Rx FOR HOT CITIES

Climate Resilience Through Urban Greening and Cooling in Los Angeles

LOS ANGELES URBAN °COOLING COLABORATIVE

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LOS ANGELES URBAN °COOLING COLLABORATIVE

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TreePeople's mission is to inspire, engage and support people to take personal responsibility for the urban environment, making it safe, healthy, fun and sustainable and to share the process as a model for the world.

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RX FOR HOT CITIES

Climate Resilience Through Urban Greening and Cooling in Los Angeles

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

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Extreme heat causes more deaths in the United States than all other weather-related causes combined. In a warming climate, health impacts are on the rise, especially in cities, which are warming at a faster rate than non-urban areas. Reducing urban heat exposure is an equity issue, as low-income communities and communities of color are more likely to live in neighborhoods with older buildings, low tree cover, more heat-retaining surfaces, and limited access to coping strategies such as air conditioning. In Los Angeles, the three groups expected to see the largest increases in mortality as L.A.'s climate heats up are the elderly, African Americans, and Latinos.

The Los Angeles Urban Cooling Collaborative (LAUCC) is a multi-disciplinary, national partnership of researchers and expert practitioners working with communities and government toward the goal of understanding and implementing urban cooling strategies. LAUCC completed a modeling study of current and projected heat in Los Angeles County to:

* Identify geographic areas with the highest vulnerability to heat-related death;

* Quantify at the County level, and at a more granular level, how various scenarios (or "prescriptions") combining increases in tree cover and solar reflectance of roofs and pavements would impact heat-related mortality, temperature, humidity, and oppressive air masses that lead to more mortality;

* Quantify the number of years that climate change-induced warming could be delayed as a result of implementing these prescriptions; and

* Create a replicable framework that other cities or regions can adopt and improve upon.

We analyzed meteorological data for four historical summer heat waves against mortality data to determine the numbers of excess, heat-related deaths that occur due to common heat waves in Los Angeles. We then explored the effects that various land cover prescriptions would have on reducing temperature heat and heat-related deaths. We found that roughly one in four lives currently lost during heat waves could be saved, largely in low-income communities and communities of color. We also found that climate change-induced warming could be delayed approximately 25 to 60 years under business-as-usual and moderate mitigation scenarios, respectively.

We discuss implications for heat mitigation at the neighborhood, city, and regional level, and present approaches from around the world for how to advance heat mitigation. We share examples for how to:

* Enable and establish heat-related data collection;

* Raise awareness and engage communities;

* Lead by example through heat mitigation policies and programs;

* Offer incentives to implement heat mitigation; and

* Adopt mandatory requirements and regulations to support heat mitigation.

We close with recommendations for heat-vulnerable regions, offering a wide array of entry points for individuals and entities interested in helping reduce heat-related impacts in their city.
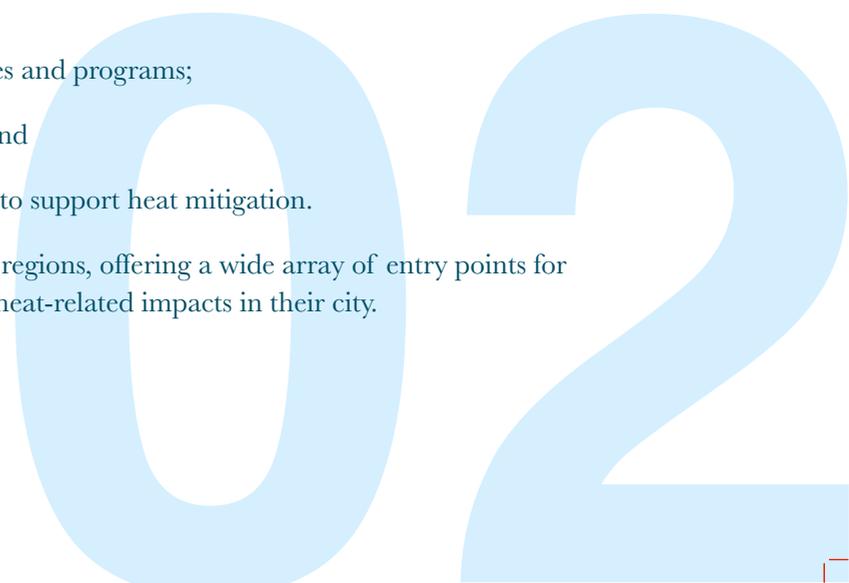
INTRODUCTION

INTRODUCTION

Extreme heat has long been a major problem in urban areas, leading to many negative health outcomes, including increases in emergency room visits, hospitalizations, and premature deaths. Extreme heat in cities is already the leading weather-related killer in many countries, including the United States. Annually, extreme heat causes more deaths than hurricanes, floods, tornadoes and lightning combined; more than 7,800 official heat-related deaths occurred in the United States from 1999 to 2010.[1] Consecutive days of intense heat can cause dramatic spikes in incidences of a wide variety of illnesses, causing increases in deaths from all causes. While the health risks caused by extreme heat already pose a threat in today's climate, the projected increases in length, frequency, and intensity of extreme heat in a changing climate loom large. As the planet warms, cities are heating up at twice the rate of non-urban areas, rendering many cities potentially uninhabitable and highlighting the importance of better understanding the issue in order to provide a fitting response.

In Los Angeles, the three groups expected to see the largest increases in mortality as L.A.'s climate heats up are the elderly, African Americans, and Latinos.

Urban areas face significant challenges as the threat of extreme heat rises, owing to a built environment that concentrates and amplifies heat. The burden of extreme heat disproportionately affects low-income urban populations and people of color.[2] These communities often live in neighborhoods that have older, lower-quality building stock, less urban tree cover, and fewer buildings with air conditioning — living conditions which contribute to a pronounced urban heat-island, and which can create a feedback loop of heating effects. African Americans are 52 percent more likely than average to live in areas where a high risk for heat-related health problems exists, while Latinos are 21 percent more likely to live in such conditions.[3] During long heat waves, mortality increases in Los Angeles about fivefold from the first to the fifth consecutive day.[4] After the fifth day, mortality risk increases 46 percent in Latino communities and 48 percent in elderly African American communities.[5] In Los Angeles, the three groups expected to see the largest increases in mortality as L.A.'s climate heats up are the elderly, African Americans, and Latinos.[6]

Extreme heat events and related health problems are expected to rise in California under climate change.[7] By mid-century, average temperatures in Los Angeles are expected to rise by 3 to 7°F.[8] Due to climate and topographic variability in Los Angeles County, some cities will have 5 to 6 times the number of extreme heat days compared to current levels.[9] These extreme heat events have measurable impacts on human health: during an average Los Angeles summer, there is an 8 percent increase in all-cause mortality — deaths from all causes combined — during the hottest days.[10] Consecutive days of intense heat can have an even more dramatic impact, with all-cause deaths occasionally increasing by a staggering 30 percent, and with escalating back-to-back extreme heat days expected to occur more frequently in the future, the threats posed by extreme heat too are on the rise.[11]

