating orientations at transit stop: The bus stop on the east side of Scottsdale Road adjacent to SkySong features seats on the east and west side of a vertical shade structure, with additional shade provided by a translucent overhang. During the transects with lower sun angles (8:30am and 4:30pm), mean radiant temperatures were vastly different between the sun-exposed and shaded sides of the structure. During the 4:30pm transect, for example, the mean radiant temperature on the west (sun-facing) side of the structure approached 150°F, the highest observed anywhere on the property. The mean radiant temperature on the east (shaded) side was approximately 40°F lower.

Thermal comfort challenges

Sun-exposed hardscapes: Locations with asphalt, concrete, and dirt/stone ground cover without overhead shade had the highest mean radiant temperatures observed in the SkySong area. During the morning and midday transects, the highest mean radiant temperatures were observed at the bicycle rack area to the east of SkySong building #1 (S5). While there is relatively mature vegetation nearby in preferred directions to intercept direct sunlight (south and southwest), it is not sufficiently tall or close enough to the bicycle racks to directly shade them. Shaded bicycle parking areas may help encourage active transportation by providing respite for cyclists at the beginning and end of their journey and by protecting equipment from damaging sun exposure. Other locations with some of the highest mean radiant temperature observations included the concrete pad for pedestrians at the northeast corner of the intersection of SkySong Boulevard and Scottsdale Road (S12), a location in the desert landscaping with small shrubs near the northwest corner of the property (S16), and the fully sun-exposed parking lot (S1).

Data package contents relevant to the mean radiant temperature analysis and thermal photography accessible on the City of Scottsdale website (scottsdaleaz.gov, search for “cooler Scottsdale”) include:

1. Shape files and data tables from 16 transects with the MaRTy biometeorological cart (four locations, four times of day)
2. Collection of thermal photographs taken during MaRTy transects

Airborne Thermal Photography

Thermal photographs of locations of interest in Scottsdale were captured from a helicopter flight on June 21, 2021. These images allow for assessment of landscape and built environment features that may alleviate or exacerbate urban heat and thermal comfort at a larger spatial scale, and across more sites, than is possible from ground-based analysis. On the images below, the color scale is held constant for all images during the same time period to facilitate cross-site comparison; the color scale varies between different measurement times to allow for sufficient contrast.

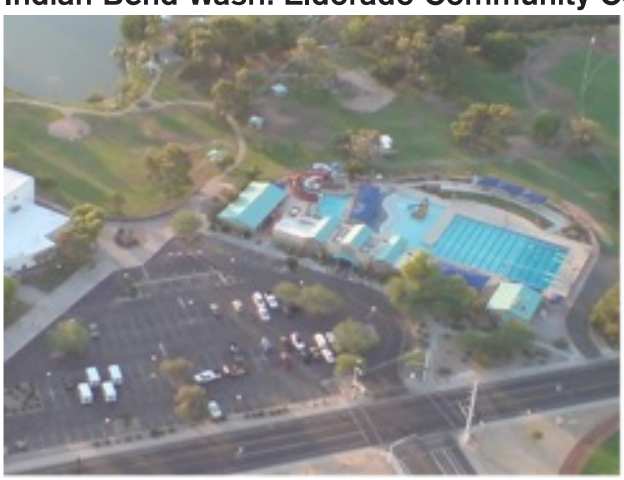
Helicopter imagery – Early morning flight (6:00am)

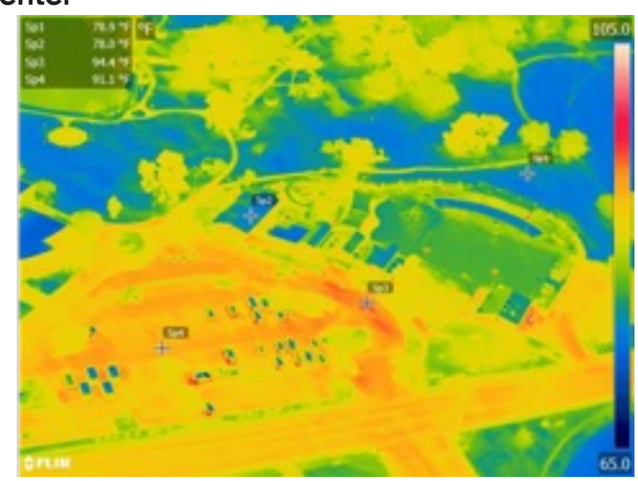
Air temperature at time of images: 89°F

Early morning provides the lowest surface and air temperatures of the day. Across the images, we see white roofs, grass or other vegetation, and water with the lowest surface temperatures (ranging ~65–85°F). Open dark parking lots and dark walkways (asphalt) produce the highest surface temperatures (range ~92–104°F) (e.g., Skysong & Promenade Parking) indicating that even after cooling all night, the surfaces have still retained heat into the early morning hours, and are thus starting at a higher temperature for the day compared to other surfaces. Lighter artificial surfaces (concrete, aged asphalt) are cooler than dark asphalt at this time of day.

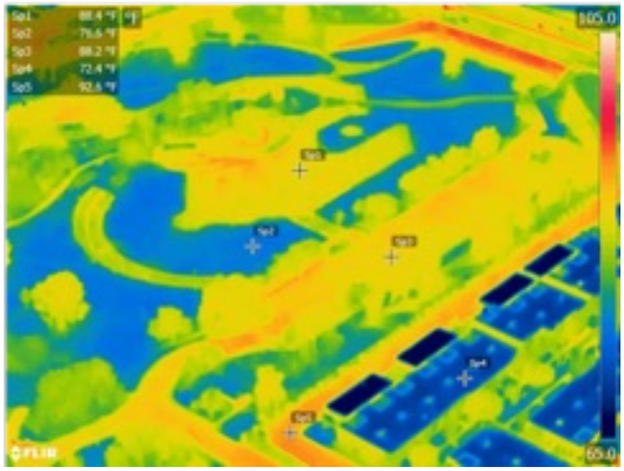
Note: The surface temperature range for all 6:00am images is 65–105°F; "Sp" in top left corresponds to select spot temperatures in the images; Tsfc under trees/shade not viewable; glass windows or aluminum surfaces will show lower than actual surface temperatures due to camera settings.