This project presents novel research, offering an evaluation of how land cover choices that are made at the local level can reduce heat burdens and alleviate health impacts borne by vulnerable communities. By modeling historic heat waves and mortality data and testing the impacts that various scenarios of increased tree cover and solar reflectance of roofs and pavements could have on reducing temperatures and heat-related death, we offer evidence that urban land cover choices can have measurable heat mitigation benefits and the potential to save many lives. We also present a first attempt at quantifying how the heat-related impacts of climate change can be delayed — or even avoided — if these land cover choices were implemented.
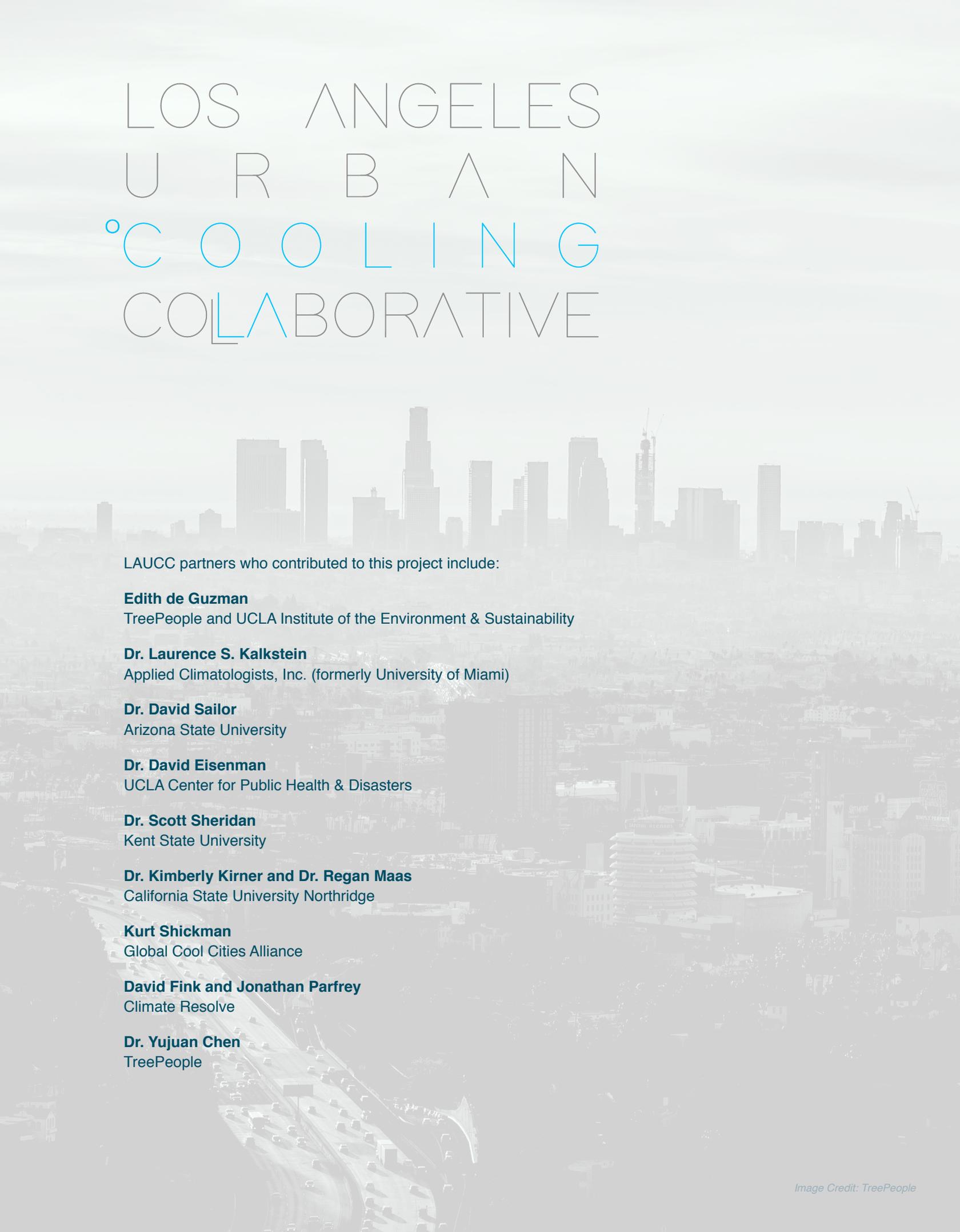
ABOUT THE LOS ANGELES URBAN COOLING COLLABORATIVE

The Los Angeles Urban Cooling Collaborative (LAUCC) is a multi-disciplinary, national partnership of academic researchers and nonprofit organizations working with communities and government agencies to research and implement data-driven, inclusive strategies for cooling urban areas and protecting vulnerable communities from heat-related health risks. LAUCC was born in 2015 out of a seemingly simple question: What should the tree canopy cover target be for Los Angeles?

This question can be answered following many different methods leading to different goals. The goal that LAUCC chose to pursue is to improve public health outcomes — specifically, the reduction of incidences of heat-related illness and death among communities at highest heat-health risk. Exploring this as the goal around both research and implementation activities led us to the realization that quantifying public health outcomes of urban land cover changes (urban tree cover and solar reflectance of built environment surfaces) was an understudied topic.

We have sought to use an approach that is inherently optimistic about humankind's ability to have a positive influence on climate-related outcomes. In an era when climate change is widely considered the existential challenge of our time, where droughts, floods, and heat often occur in extremes of biblical magnitudes, the notion that local, coordinated action can provide protection for communities most at risk strikes us as a worthwhile endeavor.

We sought to go beyond identifying geographic or demographic vulnerability, and to focus instead on solutions supporting mitigation of heat impacts, recognizing that research findings could provide goalposts for pragmatic, achievable, on-the-ground changes that could be met both through policymaking and through community engagement programs. While leading the research presented in this report, our team worked simultaneously on complementary activities with local government and city-to-city networks. Among these activities, we collaborated with the City of Los Angeles to incorporate evidence-based heat mitigation targets in the City's resilience strategy, *Resilient Los Angeles* and in its sustainability plan, known as L.A.'s *Green New Deal*. We have sought to use an approach that is inherently optimistic about humankind's ability to have a positive influence on climate-related outcomes. In an era when climate change is widely considered the existential challenge of our time, where droughts, floods, and heat often occur in extremes of biblical magnitudes, the notion that local, coordinated action can provide protection for communities most at risk strikes us as a worthwhile endeavor.

LOS ANGELES URBAN °COOLING CO(LA)BORATIVE

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GOALS OF THE PROJECT

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This project was conceived as a comprehensive modeling study of current and projected heat in Los Angeles focused on quantifying the effect that various urban greening and cooling scenarios could have on reducing temperatures and decreasing heat-induced deaths. The approaches chosen were intentionally conservative and meant to demonstrate realistic, achievable conditions rather than illustrate what is theoretically possible. We sought to accomplish several goals:

1. Identify L.A's most heat-vulnerable geographic areas.

2. Quantify how various "prescriptions" of increased urban tree cover and solar reflectance of roofs and pavements could impact summer temperatures, the number of oppressive air mass days which lead to elevated mortality, and heat-related mortality totals. These quantifications were done both in L.A. County as a whole, and at a smaller geographic scale for "districts" based on socio-economic status, ethnicity, population density, household density, and climate zone.

3. Quantify the number of years that climate change-caused warming could be delayed in Los Angeles County as a result of implementing various urban tree cover and solar reflectance prescriptions.

4. Create a replicable framework that other U.S. cities or regions can adopt (and improve upon) to coordinate interdisciplinary cross-sectoral teams to reduce urban temperatures and save lives.

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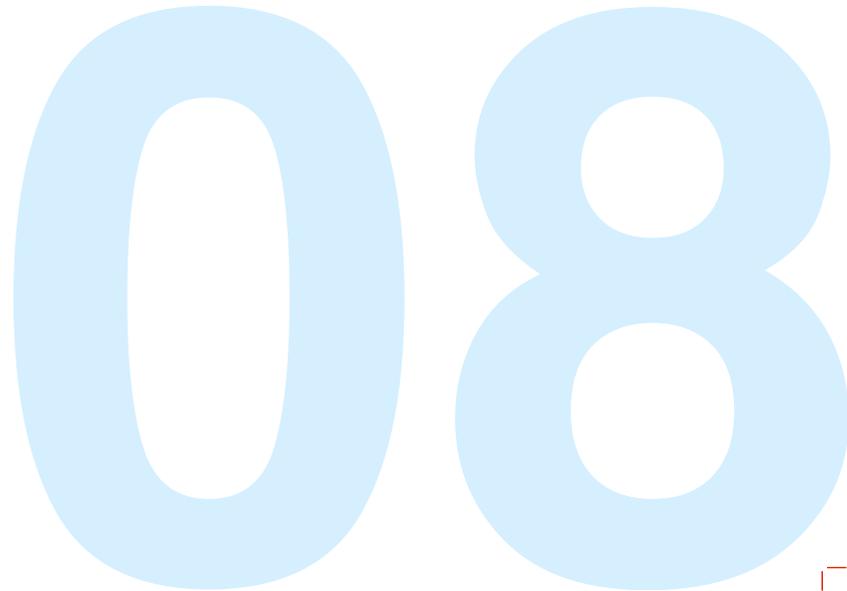
Urban Tree Cover and Cool Surfaces to Combat Extreme Heat

Urban Tree Cover and Cool Surfaces to Combat Extreme Heat

An urban forest is a network of all trees and forests in an urban area, including publicly and privately-owned trees. Urban tree cover is the layer of tree leaves, branches, and stems that provide tree coverage of the ground when viewed from above.[12] Investments in urban tree cover are well-established as providing a range of critical benefits to urban communities, such as: reduced urban heat-island effect through shading and evapotranspiration; reduced energy demand; carbon sequestration; improved air quality; improved water quality and supply through stormwater runoff management; providing wildlife habitat; enhanced community cohesion; and improving human health and well-being.[13]