Indian Bend Wash: Eldorado Community Center

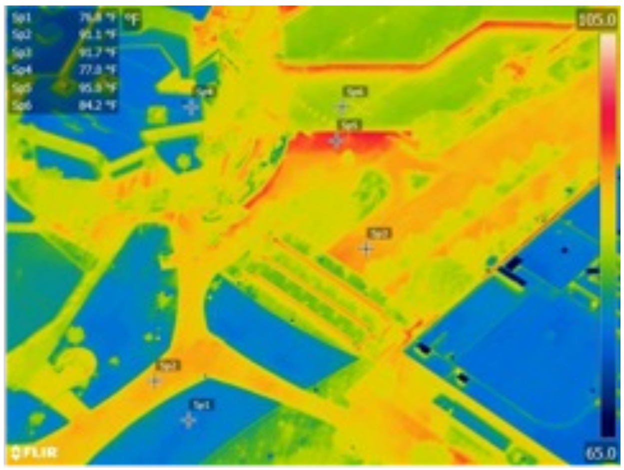




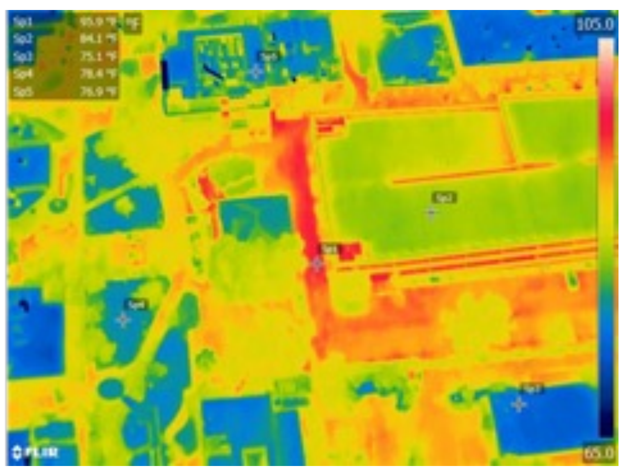
Indian Bend Wash: The Wedge Skate Park



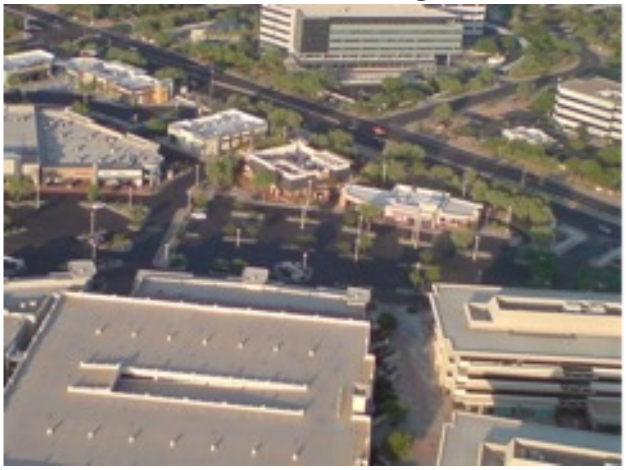
Old Town: Civic Center

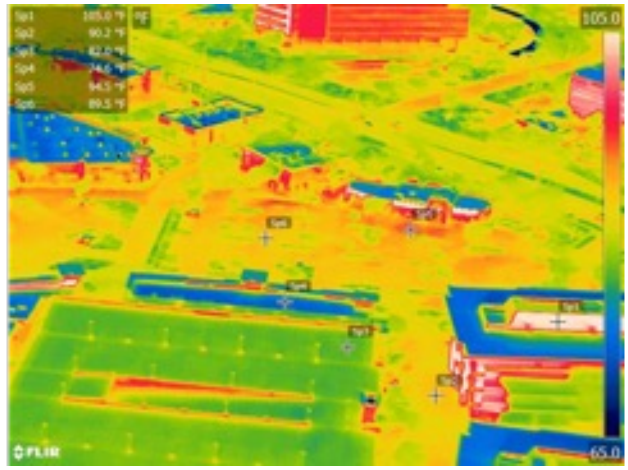


Old Town: Scottsdale Historical Museum

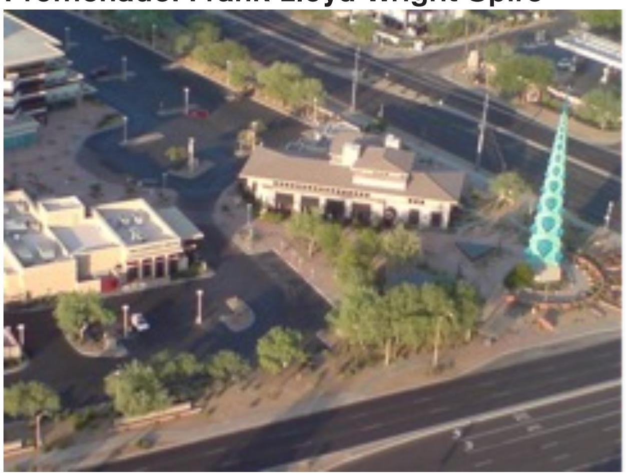


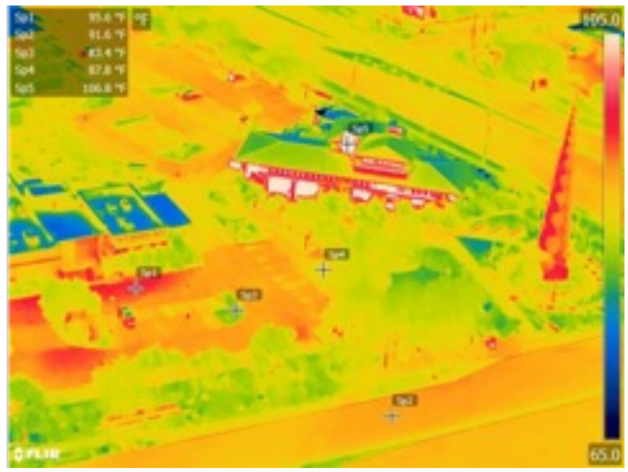
Promenade: Mall and Parking



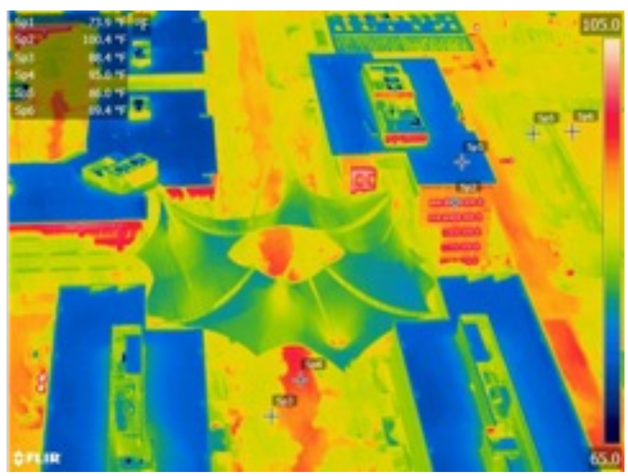


Promenade: Frank Lloyd Wright Spire

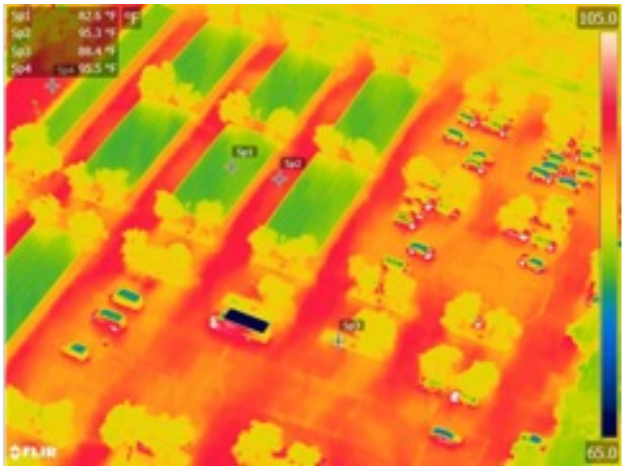




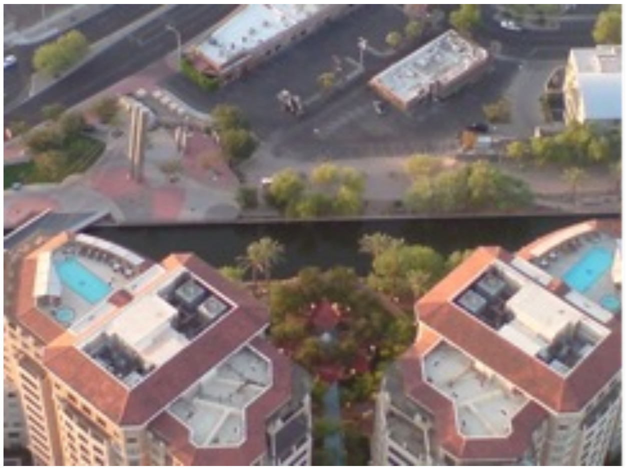
Skysong: Awning

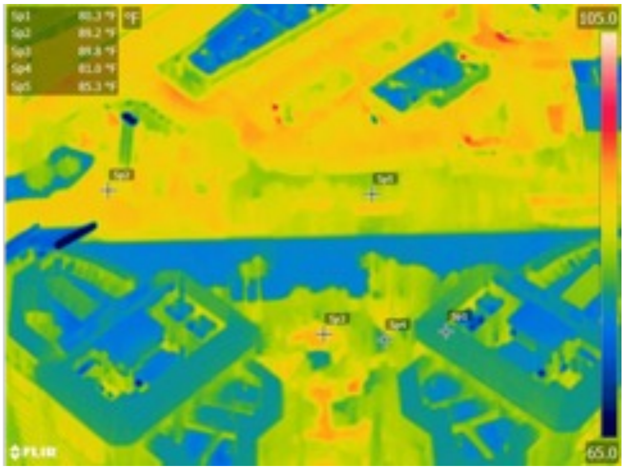


Skysong: Covered Parking

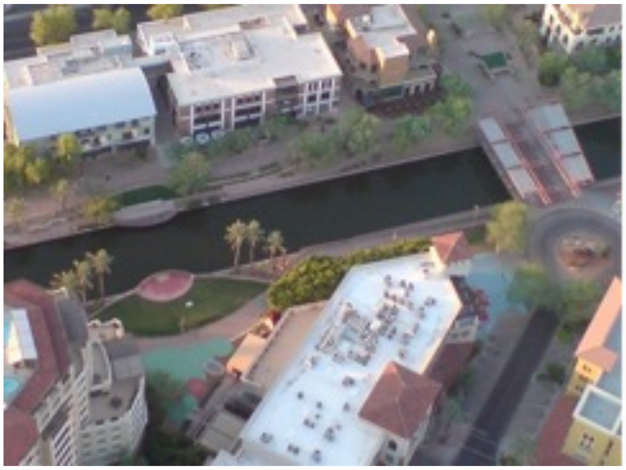


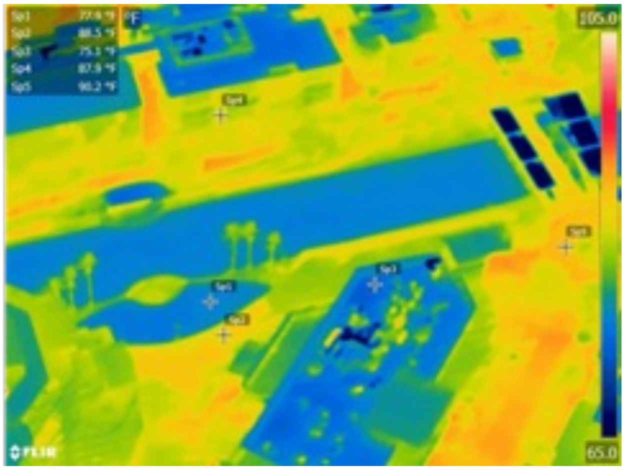
Waterfront: Mall and Canal





Waterfront: South Bridge





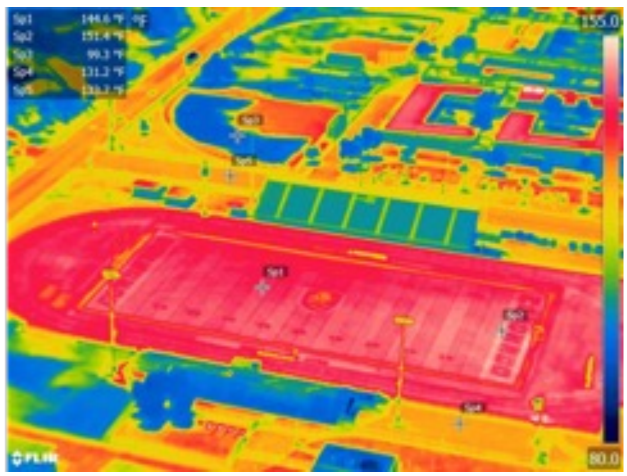
Helicopter imagery – Midday flight (noon)

Air temperature at time of images: 102°F

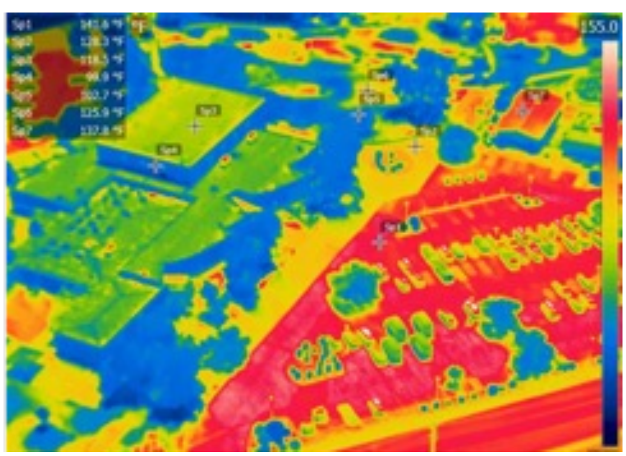
Mid-to-late afternoon often provides some of the highest surface temperatures, even though air temperatures have not yet hit their maximum. Here, the 12pm surface temperatures are shown to already reach as high as 152°F on unshaded artificial surfaces that tend to heat up very quickly, notably the Coronado High rubber track and artificial turf playing field (range 145–152°F). Other hot surfaces include unshaded dark parking lots (e.g., parking lots at Eldorado Community Center, Promenade, & Skysong), darker roofs (examples within Old Town & Coronado High roof). Notably, the two roofs displayed at the Waterfront South Bridge show 40°F difference in surface temperature due to a more reflective coating on the SE building ("Sp2" versus "Sp1"). Across the images, we see the highly reflective white roofs/awning, grass or vegetation, and water with the lowest temperatures (ranging ~ 80–102°F). Dirt (e.g., TPC Golf Course), stone, and lighter artificial surfaces (concrete, aged asphalt) show moderate surface temperatures. Finally, lighter walls facing north or west also remain cooler at this time of day (e.g., both buildings at the Waterfront South Bridge; select buildings at Promenade).

Note: The surface temperature range for all 12:00pm images is 80–155°F; "Sp" in top left corresponds to select spot temperatures in the images; Tsfc under trees/shade not viewable; glass windows or aluminum surfaces will show lower than actual surface temperatures due to camera settings.

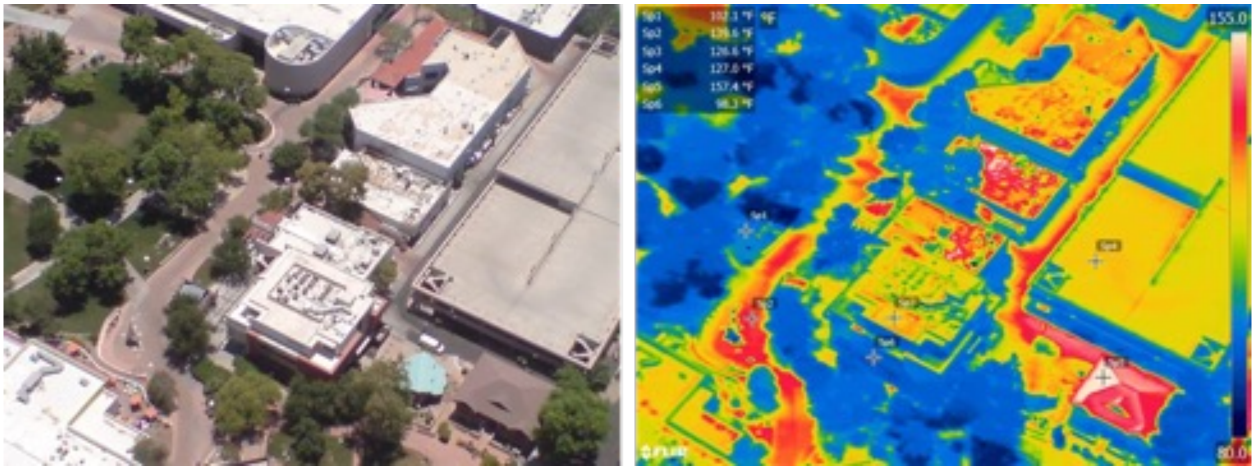
Indian Bend Wash: Coronado High School Football Field



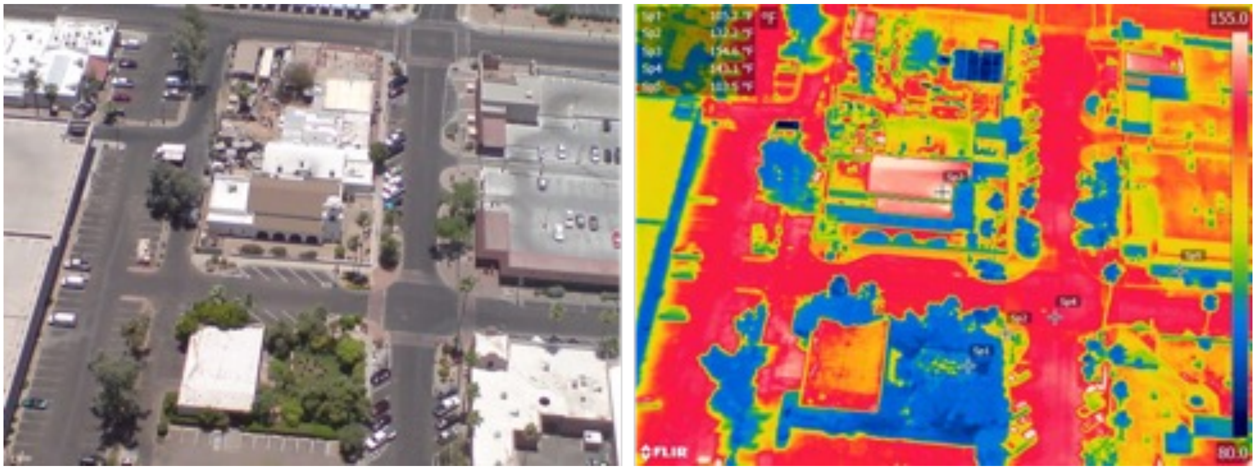
Indian Bend Wash: Eldorado Community Center