Shading and evapotranspiration effects from urban trees offer significant benefits for mitigating urban heat. One study provides an example of evapotranspiration and shading from trees contributing to decreases in park air temperatures by up to 11°F in comparison to surrounding streets.[14] Furthermore, studies modeling projected benefits of tree canopy in reducing temperatures demonstrate that maturing tree canopies can facilitate exponential cooling for urban areas, making investments in urban forestry an effective long-term strategy.[15]
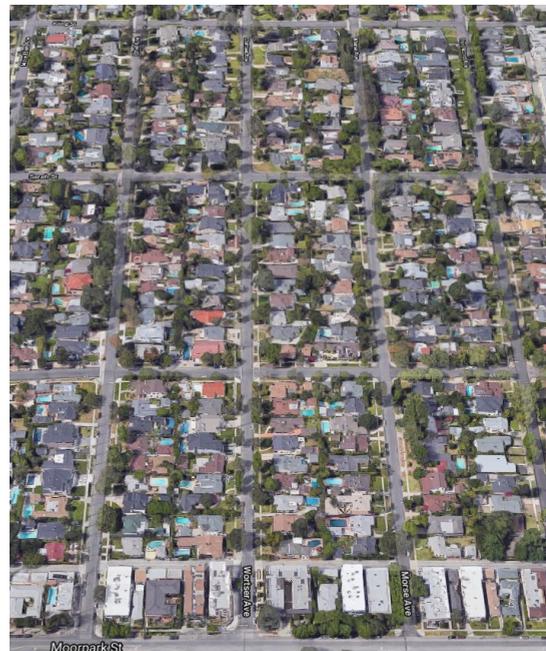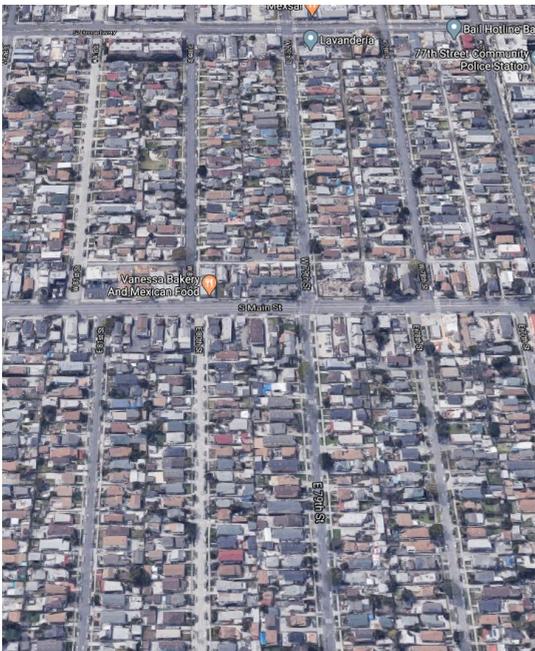
Image Credit: Google Maps

Figure 1: Side-by-side comparison of two neighborhoods in Los Angeles County showing differences in tree cover. South Los Angeles, on the left, has a tree cover under 10 percent; Studio City, on the right, offers residents much more shade and cooling.

Along with increasing urban tree cover and vegetation, urban structural improvements can be made to increase the solar reflectance of roofs, windows, walls, and pavements. Roof and pavement surfaces are typically dark and absorb rather than reflect the majority of solar radiation, converting that radiation into heat and contributing to a hotter built environment. A comprehensive review of studies evaluating the cooling ability of solar reflective and vegetated surfaces found that, if deployed at city-scale, such strategies would substantially reduce urban air temperatures. The consensus of studies was that average ambient temperatures could be reduced by 0.3°C (0.54°F) per 0.10 increase in solar reflectance across a city.[16] Peak ambient temperature decreases by up to 0.9°C (1.6°F) per each 0.10 increase in solar reflectance. Street tree deployment at scale would have a similar cooling effect of between 0.4°C (0.7°F) and 3°C (5.4°F), with the greatest cooling effect occurring within 100 feet of the tree.

In addition, there are many societal benefits of adopting strategies to cool down urban temperatures. Some of these are measurable, such as human health and air quality. Others remain challenging to quantify, such as effects on academic performance or tourism. Others still are primarily qualitative in nature, such as impacts on quality of life.

Rising urban temperatures have broad and serious negative implications for nearly every aspect of urban life. By reducing urban heat and its negative effects, the cooling strategies described in this report can produce quantifiable benefits to the same set of factors listed above. These cooling strategies have the potential to substantially offset, and at times cancel, rising urban air temperatures caused by climate change and urban heat islands. Pursuing these strategies in an integrated manner can improve conditions to the point of reducing heat-related illnesses and deaths.

URBAN TREE COVER
The layer of tree leaves, branches, and stems that provide
tree coverage of the ground when viewed from above.

SOLAR REFLECTANCE (OR ALBEDO)
The fraction of solar radiation that a surface reflects,
measured from 0 (not reflective) to 1 (fully reflective).
In general, lighter surfaces reflect more than darker surfaces.

TEMPERATURE CONVERSIONS
1 Celsius degree is equivalent to 1.8 Fahrenheit degree.
That means that a 2°C reduction is the same as
reducing temperature by 3.6°F.

EXTREME HEAT
Occurs when the weather is much hotter and/or
humid than usual, which can lead to heat-related
illnesses and deaths.

Urban cooling strategies offer measurable benefits. Here are just a few highlights:

- Based on a global study of 245 cities, trees can reduce maximum summer air temperatures by 0.5-2.0°C (0.9-3.6°F). Investing just $4 per resident in each city in tree planting efforts could improve the health of millions of people.[17]

- In the United States, urban tree canopy cover in a total of 97 cities saves 245-346 lives annually, and helps avoid more than 50,000 doctor's visits due to heat annually. The total heat-related benefits from trees are $1.3-2.9 billion annually.[18]

- Increasing the reflectance of a roof from 0.1-0.2 to 0.6 can cut net annual cooling energy use by 10 to 20 percent on the floor of the building immediately beneath the roof by reducing the need for air conditioning.[19]

- In a building that is not air conditioned, replacing a dark roof with a white roof can cool the top floor of the building by 1 to 2°C (2 to 3°F), enough to make these living spaces noticeably more comfortable and even save lives in extreme heat waves.[20]

Benefits of Urban Cooling Strategies

Health

Urban cooling strategies have the potential to provide substantial improvements to human health. Even modest increases in urban solar reflectance and vegetated cover can influence weather conditions and reduce mortality during extreme heat events. One study found that increasing average urban surface solar reflectance by 0.10 and increasing vegetated cover by 10 percent results in a 7 percent reduction in mortality during heat events.[21]

In addition to saving lives during heat events, urban cooling strategies improve human health and resilience. Reducing outdoor and indoor air temperatures on hot days improves human thermal comfort and mitigates the likelihood that existing health problems (e.g., cardiopulmonary disease, renal disease, diabetes) become an acute health emergency. Reflective and vegetated roofs and walls have been shown to reduce indoor air temperatures as well as improve occupant comfort. In Philadelphia, the Energy Coordinating Agency retrofitted attached residents with a white roof coating and taught residents the proper use of window fans. They found air temperature reductions of 2.7°C (5°F) from these upgrades in the top-floor rooms.[22]

Air Quality

Urban cooling strategies generally have a positive effect on air quality through reduced energy consumption. Using passive (i.e., non-mechanical) cooling strategies results in reduced indoor and outdoor temperatures and reduces the amount of energy needed for cooling. Urban cooling measures reduce ambient temperatures, and encourage natural processes that remove particulate matter from the air. The benefits of passive cooling strategies may be diminished in cities that rely heavily on mechanical cooling to deliver access to cooling services because cooling units exhaust heat into the air and may increase energy demand. However, energy efficiency measures in buildings may reduce the heat released from cooling units compared to less efficient buildings. Higher efficiency cooling will help reduce heat-related air quality issues such as ozone formation.

Urban greening improves air quality by removing PM2.5 from the air through a process known as dry deposition. Dry deposition occurs when airborne particulate matter deposits itself on the plant's surface, where most of it becomes incorporated into the leaf wax or cuticle, and is thus removed from the air. In some cities, trees currently remove as much as 64 tonnes of PM2.5 a year. More broadly, a review of relevant studies found that urban trees reduce nearby concentrations of PM2.5 anywhere from 9 to 50 percent with the largest effects within 100 feet of the tree.[23]

Water Quality

Increased permeable and solar reflective paving can lower the temperature of stormwater runoff or delay its release into urban waterways until it has cooled down. Urban greening efforts also retain and delay the release of stormwater runoff by increasing permeable surface areas that water can infiltrate. One study found that the water absorbed by trees can reduce direct stormwater runoff by as much as 62 percent.[24] Stormwater from cities often contains harmful pollutants, such as nitrogen and phosphorus from fertilizers and pet and yard waste. Unless treated, these pollutants can be directly discharged into nearby water bodies. Urban vegetation provides some filtering of pollutants that would otherwise flow into waterways.

Energy Use

There is a deep body of research demonstrating that solar reflective and green roofs reduce energy use and improve indoor thermal conditions. Typically, solar reflective roofs reduce peak indoor temperatures during the summer by up to 2°C (3.6°F) in moderately insulated buildings while cooling energy demand reductions may range between 10 percent and 40 percent. In winter, heating penalty may range between 5 and 10 percent as a function of the local climate and building characteristics.[25]

Increased vegetation and tree canopy cover also result in reduced energy demand. Well-placed trees shade buildings and cool the area around them by reducing the amount of sunlight that reaches the building envelope, especially if these trees shade windows and part of the building's roof. Benefits vary based on the orientation and size of the plantings, as well as their distance from a building. Street trees can reduce annual energy costs anywhere from $2.16 per tree per year to $64 per tree per year, depending on local climatic conditions.[26] The effect of trees on energy savings varies by climate. A 25 percent increase in tree canopy cover was estimated to reduce cooling energy use by 57 percent in Sacramento, California (temperate to hot climate), 25 percent in Lake Charles, Louisiana (hot/humid climate) and 17 percent in Phoenix, Arizona (hot/dry climate).[27]

Beyond base energy use, urban cooling strategies are particularly good at reducing summer peak demand because their energy reduction benefits occur when the sun is strongest and temperatures are highest. Cooling strategies such as increased surface reflectivity of roofs and pavements could reduce maximum peak power demand by up to 7 percent, lessening the likelihood of power outages during the hottest days of the year.[28] Further, when the grid is at max load peaker plants are fired up. Even modest energy efficiency gains can reduce the need for usage of peaker plants which in many regions rely on natural gas-fired or coal-fired diesel generators which emit deleterious black smoke.

Economy

The benefits of reducing urban air temperatures described in this report are potentially worth billions of dollars to the average city. An economic analysis of the costs and benefits of four combined urban cooling strategies in 1,692 cities found that all of the cooling strategies considered would generate positive net present values under each of the future climate scenarios studied.[29]

STUDY METHODS AND FINDINGS

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SYNOPTIC CLIMATOLOGY

For this study, we developed a model for Los Angeles County to see what various combinations — or "prescriptions" — of increases in urban tree cover and albedo would do to **temperature**, **humidity**, **air mass type**, and **heat-related mortality**. We studied four historical summer heat waves between the years 2006 to 2010, each with different characteristics, which enabled us to capture the range of heat events that commonly impact Los Angeles. We considered heat waves with characteristics such as early vs. late season, dry vs. humid, and intense vs. moderate heat. We then tested the impacts of four different prescriptions for L.A. County as a whole, and in 11 smaller districts in the county most vulnerable to heat-health risk.

We used a "synoptic" climatological approach, which classifies days into one of a number of discrete "air mass" types that traverse a given area and provide unique weather characteristics to that area. Rather than analyzing temperature, humidity, and other meteorological variables separately, the holistic approach of synoptic evaluation allows us to pinpoint "offensive" conditions that lead to unusually high health impacts, such as heat-related mortality.[30] This is important because humans respond to an entire suite of weather variables that impact the individual simultaneously. Our modeling team has used this approach to examine heat-health relationships in major cities around the world.

By considering observations of temperature, dewpoint, pressure, wind, and cloud cover four times daily for a particular location, we develop a "spatial synoptic classification" that classifies days into air mass types.[31] Two particular air masses have been found in many studies to be associated with statistically significant higher mortality rates, particularly during the summer months: dry tropical (DT) and moist tropical plus (MT+).[32] These are the air mass types we focused on.

Table 1: Summary of air mass type abbreviations and descriptions.
Bold items indicate air mass types with statistically significant higher mortality rates.

SSC Air Mass Type Abbreviation	Air Mass Type Description
DP	Dry Polar: cool, dry air mass
DM	Dry Moderate: comfortable and seasonally warm
DT	**Dry Tropical: hot, dry, and very oppressive**
MP	Moist Polar: cool and moist, overcast
MM	Moist Moderate: warmer than MP but still wet and overcast
MT	Moist Tropical: typical summer air mass, warm and humid
MT+, MT++	**Moist Tropical Plus: excessively hot and humid; oppressive**
TR	Transition between different air masses; frontal boundary

We developed a model for Los Angeles County to see what various combinations — or "prescriptions" — of increases in urban tree cover and albedo would do to temperature, humidity, air mass type, and heat-related mortality. We used a "synoptic" climatological approach, which classifies days into one of a number of discrete "air mass" types that traverse a given area and provide unique weather characteristics to that area.

COUNTY-LEVEL ANALYSIS: METHODS

To explore the effects of increasing urban tree cover or albedo at the district scale, we used a leading regional scale atmospheric model called the Weather Research and Forecasting (WRF) model, version 3.8.1.[33] This model is routinely used to simulate urban climates, considering the effects of individual buildings and the various processes occurring within an urban area. For this study, we simulated Los Angeles County using three nested domains, with the innermost domain covering the entire county with 156 by 156 grid cells of 500 meters per side. For more information about the modeling approach, see Appendix A.

For this analysis, we focused on how heat impacts human mortality in Los Angeles — that is, to what degree the number of average daily deaths that occur from all internal causes in Los Angeles County increase under different heat wave conditions. Vital statistics mortality data were provided from California's Department of Public Health (CDPH), and made available for this study through UCLA, which has the data on its servers. These patient-level mortality data, reported by zip code, were used to generate frequencies of the number of deaths resulting from all internal causes on each day between May and October for the years 2000 through 2010 in Los Angeles County. "All internal causes of death" were assigned to individuals whose cause of death was in the following categories, either as a primary or secondary cause of death (as listed within up to 20 secondary causes): exposure to excessive natural heat, effects of heat and light, cardiovascular, respiratory, acute kidney failure and chronic kidney disease, disorders of fluid, electrolyte and acid base imbalance, dehydration, and diabetes.

Correlating the mortality data with the meteorological data for the offensive air masses (DT, or dry tropical, MT+, or moist tropical +), we arrived at the following statistically significant algorithm:

$$\% \text{ MORT} = -1.426 + 0.363 \text{ NFPTS} + 5.219 \text{ DT} + 1.609 \text{ MT} + 0.057 \text{ AT05}$$

Where:

✱ **% MORT** is the percent change in mortality from the baseline (average) value (we consider this heat-related mortality)

✱ **NFPTS** is the Nairn-Fawcett Extreme Heat Factor, which evaluates heat in three consecutive day increments and determines whether the period before the heat wave has been hot or comfortable, which could have a significant impact on health outcomes[34]

✱ **DT** is a dummy variable which is added just for the DT air mass days

✱ **MT** is a dummy variable for MT+ which is added just for the MT+ days

✱ **AT05** is apparent temperature at 5:00 AM

Using this algorithm, we determined that during an average five-day Los Angeles heat wave, there are 4.1 percent more deaths above the baseline on the first day of the event, and 11.9 percent more deaths on the fifth day of the event. Clearly, heat is a significant threat to the health of residents of this region.

The next step in the project was to estimate how the various combinations — or prescriptions — of changes in urban tree cover and albedo would impact the local meteorology. We selected four distinct prescriptions plus a present-day baseline case (Table 2). The four prescriptions vary considerably in tree cover and reflectance of pavements and roofs, with Rx 4 being the most aggressive scenario.

Table 2: Tree cover and solar reflectance "prescriptions" tested.

	Tree Cover	Solar Reflectance (Albedo)
Rx 1	Low	High
Rx 2	High	Low
Rx 3	Medium	Medium
Rx 4	High	High

Tree Cover Prescriptions Defined
Low = 25% relative increase (baseline x 1.25)
Medium = 100% relative increase (baseline x 2)
High = 40% tree cover (regardless of baseline)
For example, the tree cover for L.A. County is approximately 16%. A low scenario would be an increase to 20%; medium to 32%; high to 40%.