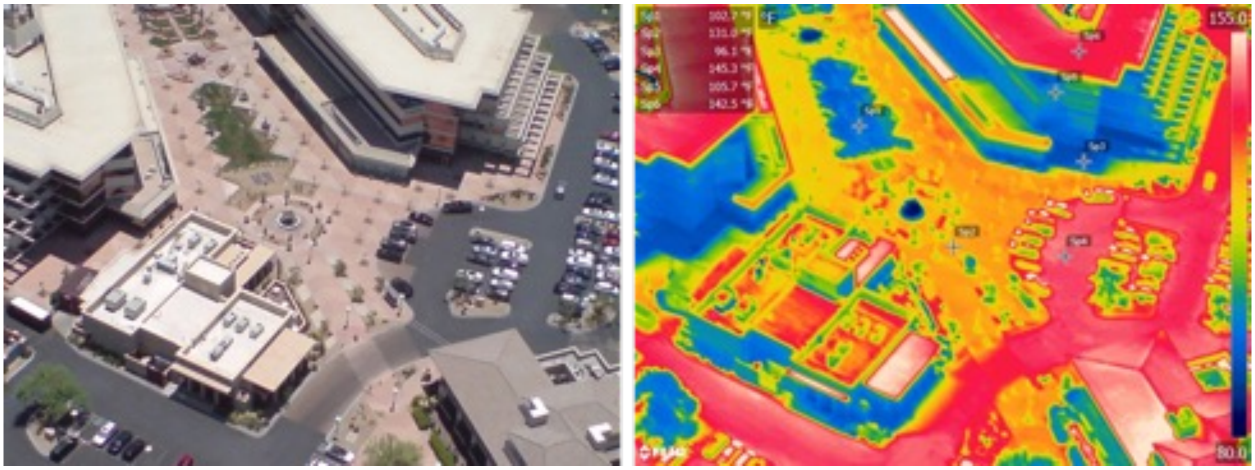
Old Town: Civic Center/Historical Museum



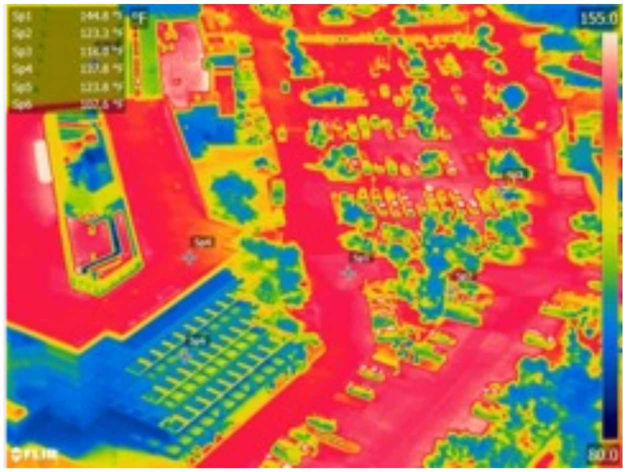
Old Town: The Mission



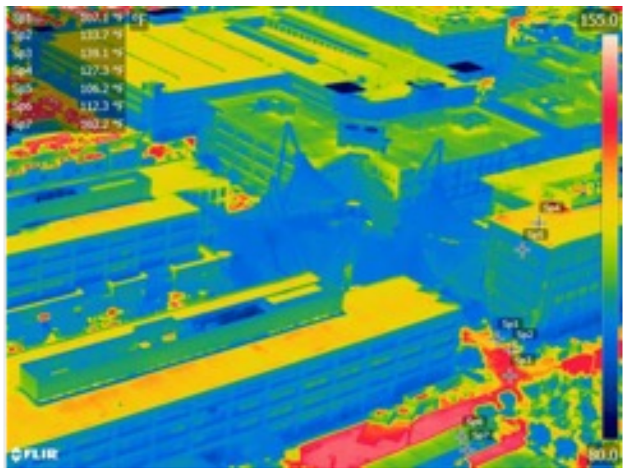
Promenade: Mall



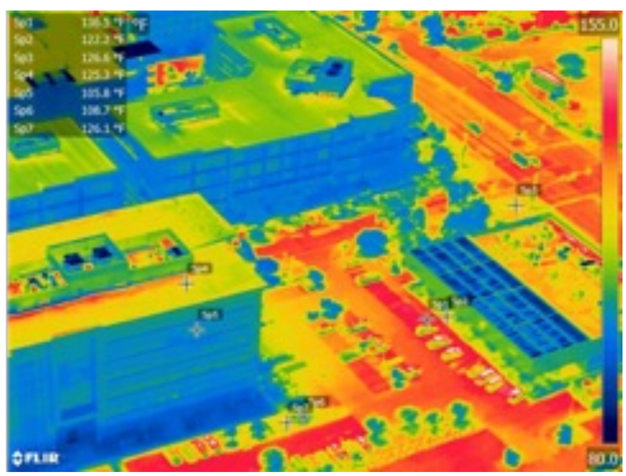
Promenade: Parking



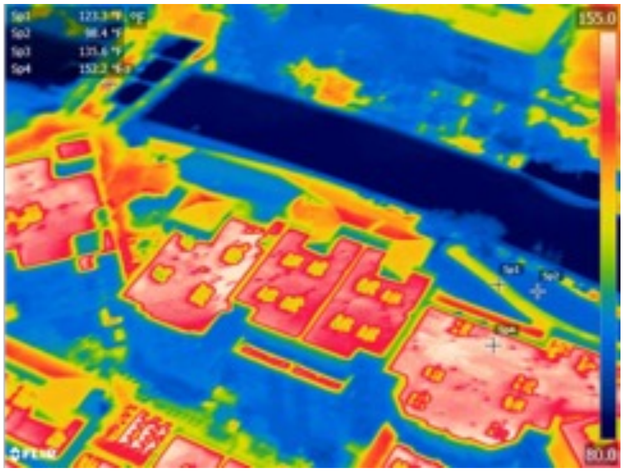
Skysong: Awning



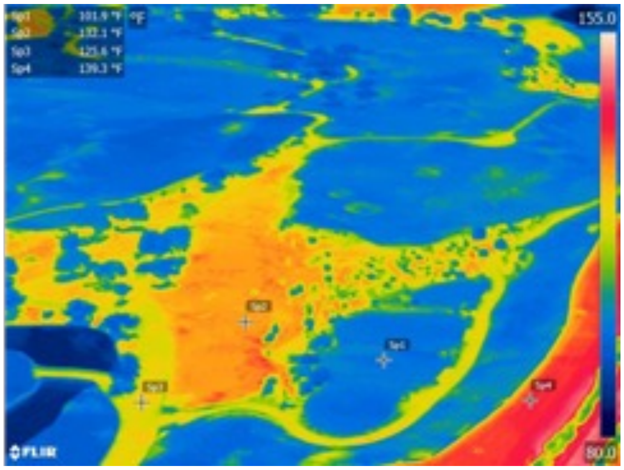
Skysong: Parking



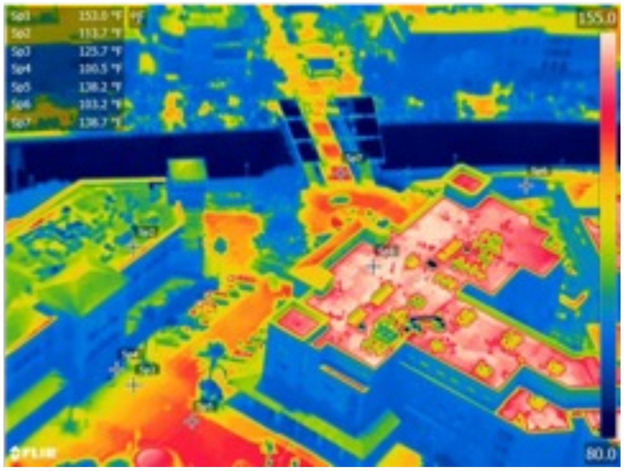
Waterfront: Apartments



TPC Golf Course



Waterfront: South Bridge



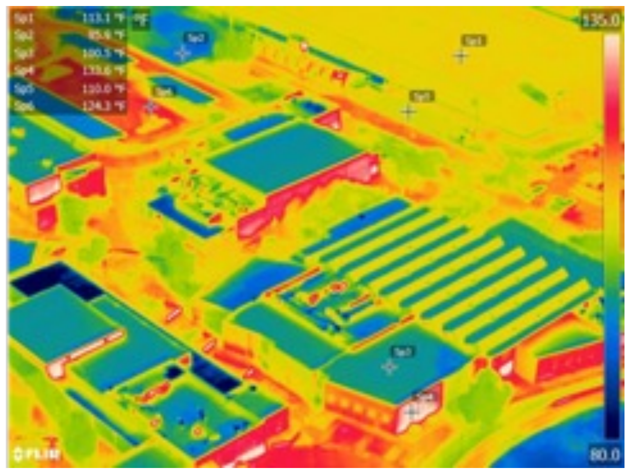
Helicopter imagery – Evening flight (6:00pm)

Air temperature at time of images: 106°F

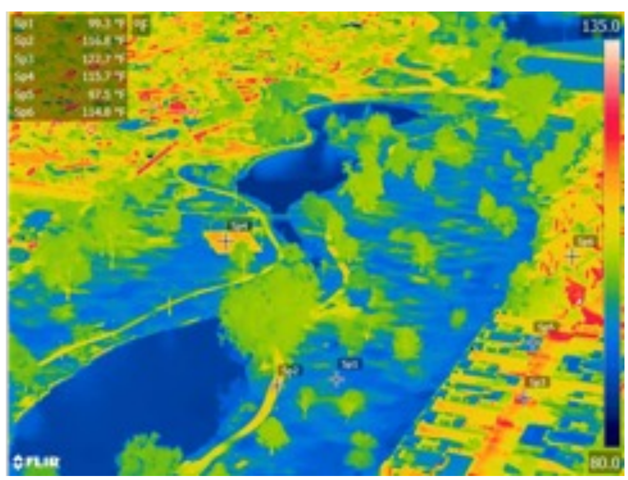
At this time of day, surfaces are no longer heating up as fast as in the day, with some cooling off depending on orientation and type. The 6:00pm surface temperatures are shown to reach as high as 135°F on unshaded dark asphalt that retains heat throughout the day, with the artificial turf and rubber surfaces at Coronado High cooling off quicker (now at 113°F compared to ~150°F at noon). The notable hot spots are similar to hot locations at 12pm (unshaded dark parking lots, e.g., Eldorado Community Center, Promenade, & Skysong). West and south facing building walls also show that they have warmed to ~135°F (e.g., Waterfront Apartments, select Promenade Buildings). Across the images, we see grass, vegetation, and water with the lowest temperatures, particularly in Indian Bend Wash and TPC Golf Course (healthy grass ranges from ~80–100°F), and trees around 100–110°F. Lighter roofs, dirt (e.g., TPC Golf Course), stone, and lighter artificial surfaces (concrete, aged asphalt) show moderate surface temperatures for this time of day (~105°F) .

Note: The surface temperature range for all 6:00pm images is 80–135°F; "Sp" in top left corresponds to select spot temperatures in the images; Tsfc under trees/shade not viewable; glass windows or aluminum surfaces will show lower than actual surface temperatures due to camera settings.