Solar Reflectance Prescriptions Defined
Baseline = All roofs combined reflect 17% of the solar energy that falls on them. Pavements, on average reflect 10%.
Low = Roofs reflect 27% of solar energy. Pavements reflect 20%.
Medium = Roofs reflect 37% of solar energy. Pavements reflect 25%.
High = Roofs reflect 45%. Pavements reflect 35%.

We then selected four historic, distinct heat waves to evaluate for the Los Angeles County area, each different from the others. Note that the heat waves occur at different times during the summer season.

July 22-26, 2006: hot and humid, dominated by MT+ air mass days.

June 19-22, 2008: a drier event with a mixture of MT and DT days.

August 26-30, 2009: the least excessive heat wave of the four; we wanted to evaluate a more common situation that was not extreme.

September 24-29, 2010: a very hot Santa Ana event, with an abundance of DT days.

COUNTY-LEVEL ANALYSIS: RESULTS

We saw clear changes in temperature and dewpoint temperature across all four prescriptions. Temperatures mostly showed decreases in the range of 1-2°C (1.8-3.6°F), while dewpoint temperatures showed similar increases in magnitude. Rx 1 and Rx 3, which have more modest urban tree cover increases that the other prescriptions, show smaller changes than Rx 2 and Rx 4, with the most aggressive tree canopy increases. This is not a surprising result, since added tree cover would add water vapor into the atmosphere through evapotranspiration, thus increasing the dewpoint temperature. Nevertheless, in general, the largest decreases in temperature also occur in Rx 2 and Rx 4, sometimes exceeding 3°C (5.4°F), especially during the August 2009 event (Table 4), when maximum temperatures reached 36-40°C (97-104°F), depending on location.

Tables 3 and 4. Changes in meteorology for the June 2008 and August 2009 heat waves.
All four scenario "prescriptions" are presented. Delta T is the change in temperature (°C) from the baseline.
Delta Td is the change in dewpoint temperature (°C) from the baseline. Increasingly dark blue represents greater reductions; increasingly dark orange represents greater increases.

Table 3. June 2008 heat wave.

Local Time	Rx 1		Rx 2		Rx 3		Rx 4	
	ΔT	ΔT	ΔT	ΔT	ΔT	ΔT	ΔT	ΔTd
06-19-08 5:00	-0.6	-0.6	-0.7	-1.3	-0.5	-0.9	-1.0	-1.3
06-19-08 11:00	-1.6	0.3	-1.2	2.5	-1.3	1.3	-2.2	2.6
06-19-08 17:00	-0.9	1.7	-1.0	3.4	-0.9	2.5	-1.4	4.3
06-19-08 23:00	-1.1	1.6	-1.4	1.9	-1.2	1.9	-1.9	2.3
06-20-08 5:00	-1.6	-1.2	-1.2	-1.6	-1.4	-1.4	-1.9	-1.4
06-20-08 11:00	-1.8	0.5	-1.4	3.7	-1.6	2.1	-2.5	4.0
06-20-08 17:00	-0.9	0.4	-1.0	1.9	-0.9	1.1	-1.4	2.1
06-20-08 23:00	-1.2	-0.7	-1.6	-0.3	-1.4	-0.4	-2.2	-1.2
06-21-08 5:00	-1.8	-1.8	-1.4	-2.1	-1.5	-1.8	-2.4	-3.1
06-21-08 11:00	-2.3	0.7	-1.6	3.7	-1.9	2.3	-3.1	4.0
06-21-08 17:00	-1.0	0.6	-0.9	1.8	-0.9	1.2	-2.4	3.4
06-21-08 23:00	-0.6	-0.2	-0.7	0.0	-0.5	0.0	-1.1	-0.1
06-22-08 5:00	-1.3	-0.8	-1.2	-1.2	-1.2	-0.9	-1.8	-1.3
06-22-08 11:00	-1.7	-0.5	-1.4	1.9	-1.5	0.7	-2.5	1.9
06-22-08 17:00	-1.0	0.4	-1.1	1.6	-1.0	1.0	-1.5	1.8

Table 4. August 2009 heat wave.

Local Time	Rx 1		Rx 2		Rx 3		Rx 4	
	ΔT	ΔT	ΔT	ΔT	ΔT	ΔT	ΔT	ΔTd
08-26-09 5:00	0.4	0.2	0.4	0.1	0.4	0.2	0.4	0.1
08-26-09 11:00	-1.1	0.6	-0.7	2.2	-0.9	1.4	-1.5	2.6
08-26-09 17:00	-1.0	2.3	-1.1	3.0	-1.0	2.6	-1.8	4.6
08-26-09 23:00	-1.9	-0.8	-1.8	-0.6	-1.9	-0.8	-2.8	-1.2
08-27-09 5:00	-1.1	-2.8	-1.1	-0.2	-1.1	-2.2	-1.6	-2.7
08-27-09 11:00	-1.3	0.9	-0.9	3.8	-1.1	2.5	-1.8	4.4
08-27-09 17:00	-1.3	-0.1	-1.4	1.4	-1.4	0.7	-2.2	1.2
08-27-09 23:00	-1.8	0.9	-1.9	0.6	-1.9	0.9	-2.8	1.5
08-28-09 5:00	-1.1	-0.9	-0.8	-0.4	-0.9	-0.6	-1.5	-0.9
08-28-09 11:00	-1.9	-0.2	-1.5	2.2	-1.8	1.2	-2.6	1.9
08-28-09 17:00	-0.6	0.7	-0.9	2.0	-0.7	1.4	-1.0	1.8
08-28-09 23:00	-1.2	0.0	-1.3	-0.4	-1.2	-0.2	-1.9	-0.5
08-29-09 5:00	-1.2	0.0	-0.8	0.2	-1.0	0.2	-1.7	0.3
08-29-09 11:00	-1.3	0.9	-0.9	3.0	-1.1	2.1	-1.8	3.8
08-29-09 17:00	-0.3	0.2	-0.6	1.7	-0.5	1.1	-0.8	2.1
08-29-09 23:00	-0.9	-0.4	-1.1	-0.4	-1.0	-0.4	-1.7	-0.8
08-30-09 5:00	-0.8	0.3	-0.6	0.4	-0.7	0.5	-1.1	0.6
08-30-09 11:00	-1.3	0.0	-0.9	2.3	-1.1	1.3	-1.8	2.7
08-30-09 17:00	-1.1	0.1	-1.2	1.3	-1.3	0.8	-2.1	1.6

Besides evapotranspiration increases, some of the increases in dewpoint temperature are actually physically attributed to the cooling temperatures themselves, especially for Rx 2 and Rx 4. When temperatures are cooled, vertical motion of the atmosphere is inhibited, and the dispersal of near-surface moisture is therefore less efficient. Thus, moisture from sources such as car exhaust, air conditioning, and even from trees is less likely to be dispersed vertically and more likely to accumulate near the ground.

However, the decrease in air temperature is more important in terms of human well-being than an accompanying increase in dewpoint temperature. The apparent temperature, which is the perceived temperature by humans and represents the combined impacts of thermal and moisture characteristics in the atmosphere (sometimes called the "heat index"), is more impacted by a drop in temperature than a rise in dewpoint temperature. For example, an air temperature of 40°C (104°F), coupled with a dewpoint temperature of 20°C (68°F), yields an apparent temperature of 44°C (111°F). If the temperature is dropped to 37°C (99°F) and the dewpoint temperature is raised to 22°C (72°F) — something that is common within the scenarios we modeled for this study — the apparent temperature drops to 42°C (107°F). Thus, the air temperature plays a more important role in human perceived conditions than does dewpoint temperature.

More important to our study than the changes in meteorology is its impact on human mortality, as demonstrated in Tables 4 and 5. Also shown for each day is the air mass type and the 5AM and mean daily apparent temperature. A desired outcome is a reduction in the percent increase in mortality across the cases when compared to the baseline. This reduction represents a decline in heat-related mortality.

The June 2008 heat wave (Table 5) provides a good example. Based on our algorithm for Los Angeles, we estimated that 43 people died in the County from heat-related causes during this heat event. On June 19, 2008, the baseline shows that an MT air mass was present that day (in the baseline case). The same was true for June 20, and a DT air mass was present on June 21, while a transition air mass (change from one air mass to the next; cold front passage) was present on June 22. The 5AM apparent temperature on each day (e.g., 18.2°C on June 19), is shown, along with the daily mean. In the baseline case, which represents reality, the mortality increase was 1.2 percent above the mean daily mortality, meaning that the heat increased the number of people that died in Los Angeles County by 1.2 percent per day. On June 21, 2008, the hottest day of the heat wave, the mortality increase was 11 percent and on June 22, it was 13.5 percent. Observing the apparent temperatures on June 22, it is clear that a cold front came through during the day, ending the heat wave. The 5AM apparent temperature is higher than the daily mean; 5AM is usually around the coolest time of the day.

Looking at Rx 1 for June 19, there was no reduction in excess mortality although apparent temperatures were somewhat lower. It was still 1.2 percent above the mean. Yet reductions can be seen for the other three days of the heat wave: on the 20th, from 1.9 percent in the baseline to 1.7 percent in Rx 1; on the 21st, from 11 percent in the baseline to 8.5 percent in Rx 1; and on the 22nd, from 13.5 percent in the baseline to 12.1 percent in Rx 1. Thus, for the entire four-day heat event period, Rx 1 produced a 1 percent decline in excess mortality, from 6.9 to 5.9 percent. This is a 15 percent decrease in heat-related mortality (1 percent decrease divided by 6.9 percent equals about 15 percent), and represents about 6 saved lives (from 43 excess deaths to 37 deaths). In contrast, Rx 2 only reduced excess mortality by 8 percent (or 3 deaths) when compared to the baseline. Rx 3 did slightly better than Rx 2, but Rx 4, the most aggressive case in terms of increasing tree cover and albedo, reduced excess mortality by 18 percent, or about 8 deaths (from 43 to 35). We find these results to be encouraging, as they indicated that heat-related deaths could be reduced by up to 18 percent in a heat wave of this type.

Tables 5 and 6. Changes in air mass type and mortality for each of the prescription scenarios under different heat waves.
5AM apparent temperature and mean daily apparent temperature are displayed for each day during the heat wave. Red rows indicate percent increase in excess mortality over the mortality standardized value. The mean increase for all heat wave days is shown at the second row from the bottom. The net decrease in heat-related mortality from the baseline scenario is shown in the bottom row. Blue rows show air mass type. Dark blue cells (Table 6) show actual changes in air mass type due to a significant meteorological change.

Table 5. June 2008 heat wave.

		Baseline	Rx 1	Rx 2	Rx 3	Rx 4
6/19/08	SSC Type	MT	MT	MT	MT	MT
	5am AT	18.2	17.4	17	17.3	16.7
	Mean AT	23	22.2	22.5	22.4	22.1
	Mortality Increase %	1.2	1.2	1.1	1.2	1.1
6/20/08	SSC Type	MT	MT	MT	MT	MT
	5am AT	24.4	22.3	22.6	22.5	22
	Mean AT	25.1	23.6	24.3	23.9	23.4
	Mortality Increase %	1.9	1.7	1.7	1.7	1.6
6/21/08	SSC Type	DT	DT	DT	DT	DT
	5am AT	24.9	22.5	22.4	22.4	21.1
	Mean AT	26.4	24.9	25.5	25.3	24.6
	Mortality Increase %	11.0	8.5	9.5	9.1	8.1
6/22/08	SSC Type	TR	TR	TR	TR	TR
	5am AT	26.3	24.7	25.1	25.2	24.5
	Mean AT	24.9	23.8	24.3	24.1	23.8
	Mortality Increase %	13.5	12.1	13.2	12.7	11.7
Mean 4-day (6/19-22) increase in Mortality %		6.9	5.9	6.4	6.2	5.6
Net decrease in heat-related mortality cases		n/a	-15%	-8%	-11%	-18%

The September 2010 event (Table 6), a dry Santa Ana event, had even more encouraging outcomes. Most of the days during this heat wave were DT (dry tropical), the air mass type that kills the most people in Los Angeles. On September 26, there was an actual air mass change under Rx 2, 3, and 4, from DT to a more benign dry moderate (DM) air mass. Such air mass changes are rare in similar evaluations of cities. This change has a great impact on reducing heat-related mortality, as can be seen for Rx 2, 3, and 4 on September 26. During this heat wave, the mean percentage reduction on the days when excess mortality was estimated dropped fairly dramatically. There was a 29 percent reduction in mortality for Rx 4, which is the equivalent of saving 23 lives during that heat event (from 78, based on our algorithm for this heat event, to 55 deaths). This result was among the most encouraging we have seen for such heat wave analysis in any large urban area.

For a discussion of the 2006 and 2009 heat event findings for Los Angeles County, see Appendix B.

SUMMARY OF COUNTY-LEVEL RESULTS

All four heat events evaluated in this countywide analysis saw double-digit decreases in mortality. The most encouraging outcomes were seen in the September 2010 heat wave, which demonstrated a 20 percent or greater decrease in excess mortality for three of the four prescriptions. This event was a typical Santa Ana heat wave, with very hot daytime temperatures accompanied by low dewpoints. Seeing such mortality reductions suggests that modifying the land cover in Los Angeles County can save many lives during common heat waves.

Table 6. September 2010 heat wave.

		Baseline	Rx 1	Rx 2	Rx 3	Rx 4
9/24/10	SSC Type	DM	DM	DM	DM	DM
	5am AT	18.6	18.4	18.4	18.5	18.5
	Mean AT	20	19.2	19.7	19.5	19.2
	Mortality Increase %	0	0	0	0	0
9/25/10	SSC Type	DM	DM	DM	DM	DM
	5am AT	20.3	19.5	19.9	19.9	19.6
	Mean AT	22.4	21.8	22	22	21.7
	Mortality Increase %	0	0	0	0	0
9/26/10	SSC Type	DT	DT	**DM**	**DM**	**DM**
	5am AT	20.9	20	20.3	20.1	19.9
	Mean AT	22.5	21.6	21.6	21.4	21.1
	Mortality Increase %	5.0	4.9	0	0	0
9/27/10	SSC Type	DT	DT	DT	DT	DT
	5am AT	24.6	23.7	23.9	23.9	23.6
	Mean AT	27.7	26.7	27	26.9	26.5
	Mortality Increase %	11.7	9.5	9.9	9.7	8.8
9/28/10	SSC Type	DT	DT	DT	DT	DT
	5am AT	23.8	23.1	22.9	23	22.7
	Mean AT	26.4	25.8	26	26	25.6
	Mortality Increase %	18.2	15.4	15.9	15.6	14.3
9/29/10	SSC Type	MT	MT	MT	MT	MT
	5am AT	21.5	20.6	20.8	20.8	22.3
	Mean AT	22.9	22.4	22.6	22.5	22.8
	Mortality Increase %	14.5	12	12.8	12.5	12.1
Mean 6-day (9/26-29) increase in Mortality %		**12.4**	**10.5**	**9.7**	**9.5**	**8.8**
Net decrease in heat-related mortality cases		**n/a**	**-16%**	**-22%**	**-24%**	**-29%**

How Tree Canopy and Albedo Scenarios Were Developed

Tree canopy and albedo scenarios were developed for both the countywide analysis and the district analyses. For the countywide analysis, a baseline number was determined to represent existing tree cover, roof albedo, and pavement albedo. Using the baseline, four scenario combinations or "prescriptions" were developed to test the relative impact of tree cover and albedo.

County-Level Analysis

We conducted an assessment of land cover classes by using i-Tree Canopy, which allowed us to identify baseline tree cover. i-Tree Canopy is part of the i-Tree suite of peer-reviewed software tools developed by the USDA Forest Service, Davey Tree Expert Company, and other partners, used to facilitate urban and rural forestry analysis and benefits assessment (see itreetools.org). We used i-Tree Canopy to determine the tree cover for L.A. County's urban areas only, as this is where urban populations are concentrated and where target neighborhoods would be identified for tree cover and albedo increases. Through this process, we determined that the existing tree cover for L.A. County's urban areas is 16.6 percent, with an error of +/- 1.7 percent.