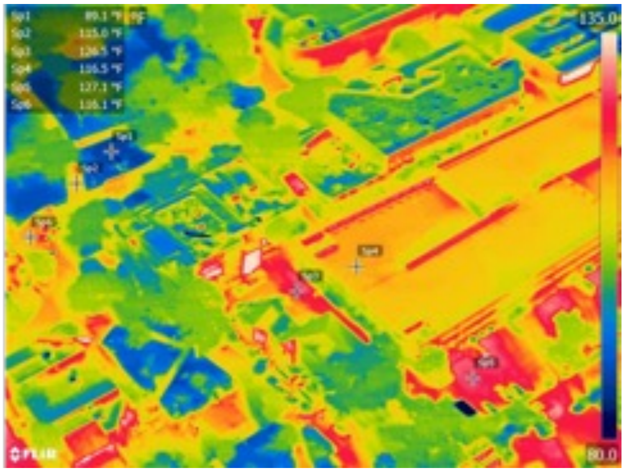
Indian Bend Wash: Coronado High School



Indian Bend Wash: Vista del Camino Park

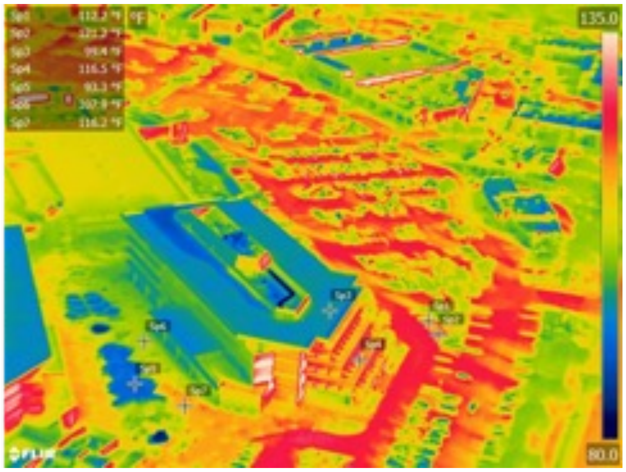


Old Town: Civic Center/Historical Museum



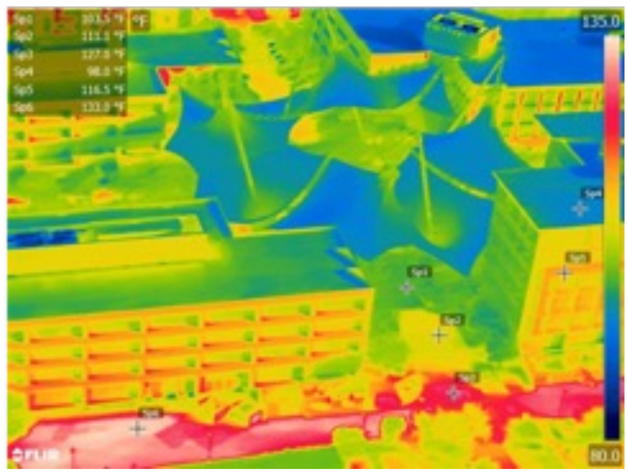
Old Town: The Mission

Promenade: Mall and Parking

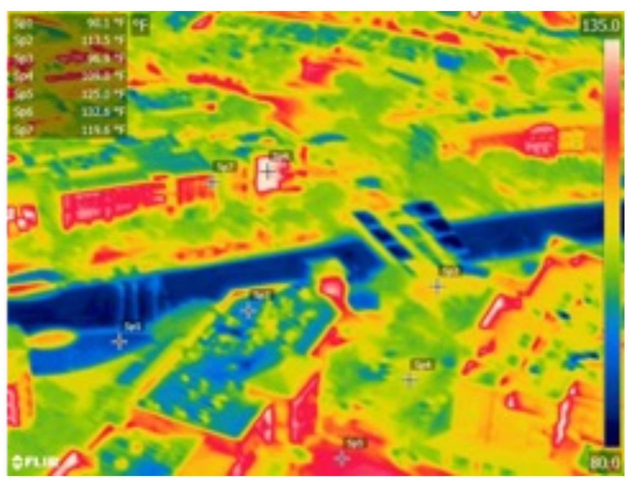


Skysong: Parking

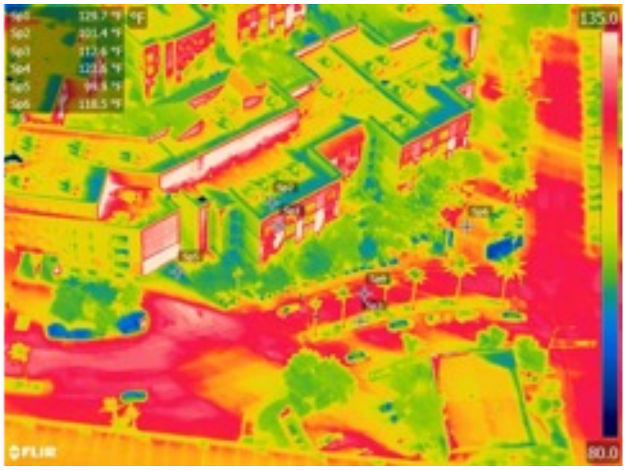
Skysong: Awning



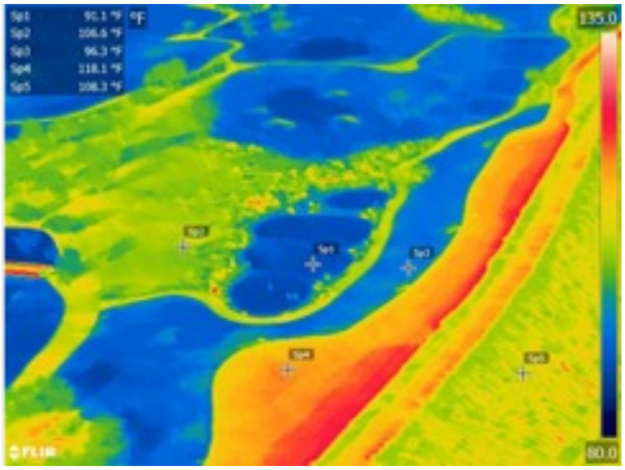
Waterfront: South Bridge



Waterfront: Apartments



TPC Golf Course



Data package contents relevant to the airborne thermal photography include thermal photographs taken from helicopter flights, accessible on the City of Scottsdale website (scottsdaleaz.gov, search for "cooler Scottsdale").

Indian Bend Wash Air Temperature Assessment

Motivation and Methods

The project team benefited from regular conversation with staff members from multiple city departments as well as engagement with the Scottsdale Environmental Advisory Commission. One line of inquiry that emerged in the early stages of the project concerning the cooling benefits provided by Indian Bend Wash, which serves an internationally recognized environmental asset for the community. Staff and Commission members asked about the air temperature benefits that the Wash might provide given the substantial differences in land surface temperature that were documented in the Wash early in the project period. As the project team was not able to find any previous analysis quantifying the impact of the Wash on near-surface air temperature, a small-scale measurement campaign was implemented in summer 2021.

The project team deployed nine temperature and relative humidity data loggers at locations in and adjacent to the Wash that collected data at 15-minute intervals for a period of approximately three months. Six sensors outside the Wash were placed on utility poles in residential areas; three sensors in the Wash were placed on light and utility poles as close to the center of the Wash as possible. All sensors were placed at approximately 10' above the ground surface to reduce the risk of tampering and vandalism. The specific sensors used were HOBO Pro v2 External Temperature/Relative Humidity Data Loggers (U23-002) with RS3 Solar Radiation Shields.

Figure 40. Location of temperature and relative humidity data loggers reployed for Indian Bend Wash Temperature Assessment in summer 2021.

Results

The air temperature in Indian Bend Wash was consistently and significantly lower than that measured in surrounding neighborhoods during the study period (Figure 1). We did not find any notable differences in air temperature between the neighborhoods to the east and west of the Wash (Figure 2), even when accounting for different prevailing wind directions. On average, the air temperature in the Wash was 2.05°F lower than the air temperature in the surrounding neighborhoods. The difference between the air temperature in the Wash and in surrounding neighborhoods was typically largest during the early-to-mid afternoon hours with a mean difference during that time period exceeding 2.5°F (Figure 3). Temperature differences occasionally exceeded 4°F, and in a few cases, exceeded 8°F. Future research could identify the specific regional-scale meteorological conditions associated with these particularly large deviations, as well as the conditions in place during the few instances where the air temperature in the Wash exceeded that in surrounding neighborhoods.

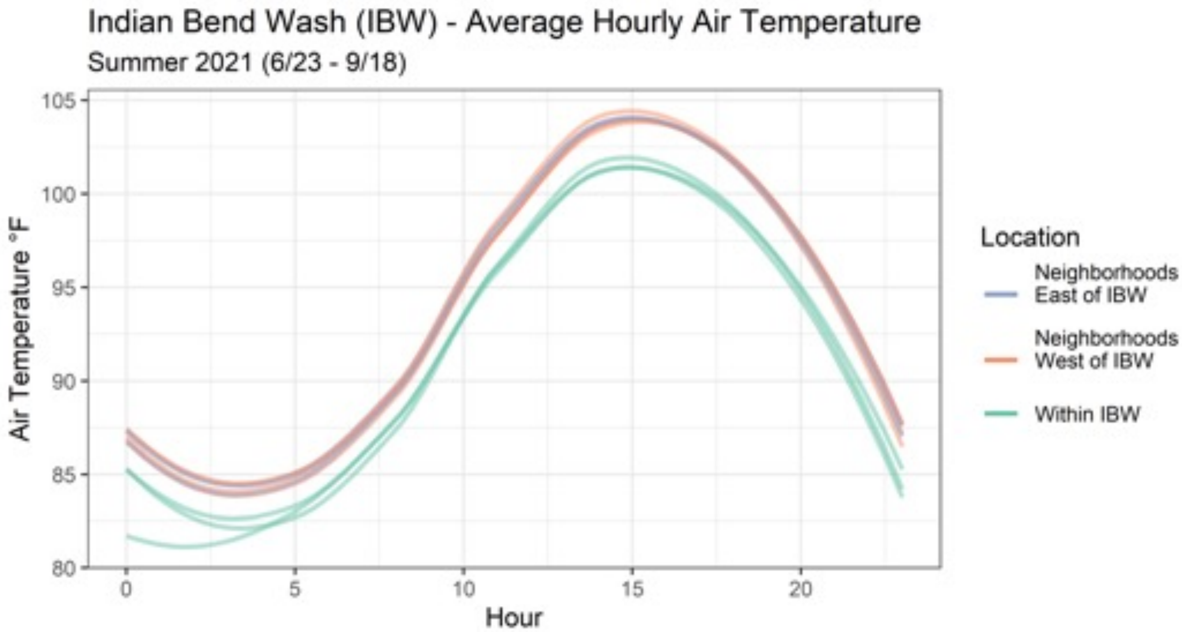


Figure 41. Average daily pattern in hourly air temperature at weather stations in (blue) neighborhoods east of Indian Bend Wash, (red) neighborhoods west of Indian Bend Wash, and (green) within Indian Bend Wash during summer 2021. There were three weather stations located in each area mounted on light poles 10 feet above the ground. All stations were located between Thomas Road to the north and McKellips Road to the south, and within ¼ of a mile of Indian Bend Wash to the east and west.

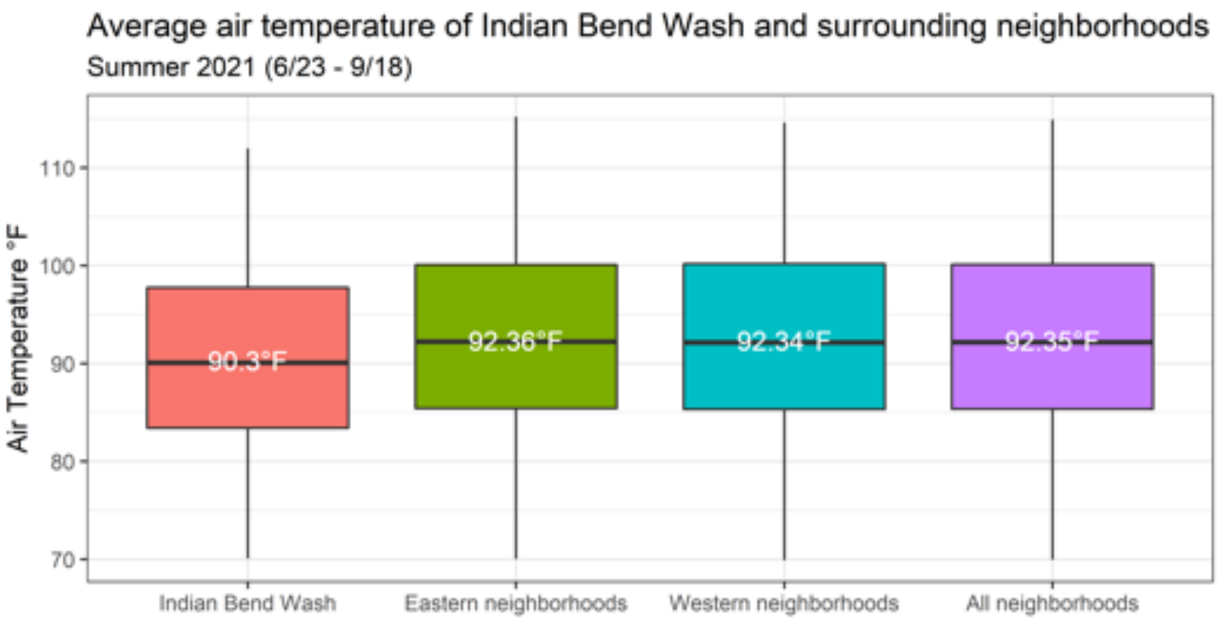


Figure 42. Distribution of hourly air temperature at weather stations in (blue) neighborhoods east of Indian Bend Wash, (red) neighborhoods west of Indian Bend Wash, and (green) within Indian Bend Wash during summer 2021. There were three weather stations located in each area mounted on light poles 10 feet above the ground. All stations were located between Thomas Road to the north and McKellips Road to the south, and within ¼ of a mile of Indian Bend Wash to the east and west. The boxes indicate the range of values corresponding to the central 50% of all observations; the horizontal blank line within each box shows the median. Whiskers extend to the full range of values with the exception of statistical outlier points, shown by black dots.