We then reviewed relevant literature and tree cover increase efforts to arrive at tree canopy increase scenarios that represented a range of ambitions, from moderate to more aggressive. The scenarios that were ultimately tested for the countywide analysis were:

- **Baseline = 16.6% tree cover**

- **Low = 25% relative increase** (baseline x 1.25)
  This is considered a reasonably implementable target

- **Medium = 100% relative increase** (baseline x 2)
  This is consistent with tree cover goals in numerous cities around the world

- **High = 40% tree cover** (absolute number, regardless of baseline)
  We consider this an achievable uppermost limit for demonstration purposes

In 2019, a parcel-level tree canopy cover assessment of Los Angeles County was conducted as an extension of this project, funded by the USDA Forest Service and the California Department of Forestry and Fire Protection. That assessment was completed toward the latter part of this study, and the timing of the two efforts unfortunately did not match. The high-resolution assessment is nevertheless available for all subsequent analyses that will follow this study, and the assessment data are in fact being incorporated in multiple efforts led by various municipalities and researchers in the L.A. region.

To determine baseline roof and pavement albedo and propose scenarios for their increase, we reviewed relevant literature and efforts, such as Lawrence Berkeley National Laboratory's Hot Roofs, Cool Roofs mapping tool (see albedomap.lbl.gov). Through this process, we arrived at the assumption that the existing albedo for L.A. County was 17 percent for roofs and 10 percent for pavement. The percent of solar energy that is reflected by a given surface is generally expressed not as 17 percent and 10 percent, in our example above, but in the format 0.17 and 0.10, respectively.

The scenarios tested for the county-level analysis were:

⊚ **Baseline = 0.17 for roofs, 0.1 for pavement**

⊚ **Low = 0.27 for roofs, 0.2 for pavement**

    — Roofs: The scenario is based on existing regulation in California and Los Angeles for cool roofs on low and steep slope roofs.

    — Pavement: The scenario factors in pavement aging for asphalt (which tends to lighten the pavement) and the inclusion of lighter-colored concrete pavement surfaces.

⊚ **Medium = 0.37 for roofs, 0.25 for pavement**

    — Roofs: The scenario assumes more rapid deployment of highly solar reflective low-slope roofs that exceed California Title 24 requirements.

    — Pavement: The scenario envisions greater deployment of cool pavement products currently deployed in a large pilot project in the city.

⊚ **High = 0.45 for roofs, 0.35 for pavement**

    — Roofs: The scenario assumes maximum implementation following these assumptions: a split of 60 percent steep roofs/40 percent low roofs, where high-albedo roof options would yield 0.25 for steep and 0.75 albedo for low, for an average of 0.45.

    — Pavement: The scenario envisions maximum deployment of cool pavement applications.

District-Level Analysis

We used i-Tree Canopy to conduct a land cover assessment to determine baseline tree cover and albedo numbers for each district. The categories of land cover we assessed included: tree; pervious land including groundcover and low-lying shrubs; roof - steep slope (shingle or tile, and/or apparent slope of >2' per 12'); roof - flat slope (apparent slope of <2' per 12'); road; sidewalk (including driveway aprons); parking lot; other pavement (including playgrounds, patios, etc.); and other land cover including water. Values for each district had a standard error of +/- 3 percent or less.

The land cover assessment revealed a wide range of values for most land cover categories, confirming that a more granular analysis like the one we were attempting was warranted over a county-level one. For example, existing tree canopy cover ranged from 6.8 percent to 18.9 percent by district. For tree cover, the same low, moderate, and high scenarios were used as in the county-level analysis. For the albedo scenarios at the district level, we considered pavement, and two categories of roof — flat and steep — which tend to have very different solar reflectance values due to materials and pitch. The albedo scenarios tested for the district-level analysis were:

⊚ **Low = 0.63 for flat roofs, 0.25 for steep roofs, 0.25 for pavement**

    — Flat roof based on prescriptive requirement in Title 24

    — Steep roof based on current requirement in Los Angeles

    — Pavement scenario slightly increased over county-level analysis in consideration of increased material availability and deployment

⊚ **Medium = 0.7 for flat roofs, 0.3 for steep roofs, 0.3 for pavement**

⊚ **High = 0.75 for flat roofs, 0.35 for steep roofs, 0.35 for pavement**

DISTRICT-LEVEL ANALYSIS: METHODS

With the county-level analysis complete, we segmented Los Angeles County into districts in order to determine region-by-region variations in heat/health sensitivity as well as the effectiveness of various tree cover and albedo prescriptions. The districts that we formulated were designed to be as homogeneous as possible in terms of demographics, socio-economic status, meteorology, and climate. Refer to Appendix C for a description of the district designation process.

Based on past experience, we determined that each district should have a population of about 300,000 or greater, since smaller population sizes would contribute to variations in mortality that are more likely to be governed by local events unrelated to meteorology. The daily variations in mortality related to events such as heat waves are always better determined when the areas being examined have substantial population sizes. Maintaining the 300,000-person threshold was possible for most but not all districts.

We identified 18 fairly homogenous, heat-vulnerable districts for Los Angeles County. Some proved to be problematic for reasons such as incomplete mortality datasets or low population densities. Thus, we reduced the number of districts to be evaluated to a total of 11 (Figure 2; see Appendix D for a list of cities/neighborhoods and corresponding zip codes included in each district). These districts were developed to be completely inclusive of zip code areas, which is the finest scale at which the mortality data are available. Virtually all of the low-income districts among the original 18 districts were included in the 11 districts selected for evaluation.
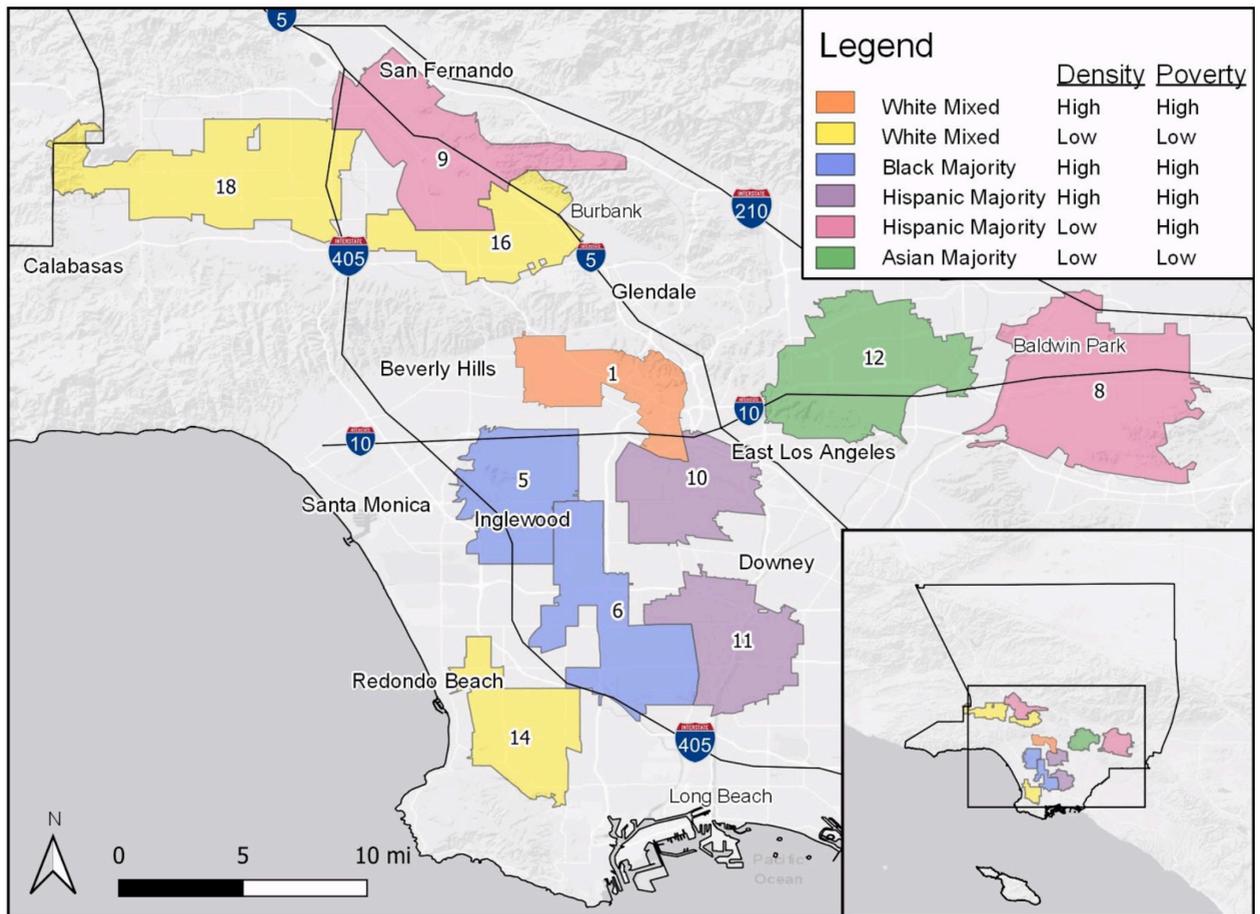
Credits: GIS analysis by Dr. Regan Maas; map by Cassie Roberts.