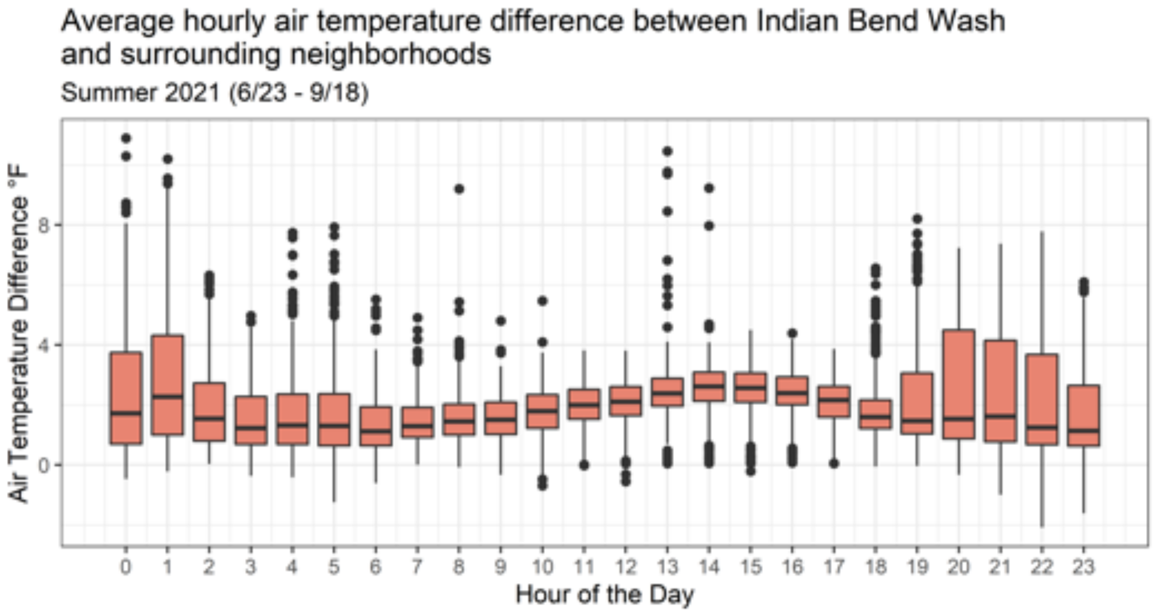


Figure 43. Distribution of air temperature differences by hour between weather stations located in neighborhoods to the east and west of Indian Bend Wash and weather stations located within Indian Bend Wash during summer 2021. Positive values on the chart indicate higher temperatures in the neighborhoods than in the Wash. There were three weather stations located in each area mounted on light poles 10 feet above the ground. All stations were located between Thomas Road to the north and McKellips Road to the south, and within ¼ of a mile of Indian Bend Wash to the east and west. The boxes indicate the range of values corresponding to the central 50% of all observations; the horizontal blank line within each box shows the median. Whiskers extend to the full range of values with the exception of statistical outlier points, shown by black dots.

Temperature measurements from the Indian Bend Wash analysis are available in the data package that accompanies this report, accessible on the City of Scottsdale website (scottsdaleaz.gov, search for "cooler Scottsdale").

Heat Mitigation Goals and Strategies

Overview

Analysis of the data collected for the Cooling Scottsdale project, conversations with City staff, and consultations with scientific experts led the project team to identify three broad goals for heat mitigation in the City, and a wide suite of specific mitigation strategies that could help the City become a cooler and more comfortable place for residents and visitors. The recommendations may also support other existing and developing citywide goals and initiatives related to sustainability, open space conservation, transportation, and equity. While the recommendations below do not reflect the full set of possible actions the City could take to address urban heat, they do represent actions that are anticipated to yield a significant return on investment as related to cooling and comfort, and are supported by the results of this project and the peer-reviewed scientific literature at large.

The three broad goals for heat mitigation are:

1. Increase tree canopy, particularly along frequently traveled pedestrian walkways and along the south and west facades of buildings;
2. Reduce the land area of exposed dark asphalt, dark roofs, and other hot surfaces;
3. Improve and increase pedestrian shade amenities through building-integrated and free-standing shade structures, particularly along frequently traveled walkways and in locations that support public transportation.

Scottsdale's existing planning documents and design guidelines already provide abundant language in support of a wide range of urban heat mitigation strategies, including those reflected in the goals above. Reducing urban heat and creating comfortable environments for pedestrians in a desert climate are clearly important goals for the City and have been for at least two decades, dating back to the 2001 General Plan. Newer documents offer recommendations about how various urban heat mitigation strategies could be implemented, and in some cases, new development projects reflect these recommendations. In particular, the Design Standards & Policies Manual provides specific targets for hardscape on new development that will attenuate (but not eliminate) adverse impacts on the urban climate from continued growth. Staff are encouraged to continue to monitor compliance with these guidelines and to regularly explore opportunities to strengthen them, either by increasing the fraction of the hardscape that is subject to heat island mitigation measures, or by increasing the efficacy of the proposed options (e.g., increasing the reflectivity requirement).

While strengthening, monitoring, and enforcing existing guidelines and aspirations relevant to new development, the data collected in this project highlight a need to **prioritize cooling strategies for the previously developed parts of Scottsdale**. Finding opportunities to reduce, cover, or alter the high amount of land area covered by dark, heat-absorbing, and impervious surface materials (including roofs) is necessary to reduce urban heat. This is especially true for the three growth areas, which accounted for a disproportionately high percentage of "hot spots" in land surface temperature data and had some of the highest percentages of asphalt and building land cover observed anywhere in the City. Growth in these areas, which serve as key economic engines for Scottsdale, has undoubtedly brought many benefits to the City and its residents. Thus far, however, that growth has come with a tradeoff of increased urban heat and potentially significant consequences with respect to energy consumption, health, comfort, and infrastructure performance. The City can model best practices for heat mitigation on its own properties and rights of way, but creative approaches will be required to engage private land holders for significant reductions in urban heat to be realized. Staff are encouraged to work with residents, private businesses, community-based organizations and advocacy groups, and other experts to identify and develop the appropriate incentives, rationale, relationships, and legal mechanisms to do so. The Nature Conservancy's Heat Action Planning Guide for Greater Phoenix offers a template and neighborhood-specific case studies for robust community engagement around urban heat.

While this report is primarily intended to guide citywide actions related to urban heat, every person who lives, works, and recreates in Scottsdale, or has interests within the City's boundaries, can play a role in pursuing heat mitigation goals. Not all individuals in the City have equal access or opportunity to fully participate in heat mitigation strategies; renters, for example, have limited or no ability to modify the landscape at their place of residence. Engaging the entirety of the community in developing and implementing heat mitigation strategies must be a priority for staff to ensure that historically underserved communities, and the Whole Measures Rubric for Urban Heat Solutions in the Heat Action Planning Guide referenced above offers useful benchmarks for how to do so. Actions that can be taken at the individual level in support of the heat mitigation goals include:

- Planting and maintaining a tree on one's property
- Volunteering for a tree-planting event organized by the city or a nonprofit organization
- Donating to a tree-planting program or organization
- Engaging a neighbor, co-worker, or family member in conversation around tree planting and other heat mitigation strategies
- Attending a tree planting workshop organized by local nonprofits and utilities
- Modifying the roof color on one's property, especially when the current roof is at the end of its lifecycle
- Communicating to city staff about any needed maintenance for trees or shade structures in the public right-of-way
- Supporting local businesses that adopt heat mitigation features and programs
- Attending City Council meetings, Board & Commission meetings, and other city functions to express opinions about the state of the city's heat mitigation efforts and ask for related resources
- Directly writing to City Council members to express opinions about the state of the city's heat mitigation efforts and ask for related resources
- Voting for City Council candidates and other elected officials whose priorities for heat mitigation are aligned with one's own views and preferences

The current experience of heat is clearly inequitable for Scottsdale's residents. Tree canopy coverage is much lower, and land surface temperature much higher, for residents of southern Scottsdale (including the South Scottsdale Growth Area, and surrounding neighborhoods). Staff are encouraged to **focus on southern Scottsdale's residential and commercial properties** as they consider new heat mitigation initiatives and policies to maximize return on investment. Given the high density of existing development in this area, enforcement of existing guidelines for new development is unlikely to be sufficient to help southern Scottsdale become cooler and more comfortable. Additional investment—investment in physical infrastructure, services and programs, and community relations—is warranted to try to change a trajectory of historical development patterns that has left south Scottsdale residents disadvantaged relative to their neighbors elsewhere in the City.

Evidence in support of each of the goals, along with more than two dozen specific mitigation strategies, and related resources, are presented below. The goals and strategies reflected in this document are those that are supported by evidence gathered in the Cooler Scottsdale project, but do not reflect the full suite of heat mitigation goals and strategies that the City may deploy in future years. For example, the emission of waste heat into the environment from air conditioners, vehicles, industrial processes, and other machinery is one major driver of the urban heat island effect. The necessary modeling techniques to diagnose waste heat emissions and target particular sources for mitigation were beyond the scope of this project. In general, strategies that support energy efficiency (e.g., particular building designs, weatherization programs, managing building electrical loads) and the use of transit modes other than private vehicles will help to reduce waste heat emissions.

No individual heat mitigation strategy will be singularly effective in achieving significant cooling and increasing thermal comfort across the City; a combination of strategies that are appropriate for their location and purpose is required. As the City crafts and expands its portfolio of heat mitigation actions, it is important to be judicious in evaluating potential trade-offs that could result in undesired outcomes. In some cases, undesired outcomes can be mitigated by appropriate choices, siting, timing, and other factors, but in other cases, may be wholly unavoidable. Examples of the types of tradeoffs that staff, residents, and elected officials may need to balance in pursuit of a cooler and more comfortable city include:

- Possible increases in outdoor water use to maintain a more robust tree canopy and other green infrastructure
- Possible pushback from residents concerning the loss of parking spaces and/or roadway lanes if pavement and asphalt are removed
- Possible increases in bird activity near Scottsdale Airport associated with local increases in tree canopy
- Possible decreases in roadway visibility for drivers, bicyclists, and pedestrians, associated with increases in trees and other vegetation
- Possible increases in maintenance costs for additional trees and other green infrastructure, as well as existing infrastructure that interacts with trees and vegetation (e.g., vehicles, utility poles)
- Possible increases in the real and/or perceived costs of real estate development and management in Scottsdale associated with adoption of stricter building codes

Finally, Scottsdale—like all cities—will likely need to evolve its approach to urban heat governance to accelerate its ability to achieve the goals suggested in this report. In nearly every municipality in the United States there is no designated lead person or department with official responsibility and accountability for managing urban heat and its impact on people, infrastructure, and ecosystems. The absence of official, explicit structures and roles concerning urban heat is perceived to be a significant hindrance for effective urban heat management, as the wide range of programs and departments whose efforts are relevant to urban heat can too easily act in an uncoordinated, inefficient manner (Keith et al. 2019). The City of Scottsdale may consider, potentially as part of its efforts to develop a Sustainability Plan, designation of certain roles and responsibilities for urban heat management, and may also consider creation of a Board, Commission, or other citizen group that can provide additional input and guidance to staff.

Note: In the subsequent recommendations and summaries of related scientific literature, readers will encounter references to three different temperature measurements: air temperature, surface temperature, and radiant temperature. These are three related, but distinct, physical measurements that should not be directly equated to one another. For example, surface temperatures can regularly exceed 150°F, nearly 30°F higher than the all-time record high air temperature at Sky Harbor airport. "Cooling benefits" with respect to air, surface, and radiant temperatures may appear to widely vary. Identification of the desired outcomes for any heat mitigation strategy is important to understand which temperature measure is most appropriate. See page 34 for definitions for each variable.

GOAL 1: INCREASE TREE CANOPY
PARTICULARLY ALONG FREQUENTLY TRAVELED PEDESTRIAN WALKWAYS AND ALONG THE SOUTH AND WEST FACADES OF BUILDINGS

Relevance & science for heat mitigation

Trees and other forms of vegetation can provide a multitude of ecosystem services to cities, including heat mitigation. Trees in particular offer multiple mechanisms by which cooling and increased thermal comfort can be achieved. Trees can reduce urban air temperatures via evapotranspiration of water through their leaves, as well as by blocking sunlight from reaching urban surfaces that retain more heat than natural landscapes. A recent meta-analysis of the scientific literature reported an approximately 0.6°F afternoon air temperature reduction per 10% increase in urban tree canopy coverage, with an effect roughly half as large at night (Krayenhoff et al. 2021).

Buildings that are shaded by trees will likely have lower cooling and electricity demand in the summer months, supporting reductions in greenhouse gas emissions. Of particular value are trees planted on the south and west sides of buildings and located specifically to shade cooling equipment (AC condenser units). Warm season energy savings from reduced cooling costs have been estimated to exceed 15% of total demand (Hsieh et al. 2018).

Additionally, when planted in appropriate locations, trees can provide shade for urban residents, reducing radiant temperatures experienced by the human body and increasing thermal comfort. Reductions in mean radiant temperature experienced by pedestrians in tree shade can reach 40°F (Middel et al. 2021). Like many other heat mitigation strategies, there are important tradeoffs to consider when proposing increases to urban tree canopy, including water requirements, utility and infrastructure conflicts, maintenance costs, pedestrian safety (e.g., thorns, visibility) and accessibility, and production of pollen and ozone precursor gasses (Roman et al. 2021).

Data and examples from the Cooling Scottsdale project

Urban tree canopy is highly variable across the City of Scottsdale and, has been widely observed elsewhere in the scientific literature, places with more trees tended to have significantly lower surface, air, and radiant temperatures. Our analysis of data from Scottsdale revealed that:

- As of 2015, trees and shrubs accounted for approximately 13% of the total land cover in the City of Scottsdale and 14% of the total land area in Metro Scottsdale.
- Metro Scottsdale had 299,046 trees in 2014 according to LiDAR estimates
- Tree and shrub coverage was lower in the three prioritized growth areas, with 10% coverage in the Old Town growth area, 8% in the Airpark growth area, and 6% in the South Scottsdale growth area. Similarly, tree density was lower in the three growth areas than Metro Scottsdale according to LiDAR estimates.
- At the census block group scale, tree and shrub coverage varied from a low of 6.5% (in southern Scottsdale) to a maximum of nearly 25% in the Shea/East Shea Character Area.
- Each 1% increase in tree and shrub coverage was associated with a 0.59°F reduction in surface temperatures, at the census block group scale
- Field results from local microclimate assessments found that mature, fully-leafed trees provided some of the lowest mean radiant temperature (MRT) values observed in this project. MRT reductions of ~55°F compared to open surfaces were measured under trees in Old Town and along the Waterfront.

- Select locations showed that mature, desert adapted trees also provide substantial decreases in MRT that improve thermal comfort, with MRT reductions ~30°F.
- The benefits of a single tree is highly dependent on the time of day; strategic planting of multiple trees can maximize shade and prevent times of discomfort.

Tree canopy language in existing City documents, ordinances, and plans

Scottsdale's planning and design documents generally contain strong language in support of increasing tree cover in the City, with urban heat island mitigation and shading for pedestrian thermal comfort often referenced as desired outcomes. The 2018 Design Standard & Policies Manual provides detailed guidance regarding tree planting, including recommendations for species selection and avoiding conflicts with City infrastructure. While there are no apparent specific benchmarks or targets for tree canopy coverage, current conditions, with canopy as low as 6.5% in some areas of the City, do not fully reflect the vision articulated in the planning documents. Sample language from the City's planning and design documents related to increasing tree cover includes:

Scottsdale General Plan: Trees are referenced in multiple different elements of the City's general plan. In particular, the Preservation and Environmental Planning Element encourages "increasing the use of natural and man-made shading for parking lots, streets, and pedestrian areas," and "encouraging the retention of mature native trees" for multiple benefits, including those related to air quality and water conservation. Additionally, the Community Mobility Element recommends "promoting comfortable alternative paths and trails by providing shade trees, canopies, cooling/misting systems and other options."

Old Town Character Area Plan: The Old Town Character Area plan references trees as a strategy to improve pedestrian thermal comfort in multiple locations, such as the recommendation to "Enhance outdoor pedestrian comfort through the creation of microclimates that incorporate a variety of shade, trees, and other drought tolerant landscape features to create passively cooler temperatures" as part of the Character and Design section. This plan also calls for creation of a comprehensive Downtown Shade and Tree Plan, and an inventory of existing conditions.

Southern Scottsdale Character Area Plan: This plan also encourages tree planting for shade provisioning in multiple contexts. The plan "encourages plant placement that maximizes shade opportunities in pedestrian spaces, parking lots, and streetscape environments." It also encourages attention to species selection to reduce landscape water use and lists trees and shade as components of mobility improvement programs.

Airpark Character Area Plan: Of the three Character Area Plans examined for this report, this plan contains the fewest explicit references to tree planting. However, trees are mentioned as part of a policy to "Increase the use of effective nature and man-made shading for parking lots, streets, and pedestrian areas," and trees are also recommended as a measure to reduce ground-level ozone.

Design Standards and Policies Manual: There are numerous guidelines related to tree planting in different contexts to minimize conflicts with utilities and other City infrastructure, ensure motorist and pedestrian safety, and align with the City's aesthetic principles. The most specific language related to trees as part of heat mitigation strategies is in Chapter 2, Section 2-1.211, concerning Sustainable Site and Building Design. The plan states that "not less than 50% of site hardscape should be provided with one or any combination of the following methods," and vegetated ground cover and trees are included as one of four options for meeting the 50% benchmark.

Examples, practices, policies from elsewhere

Multiple municipalities in the Southwest have adopted Tree and Shade plans in recent years, including:

- City of Phoenix Tree and Shade Master Plan (2010)
- City of Tempe Urban Forestry Master Plan (2017)
- Austin's Urban Forest Plan (2014)

Cities are also taking action to provide necessary financial resources to maintain and grow urban forests, as well as enact and enhance key policies and ordinances that require or incentive tree planting and/or preservation. The City of Phoenix provides two recent case studies:

- The 2021-2022 Phoenix City Council-approved budget includes $2.8M in Climate Change and Heat Readiness investments. Those investments include a new full-time Tree and Shade Administrator, as recommended by the City's Environmental Quality and Sustainability Commission. Additional staff are to be added to the Parks Department's Forestry crew, whose responsibilities will include tree planting in City parks. The City is allocating money to update the City's tree inventory and database. Finally, $1.5M is allocated to a Cool Corridors program, which will support planting 200 trees per mile on each of nine one-mile project areas (1,800 trees total) each year. While Phoenix is clearly a much larger city than Scottsdale, elements of this investment may be adaptable, such as a prioritized street tree planting program.
- In June 2021, Phoenix City Council approved changes to Chapters 5 and 7 of the City's Zoning Ordinance that include considerations, presumptions, and new requirements. Among the several changes are updates to design guidelines about tree placement and shade coverage, as well as new requirements concerning landscape inventory and maintenance plans, as well as tree protections, removal, and replacement. The full set of amendments is available through the City Clerk's office and in a Council meeting agenda.

Elsewhere in the region, Mesa offers up to $75 for residents to add shade trees to their property when participating in the City's "Grass-to-Xeriscape" program.

Possible strategies

- Develop a comprehensive urban forestry master plan, allocating sufficient budget and personnel resources to engage residents and other stakeholders in the planning process, plant and maintain new trees, implement necessary enforcement and compliance mechanisms, and provide other necessary auxiliary services (tree education, tree removal, infrastructure upgrades, etc.). Engagement with city staff in Phoenix and Tempe could help identify successes and challenges encountered with previously adopted urban forestry master plans.
- To prioritize equity, the City could adopt a goal for minimum tree coverage in all census block groups (or other spatial units), instead of, or in addition to, a citywide target. There are currently 25 census block groups in the City with less than 10% tree and shrub coverage, 15 of which are in the bottom 25% of per capita income in Metro Scottsdale (median per capita income <$39,642).
- Create new recommendations, incentives, and/or requirements for tree planting and preservation in the City's growth areas. These three areas are currently home to some of the lowest tree coverage in the entire City, even when compared to their immediate surroundings.
- Create new recommendations, incentives, and other programs for tree planting and preservation on residential parcels in southern Scottsdale.

- Add resources to the City website to help residents learn about planting and maintaining trees, and receive assistance to do so.
- Develop and enhance partnerships with local utilities and nonprofit and community-based organizations that can assist with tree education, tree planting, and related services.
- Review the Capital Improvement Plan to identify opportunities for infrastructure upgrades and modifications necessary to increase tree canopy in the city (e.g., relocating utility lines, adding water access to unirrigated landscape areas).
- Designate responsibility for increasing tree canopy in urban Scottsdale to one or more city staff members, departments, and/or programs.

GOAL 2: REDUCE THE LAND AREA OF EXPOSED DARK ASPHALT, DARK ROOFS, AND OTHER HOT SURFACES

Relevance & science for heat mitigation

The materials used to build urban infrastructure are among the most significant contributors to the urban heat island effect. Hard, dark surfaces like asphalt and many roofing materials are excellent absorbers of incoming solar energy. In turn, those surfaces heat up and slowly re-radiate heat into the urban environment: heat storage and absorption of urban areas is estimated to be more than double that of rural areas during the daytime hours (EPA 2008). Surfaces like asphalt, roof tiles, and concrete can reach temperatures that are more than 50°F higher than the ambient air temperature when exposed to the sun for several hours. These hot surfaces subsequently warm the air above them, contributing to elevated urban temperatures compared to surrounding areas.

In addition to the impacts on local and regional air temperatures, hot urban surfaces are often associated with lower thermal comfort, as people are exposed to both higher air temperatures and greater longwave radiation. Furthermore, runoff from urban parking lots, streets, and roofs can raise the temperature of regional surface water supplies, which can pose challenges for ecological and infrastructure systems (EPA 2008). Widespread deployment of reflective and other "cool" surface materials can substantially reduce urban temperatures, with one study estimating that the cooling effect of reflective materials could fully offset projected air temperature increases from global climate change (Georgescu et al. 2014).

Data and examples from the Cooling Scottsdale project

Many places in Scottsdale have high fractions of the land surface used by asphalt and other hard and dark building materials that contribute to the local and regional urban heat island. In general, places in Scottsdale with more asphalt and buildings had much higher surface, air, and radiant temperatures. The guidelines and ordinances that apply to new development and major renovations will constrain (but not fully eliminate) further contributions to urban heat with continued growth. However, the City faces a serious challenge with a significant portion of prior development not meeting current aspirations with respect to avoiding large areas of hard, dark surface materials that exacerbate urban heat.

- As of 2015, buildings and asphalt accounted for approximately 33% of the land area of the City of Scottsdale and 39% of the land area of Metro Scottsdale, based on landscape classification of satellite imagery.
- Asphalt and building coverage was higher in the three prioritized growth areas, with 40% coverage in Airpark, 66% in Old Town, and 69% in South Scottsdale. In the South Scottsdale growth area, asphalt comprised 48% of the total land area.
- At the census block group scale, building and asphalt coverage varied from a low of 17% near McDowell Mountain Ranch to a high of more than 71% near Old Town, southeast of the intersection of Camelback and Miller.
- Each 1% increase in asphalt land cover was associated with a 0.31°F increase in land surface temperature at the census block group scale. Buildings had a similar effect (+0.25°F per 1% increase).
- Approximately 53% of parcels in Metro Scottsdale (50,939 of 95,676 individual parcels) had at least 50% of their land area classified as building or asphalt as of 2015.

- Approximately 32% of parcels larger than one acre in size in Metro Scottsdale (1,345 of 4,192 parcels) had at least 50% of their land area classified as building or asphalt as of 2015.
- There were 45 individual parcels in Metro Scottsdale that had 10 or more acres of building or asphalt land cover as of 2015.
- Thermal images taken within sites across the Scottsdale growth areas show significantly lower surface temperatures under full, large overhangs, particularly for north facing buildings. These results were particularly prominent at the Scottsdale Promenade (Greater Airpark area) and Old Town, where the surface temperatures were ~50-70°F cooler than the same sun-exposed surface. Bus stops with full, wide shade resulted in up to 50°F lower surface temperatures.
- Airborne thermal imagery identified hard, dark surfaces as having some of the highest land surface temperatures in the photographed areas during the early morning flight, and indication of the heat-retaining properties of those surfaces that contribute to the urban heat island effect.
- The hottest surface found was brick interlaced among artificial turf near the Scottsdale Waterfront, reaching 180°F when sun exposed.
- Dry soil and/or rocks reached similar surface temperatures as concrete midday, yet cooled off very quickly after sunset and thus would not affect the nighttime UHI.

Language about heat-absorbing surfaces in existing documents, ordinances, plans

Several planning and design documents for the City of Scottsdale directly and indirectly reference strategies to reduce the prevalence of exposed asphalt and other hard and dark surfaces. Providing shade above parking areas with natural and engineered structures, including solar panels, is a commonly suggested strategy. Plans also encourage attention to landscape design to maximize shade provisioning for parking lots, streets, and other pedestrian areas. The use of alternative, reflective, pervious and/or cool paving materials appears in some, but not all, planning and design documents that were reviewed for this project. The Design Standards & Policies Manual and City Building Codes and Amendments provide specific targets for total site hardscape coverage (50% must meet specific requirements designed to mitigate urban heat) and roof reflectivity, with more aggressive targets available for new development and renovations adhering to the International Green Construction Code. The extent to which new development projects are complying with these targets was not publicly available at the time this report was written.

As was the case with tree canopy, current conditions across parts of Scottsdale do not clearly reflect the vision articulated in the planning documents with respect to heat-absorbing documents. Furthermore, the plans do not elaborate any resources that are currently available, or could become available, to residents or business owners to make improvements to currently developed parcels. Sample language from the City's planning and design documents related to exposed asphalt and other dark surfaces includes:

Scottsdale General Plan: The general plan includes a high-level recommendation that "encourages landscape designs that...reduce the urban heat island effect" as part of the Character and Design Element. The plan also recommends an "increase in the use of natural and man-made shading for parking lots, streets, and pedestrian areas" as part of the Preservation and Environmental Planning Element.

Old Town Character Area Plan: Attention to hard surfaces in this character area plan primarily concerns parking. Specifically, the plan calls for development to "seek opportunities to provide shaded parking through the provision of landscaping, shade structures, tree and solar canopies." Elsewhere, the plan recommends development and heat mitigation strategies that offer co-benefits, including the use of solar parking canopies.

Southern Scottsdale Character Area Plan: Plant placement and design details concerning landscape features are emphasized in this character plan, with intended goals of "maximizing shade opportunities" and "providing shaded pavement in parking lots and on streets." The Southern Scottsdale plan also suggests the use of reflective and cool paving materials.

Airpark Character Area Plan: Similarly to the other character area plans, the Airpark plan encourages the use of "effective shading for parking lots and streets." This is the only plan that explicitly mentions limiting the extent of impervious surfaces to combat urban heat, although no specific targets or limits are provided.

Design Standards and Policies Manual: The hardscaping guidelines in Chapter 2, Section 2-1.211, concerning Sustainable Site and Building Design, provide several options related to alternative surface types to aid in heat island mitigation. The guidelines recommend the use of materials with solar reflectance of at least 0.30, shade structures (of various forms), and pervious and permeable pavements, on at least 50% of site hardscape. Elsewhere, the design guidelines encourage the implementation of solar energy generation facilities above parking areas to provide shade and sustainable energy resources.

Building Codes and Amendments: The City of Scottsdale building codes incorporate the International Energy Conservation Code (IECC), which requires the use of cool roofs with a solar reflectance index of 64 or more on new construction. The City also provides developers seeking compliance with the International Green Construction Code a Site Heat Island Mitigation worksheet.

Examples, practices, policies from elsewhere

- The City of Phoenix implemented a cool pavement pilot program in 2020 and has applied cool pavement to more than 40 miles of city streets and parking lots. The City is partnering with ASU to conduct a comprehensive evaluation of the cool pavement, including impacts on microclimate conditions, coating performance and deterioration, and resident perception. More information about Phoenix's pilot program can be found online. The first evaluation report is expected to be released in late summer 2021.
- The City of Phoenix received a grant from Bloomberg Philanthropies in 2013 that accelerated efforts to apply reflective paint to the roofs of City-owned buildings. An estimated 71,000 square feet of roofs were coated, which led to measurable reductions in carbon emissions. The City's current policy requires all new and renovated City buildings to include cool roof coatings.
- The City of Los Angeles is in the eighth phase of a cool pavement pilot project and has planned to coat 250 miles of City streets with reflective materials by 2028 as part of "L.A.'s Green New Deal." Evaluation results for the cool pavement pilot project presented at a scientific conference are available online.
- New York City's Cool Roof program provides paid training and work experience for cool roof installers, no-cost cool roof installations for public-serving institutions as well as affordable and low-income housing, and low-cost installations to all building owners that are able to cover the cost of the coating, for qualifying roof types.
- The City of Tempe is conducting a pilot test in partnership with ASU and 3M to evaluate the performance of innovative "passive daytime reflective cooling" technology on the top of City bus shelters.
- The Global Cool Cities Alliance has launched a Cool Roadways Partnership Program that has convened 25 municipalities from across the country to provide guidance to the commercial sector, share knowledge, and ultimately leverage collective investments to implement affordable cooling solutions.

Possible strategies

- Conduct an inventory of cool roofs in the City and, where possible, collect energy consumption and other building performance data to complete a cost benefit analysis.
- Invest in reflective roof surfaces for City infrastructure; consider testing and evaluating different reflective surface materials.
- Create an incentive, rebate, workforce development, and/or volunteer program to encourage cool roof retrofits across the City on all property types.
- Add resources to the City's website to help residents learn about cool roof retrofits and receive assistance to adopt or install cool roofs.
- Develop a recognition program for private property owners who retrofit their properties to meet or exceed current IGCC and DSPM heat island mitigation benchmarks.
- Implement a cool pavement pilot program on a limited number of City streets and parking lots; engage residents for education and feedback.
- Invest in shade structures for City parking lots; consider solar canopies where feasible.
- Create incentive programs for adding shade structures, solar panels, and trees to privately owned parking lots. Provide technical guidance and additional capacity as needed in partnership with local engineers, architects, and arborists.
- Explore the feasibility of temporary installations on large parking lots to reflect and/or block incoming sunlight during times of limited use. Temporary installations could include nursery trees or other vegetation, shade sails, or public art.
- Ensure that urban heat is a factor included in review of parking standards and requirements citywide.
- Increase requirements for shade coverage on surface parking lots to minimize large, continuous areas of sun-exposed pavement.
- Commission new research to further understand the economic implications of providing shaded parking, particularly with respect to tourism and associated commercial activity.
- Designate responsibility for reducing the amount of land covered by hot, dark surfaces in urban Scottsdale to one or more city staff members, departments, and/or programs.

GOAL 3: IMPROVE AND INCREASE PEDESTRIAN SHADE AMENITIES THROUGH BUILDING-INTEGRATED AND FREE-STANDING SHADE STRUCTURES, PARTICULARLY ALONG FREQUENTLY TRAVELED WALKWAYS AND IN LOCATIONS THAT SUPPORT PUBLIC TRANSPORTATION

Relevance & science for heat mitigation

Walking requires physical exertion, and the combination of exertion (which generates internal body heat) and hot weather can make walking uncomfortable, and potentially even unsafe, especially during the summer months. Maintaining opportunities for pedestrians to remain thermally comfortable can help increase the viability and appeal of public transportation and other alternative transportation modes that do not require private vehicle use. This mode shift can help reduce the emission of waste heat into the urban atmosphere, which is one of the key contributors to the urban heat island effect. Furthermore, pedestrian activity is an important economic driver in certain commercial districts. Providing effective shading and other cooling amenities for pedestrians thus offers multi-pronged benefits with respect to public health, heat island mitigation, economic activity, and other desired outcomes.

In hot, dry desert climates, solar radiation is one of the most important determinants of human thermal comfort and heat-related health risks (Vanos et al. 2021). A wide variety of infrastructure types, including buildings, shade structures, and shade sails, as well as living infrastructure, including trees, shrubs, and other vegetation, can provide sufficient shade to significantly improve pedestrian thermal comfort and reduce risk of heat exhaustion and other heat-related illnesses. A comprehensive study of the impact of 50 different types of shade was recently published by Middel et al. (2021) that is publicly available as a resource to guide future decision-making related to shading infrastructure.

The benefits for pedestrian thermal comfort are best measured based on reductions in mean radiant temperature. While benefits vary by specific infrastructure type, ground cover, and by time of day, the researchers found afternoon reductions in radiant temperature by ~24°F from lightweight and engineered shade structures, ~26°F from natural shade, and ~34°F from urban form elements (including adjacent buildings). A separate study of the thermal impacts of bus stop shelters in the City of Phoenix found reductions in physiological equivalent temperature (a widely used measure of thermal comfort) approaching 40°F (Dzyuban et al. 2021). Even more substantial benefits may be possible through the use of shade structures with reflective top surfaces.

Data and examples from the Cooling Scottsdale project

- The shaded bus stop at Skysong produced some of the lowest mean radiant temperature (MRT) values at noon observed anywhere on the Skysong campus.
- Conversely, exposed bike racks at Skysong had the highest MRT values at noon observed anywhere on the Skysong campus.
- Young trees along pedestrian corridors at the Scottsdale Promenade (Greater Airpark area) did not provide sufficient shade to meaningfully impact MRT.
- As noted above, mature, fully-leafed trees provided some of the lowest mean radiant temperature (MRT) values observed in this project. MRT reductions of ~55°F compared to open surfaces were measured under trees in Old Town and along the Waterfront.
- Also noted above, select locations showed that mature, desert adapted trees also provide substantial decreases in MRT that improve thermal comfort, with MRT reductions ~30°F.

- Also noted above, thermal images taken within sites across the Scottsdale growth areas show significantly lower surface temperatures under full, large overhangs, particularly for north facing buildings. Bus stops with full, wide shade resulted in up to 50°F lower surface temperatures.
- Opposite sides of a well-designed bus stop shade shelter near SkySong had considerably different MRT during times of the day with low sun angles, enabling transit riders to find relief from the sun for morning and evening boardings.

Language about pedestrian shade and comfort in existing documents, ordinances, plans

Planning documents and design guidelines in Scottsdale provide significant attention to pedestrian thermal comfort. Every planning and design document that was reviewed for this project directly or indirectly referenced shade for pedestrian thermal comfort multiple times, and City design guidelines and supporting documents provide specific recommendations and requirements regarding the construction/installation of shading features along streetscapes, walking paths, and other pedestrian areas. Several examples of pedestrian amenities and corridors that align with planning document recommendations and guidelines and do provide excellent shade coverage were identified in the course of this project. No specific goals or benchmarks related to pedestrian shade (e.g., coverage, frequency, density) were evident in the planning documents that were reviewed, although several documents use language such as "increase" or "maximize." Sample language from the City's planning and design documents related to pedestrian shade and cooling amenities includes:

Scottsdale General Plan: The general plan references a variety of infrastructure options for providing shade, including shade trees, canopies, cooling/misting systems, and arcade-covered walkways. The plan also emphasizes pedestrian activity and pedestrian thermal comfort as key values and goals for the City, with language such as "promote comfortable alternative paths and trails," "urban districts should have a pedestrian orientation," and "emphasize strong pedestrian orientation." The plan includes the term "shaded safe paths" as part of the Community Mobility Element.

Old Town Character Area Plan: Pedestrian activity is framed as an essential component of the culture and tradition of Old Town in its character area plan. The plan refers to covered walkways, tree canopies, and shade trees to enhance comfort, improve the pedestrian experience, and "create passively cooler temperatures."

Southern Scottsdale Character Area Plan: This plan also has several recommendations relevant to the pedestrian experience, with particular attention to parking lots and streetscape environments. Of the three character area plans reviewed, this was the only one with attention to public transit. Specifically, the plan calls for the City to "support the improvement of transit stops to be more pedestrian friendly with shade."

Airpark Character Area Plan: This plan contained the least explicit language about providing shade and cooling amenities for pedestrians, but did call for a general increase in the use of shading for pedestrian areas, and referenced shade trees and shade structures as appropriate tools to do so.

Design Standards and Policies Manual (DSPM): Beyond the higher-level recommendations provided in the general plan and character area plans, the DSPM provides specific language for "providing shade for primary pedestrian circulation routes wherever possible." The DSPM also encourages the placement of bicycle racks in shaded locations, a recommendation that was not evident in other plans reviewed for this project.

Examples, practices, policies from elsewhere

- The Maricopa Association of Governments' Active Transportation Plan Toolbox includes a specific module for Shade and Thermal Comfort as part of the Pedestrian Infrastructure Recommendations. The Toolbox recommends 60% shade coverage along a 20-minute pedestrian route to be considered "excellent," with a "minimum acceptable shade coverage" target of 20%. The toolbox includes specific design principles and examples that the City could draw from to complement existing guidelines. The toolbox can be found online.
- The City of Phoenix partnered with ASU's Herberger Institute to design new bus shelters that provide a larger shade footprint throughout the day. An article describing the shelters is available here; limited installation of the shelters has recently begun. The City will also be expanding the prevalence of "artistic" bus shelters coordinated by the Phoenix Office of Arts & Culture through its recently approved 2021-2026 Public Art Budget.
- The City of Tempe completed a new transit shelter design project in 2019 and 2020 and has established a goal to have shade at every transit stop. More information about this program is available online.
- The City of Los Angeles is enhancing "Cool Amenities" at public bus stops as part of the City's "Green New Deal." 50 experimental shade umbrellas were installed in 2019, with plans for hundreds more permanent structures to be installed in the coming years. More information about this program is available online.

Possible strategies

- Scottsdale is home to several exemplary designs for transit shelters that provide high-quality shade; many City bus stops offer some access to shade. Addition of shade structures (or natural shade) to more transit stops, as well as along other highly-used pedestrian routes and corridors, could improve thermal comfort and increase the desirability of walking.
- Conduct an inventory of shade and other cooling amenities along prioritized walking routes in the City.
- Create specific targets for shade coverage for key pedestrian corridors and a framework for tracking progress toward meeting shade targets.
- Host community workshops and virtual forums to identify locations with needed shade, according to City residents.
- Conduct an inventory of shade availability at bicycle racks.
- Increase shade provisioning at bicycle racks and/or relocate bicycle racks to locations where shade is already available.
- Conduct an inventory of shade availability at public water fountains.
- Increase shade provisioning at public water fountains, and explore options to add seating to create more comprehensive "cool stops" for pedestrians and bicyclists.

Alignment of Heat Mitigation Goals with 2035 General Plan

The City's 2035 General Plan identifies a wide range of processes and programs that will be evaluated and updated following its ratification. There are significant opportunities to align these updates with the proposed heat mitigation goals identified in this report. The list below suggests a subset of those processes and programs that may be most closely aligned with efforts to cool the city and make it more comfortable. Staff designees and other stakeholders involved in these programs and policies are encouraged to incorporate heat mitigation strategies into subsequent revisions and updates as best possible, particularly in cases where heat mitigation strategies and goals are absent. The numbers in brackets indicate the heat mitigation goals suggested in this report (see page 85) that are most closely aligned with the selected programs and processes from the General Plan.

Thematic Area: Character & Culture

- Arts & Cultural Ordinances Update [1, 3]
- Arts & Cultural Strategic/Master Planning [1, 3]
- Character Area Plans-Prioritize/Create New [1, 2, 3]
- Character Area Plan Implementation [1, 2, 3]
- Design Guidelines [1, 2, 3]
- Design Standards & Policies Manual Update [1, 2, 3]
- Development Review Process Refinement [1, 2, 3]
- Zoning & Related Code Updates [1, 2, 3]

Thematic Area: Sustainability

- Energy Efficiency & Clean Fuel Updates [2]
- Green Building Program/Energy & Building Code Review/Update [1, 2]
- Infrastructure Improvements Plan [1, 2, 3]
- Native Plant Ordinance [1]
- Net-Zero Energy Strategic Plan [2]
- Stormwater Program & Master Plan Update [1, 2]
- Sustainability/Resilience Plan [1, 2, 3]
- Sustainability/Resilience Plan Code and Ordinance Amendments [1, 2, 3]
- Water Conservation Program [1]

Thematic Area: Collaboration & Engagement

- Community Survey [1, 2, 3]
- Community Outreach Programs [1, 2]
- Community Visioning [1, 2, 3]
- General Plan 5-year & Annual Reports [1, 2, 3]
- City Council Annual Priorities/Organization Strategic Plan [1, 2, 3]
- Public Involvement Plans for projects [1, 2, 3]

Thematic Area: Connectivity

- Airport Master Plan Update [2]
- Bicycle Program [1, 3]
- Old Town Scottsdale Bicycle Master Plan [1, 3]
- Transit Program [1, 3]
- Transportation Action Plan Update [1, 2, 3]

Thematic Area: Community Well-Being

- ADA Program [1, 2, 3]
- Community Health Assessments [1, 2, 3]
- Diversity and Inclusion Programs [1, 2, 3]
- Housing Rehabilitation Programs Review [1, 2, 3]
- Parks & Recreation Master Plan Review/Update [1, 2, 3]
- Strategy for Preservation & Creation of High-Quality, Safe, and Affordable Housing [1, 2, 3]

Thematic Area: Revitalization

- Asset Management Programs [1, 2, 3]
- Capital Improvement Plan/Program [1, 2, 3]
- City Facilities Master Plan [1, 2, 3]
- Community-Building & Neighborhood Organization Programs [1]
- Neighborhood Planning Program [1, 2, 3]
- Neighborhood Preservation & Conservation Programs Development/Update [1, 2, 3]
- Property Maintenance Code/Code Enforcement Program Review/Update [1, 2]

Thematic Area: Innovation & Prosperity

- Business Attraction/Retention Programs [1, 2]
- Lodging and Visitor Statistics Studies [1, 2, 3]
- Smart Cities Strategic Roadmap [1, 2, 3]
- Tourism & Marketing Strategic Plan & Implementation [1, 2, 3]
- Citywide Volunteer Program [1, 2]

Glossary of Key Terms and Acronyms

Biometeorology: An interdisciplinary science that considers the interactions between atmospheric processes and living organisms (plants, animals and humans). (Gosling et al. 2014).

CAP LTER: The Central Arizona-Phoenix Long-Term Ecological Research Program is a National Science Foundation supported research initiative at Arizona State University.

Census block group: A spatial area defined by the United States Census Bureau that is a subdivision of census tracts and aggregation of census blocks. Most census block groups contain between 600 and 3,000 people.

LiDAR: Light Detection And Ranging technology, a sensing technique that uses light in the form of a pulsed laser to measure distances to various objects. The data are often used to generate three-dimensional information about the surface characteristics of the Earth. (https://oceanservice.noaa.gov/facts/lidar.html)

Longwave radiation: Energy emitted from terrestrial objects and Earth's atmosphere, primarily in the infrared portion of the electromagnetic spectrum. (https://science.nasa.gov/ems/13_radiationbudget)

MaRTy Cart: A mobile human-biometeorological cart that measures mean radiant temperature, air temperature, relative humidity, and wind speed and direction at pedestrian height at two-second intervals. MaRTy engages 12 radiometers that measure incoming radiation from six directions. This includes shortwave radiation (visible sunlight and UV radiation) and longwave radiation (heat emitted from hot surfaces). The shortwave and longwave radiation can be integrated into mean radiant temperature. (Middel et al. 2021).

Mean radiant temperature: A parameter that combines all longwave and shortwave radiant fluxes to a single value. It is defined as the temperature of a surrounding black body that causes the same radiant heat fluxes as the complex radiant fluxes. In the context of this report, mean radiant temperature is considered to be the sum of all the radiation that hits a person's body from 360 degrees.

Metro Scottsdale: A spatial area defined for this project to facilitate comparison between the growth areas and other parts of the City (see the green area in Figure 1, in addition to the three growth areas). Metro Scottsdale is not an officially recognized unit or area by the City of Scottsdale, and was established for the purposes of this report to provide a more appropriate set of comparisons and benchmarks between the more developed parts of the City and those that remain relatively or completely undeveloped.

NASA Landsat 8: Landsat is a program of the U.S. National Aeronautics and Space Administration, with the mission to provide repetitive acquisition of high-resolution data of the Earth's surface on a global basis by remote sensing. The program has been providing data since 1972. Landsat 8 is the latest mission in the Landsat series. Landsat 8 provides synoptic coverage of continental surfaces with spectral bands in the visible, near-infrared, short-wave, and thermal infrared regions of the electromagnetic spectrum and with moderate-resolution (15 m–100 m). (Gosling et al. 2014).

Remote sensing: The process of detecting and monitoring the physical characteristics of an area or object by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). (https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used?qt-news_science_products=0#qt-news_science_products)

Solar radiation: The portion of the energy coming from the Sun in the ultraviolet, visible, and limited portion of the infrared wavelengths of the electromagnetic spectrum. (https://science.nasa.gov/ems/13_radiationbudget)

Surface temperature: Quantifies the "touch" temperature of a surface, such as roads, buildings, and roofs. (Middel et al. 2021).

Thermal comfort: The condition of mind that expresses satisfaction with the thermal environment. (Gosling et al. 2014).

References

Dzyuban, Y., Hondula, D. M., Coseo, P. J., & Redman, C. L. (2021). Public transit infrastructure and heat perceptions in hot and dry climates. International journal of biometeorology, 1-12.

Georgescu, M., Morefield, P. E., Bierwagen, B. G., & Weaver, C. P. (2014). Urban adaptation can roll back warming of emerging megapolitan regions. Proceedings of the National Academy of Sciences, 111(8), 2909-2914.

Gosling, S. N., Bryce, E. K., Dixon, P. G., Gabriel, K. M., Gosling, E. Y., Hanes, J. M., ... & Wanka, E. R. (2014). A glossary for biometeorology. International journal of biometeorology, 58(2), 277-308.

Hart, M. A., & Sailor, D. J. (2009). Quantifying the influence of land-use and surface characteristics on spatial variability in the urban heat island. Theoretical and applied climatology, 95(3), 397-406.

Hsieh, C. M., Li, J. J., Zhang, L., & Schwegler, B. (2018). Effects of tree shading and transpiration on building cooling energy use. Energy and Buildings, 159, 382-397.

Keith, L., Meerow, S., & Wagner, T. (2019). Planning for extreme heat: a review. Journal of Extreme Events, 6(03n04), 2050003.

Krayenhoff, E. S., Broadbent, A. M., Zhao, L., Georgescu, M., Middel, A., Voogt, J. A., ... & Erell, E. (2021). Cooling hot cities: A systematic and critical review of the numerical modelling literature. Environmental Research Letters.

Middel, A., et al. (2021). Cool Pavement Pilot Program report for the City of Phoenix.

Middel, A., AlKhaled, S., Schneider, F. A., Hagen, B., & Coseo, P. (2021). 50 Grades of Shade. Bulletin of the American Meteorological Society, 1-35.

Middel, A., & Krayenhoff, E. S. (2019). Micrometeorological determinants of pedestrian thermal exposure during record-breaking heat in Tempe, Arizona: Introducing the MaRTy observational platform. Science of the total environment, 687, 137-151.

Pham, J. V., Baniassadi, A., Brown, K. E., Heusinger, J., & Sailor, D. J. (2019). Comparing photovoltaic and reflective shade surfaces in the urban environment: Effects on surface sensible heat flux and pedestrian thermal comfort. Urban Climate, 29, 100500.

Roman, L. A., Conway, T. M., Eisenman, T. S., Koeser, A. K., Barona, C. O., Locke, D. H., ... & Vogt, J. (2021). Beyond 'trees are good': Disservices, management costs, and tradeoffs in urban forestry. Ambio, 50(3), 615-630.

U.S. Environmental Protection Agency. 2008. Reducing urban heat islands: Compendium of strategies. Draft. https://www.epa.gov/heat-islands/heat-island-compendium.

Vanos, J. K., Rykaczewski, K., Middel, A., Vecellio, D. J., Brown, R. D., & Gillespie, T. J. (2021). Improved methods for estimating mean radiant temperature in hot and sunny outdoor settings. International journal of biometeorology, 65(6), 967-983.

Zhang, Y., & Turner, B. I. (2020). Land-cover mapping of the central Arizona region based on 2015 National Agriculture Imagery Program (NAIP) imagery [Data set]. Environmental Data Initiative. https://doi.org/10.6073/PASTA/E671ED549A55FDA3338B177A2AD54487

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