Figure 2. Districts selected for analysis. See Appendix D for a list of cities and zip codes included in each district.
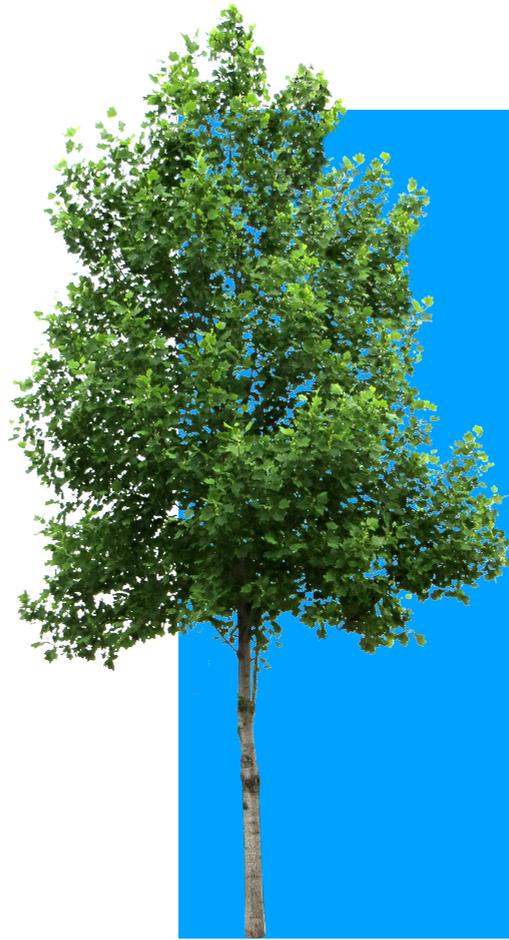
27

For the district-level modeling, we made the conservative assumption that the tree cover and albedo prescriptions applied only to the single district being evaluated, and that no land cover changes were made to any other part of the county.

The methodology used for the district-level analysis was similar to that used in the county-level analysis, with one key difference. For the district-level modeling, we made the conservative assumption that the tree cover and albedo prescriptions applied only to the single district being evaluated, and that no land cover changes were made to any other part of the county. Thus, each district was an "island" of increased tree cover and albedo within a surrounding county that remained at baseline conditions. We made this assumption to render the results as conservative as possible, even though it is unlikely that only an individual district would undergo such land cover changes without any change at all within the surrounding area.

We developed a relationship between heat and mortality for each of the districts evaluated. Our meteorological evaluation was based mainly upon the Nairn-Fawcett excess heat factor, which evaluates heat in three consecutive day increments and determines whether the period before the heat wave was hot or comfortable — which could have a significant impact on health outcomes.[35] For most of the low-income districts, the relationships between excess mortality and the Nairn-Fawcett factor was quite good; for some of the more affluent districts, the results were less aligned. We utilized the acquired algorithms for each district to estimate mortality for each of the districts during the heat waves, using the same historic heat waves that were used for the county-level model to keep the analyses parallel, and also to determine mortality reductions under each of the scenarios.

DISTRICT-LEVEL ANALYSIS: RESULTS

There were strong differences between the regions in terms of heat impact upon human mortality (Table 7). In general, lower-income, higher-density districts demonstrated a greater number of excess deaths during heat events than did the higher-income, lower-density districts. Some of the more vulnerable districts only demonstrated large mortality increases during days of the most extreme heat. For example, during less severe heat, District 5 showed little to no excess mortality, but during more extreme heat, mortality increased by 15 percent. The percent increase rose to 25 percent when there were 4 or more consecutive days. Conversely, District 11 showed high levels of anomalous mortality across all heat wave categories.

Table 7. Results showing excess deaths during excessive heat days for the 11 selected districts.
Excess deaths represent average total deaths above/below the baseline; % represents the percentage increase/decrease of excess deaths over the baseline total.

	Nairn-Fawcett Index				Synoptic Classification				
	Moderately Hot Days		Very Hot Days		Moderately Hot Days		Very Hot Days		
District	Excess deaths	%	Excess deaths	%	Excess deaths	%	Excess deaths	%	
5	-0.19	-4%	0.69	15%	0.04	1%	1.12	25%	Long Beach Region
6	0.30	8%	0.84	22%	0.15	4%	-0.19	-5%	
10	0.14	6%	0.00	0%	0.13	6%	0.81	36%	
11	0.30	12%	1.31	52%	0.42	17%	0.80	32%	
12	-0.09	-2%	0.53	12%	0.11	2%	0.44	10%	
14	0.20	9%	0.46	21%	0.16	7%	0.40	19%	
# of days	68		12		62		10		
1	-0.06	-2%	1.92	55%	0.13	4%	0.18	5%	Burbank Region
8	0.35	10%	0.50	15%	0.31	9%	0.07	2%	
9	0.61	22%	0.53	19%	0.19	7%	0.10	4%	
16	-0.05	-2%	1.03	36%	0.01	0%	0.05	2%	
18	0.06	2%	-0.82	-20%	0.00	0%	0.10	2%	
# of days	96		15		226		154		

To develop baselines and scenarios for each of the 11 evaluated districts, we used meteorological data from meteorological stations with rather complete historical records: Long Beach and Burbank. District meteorology and air mass categorizations were based upon proximity to these stations, with some districts assigned to the Long Beach climate region and others to Burbank.

The districts in the Long Beach climate region generally showed stronger results than those in the typically hotter Burbank region. This is explained by several factors. First, lower-income, higher-density districts are found in the Long Beach region, including districts 5, 6, 10, and 11. Second, our modeling team determined in numerous past studies that urban areas in hotter climates show less vulnerability to heat-related mortality than those in cooler, more variable climates. The districts in the Long Beach region generally exhibit cooler summer temperatures but are nevertheless subject to very hot conditions during Santa Ana events. Those in the Burbank region, which include eastern and valley portions of L.A. County, have less variable summer weather, with very hot conditions being more common.

It is clear that heat does not impact the health of all communities in Los Angeles County equally. Variations in heat vulnerability among districts is related to socio-economic factors, with our analysis indicating that the burden is generally borne by lower-income, more densely-populated communities. Variations may also be influenced by the frequency and intensity of common heat waves within these districts, with the hottest areas generally being less sensitive. Hotter neighborhoods are generally more adapted to heat both from a physiological and infrastructural standpoint. Variability appears to be a more significant risk factor than extremes in temperature.

We applied prescriptions of tree cover and albedo tailored to each district and derived from baseline conditions (see Table 2). We applied these prescriptions to each district individually using the same heat waves for this more granular analysis as were used in the County model. Once again, we assumed that no changes in canopy cover or albedo were made to any other part of the County outside the particular district that we were evaluating.

Reductions in temperature were noted for virtually all of the districts, and under all four prescriptions. The reductions were modest to moderate, depending upon the district and the time of day, with the largest reductions generally occurring during the midday hours. For the most aggressive prescription, Rx 4, temperature reductions approached 2°C (3.6°F) during the hottest part of the day for some districts. This degree of cooling can potentially mean the difference between life and death for some individuals.

In many instances, mortality reductions exceeded 20 percent for the more aggressive prescriptions, and sometimes for more moderate prescriptions ones as well (Table 8). In this example for District 11 for the heat wave of September 2010, reductions of greater than 20 percent from actual values occurred under all four prescriptions, a result which was common in other districts as well. These reductions exceeded 40 percent for Rx 4, which represented almost three lives saved during this particular heat event. With many heat events of this type during a typical decade, it is apparent that tree cover and albedo changes akin to those suggested in Rx 4 could yield many lives saved over a period of several summers. Excess mortality reductions within districts under the various prescriptions modeled suggest that even a 1-2°C (1.8-3.6°F) reduction in temperature can save a substantial number of lives.

Table 8. Changes in excess mortality during the heat event of September 2010 in District 11.
The "sum" row indicates the total mortality for the five-day event; the "reduction" row indicates percent mortality reduction from the baseline for each case.

Date	Actual	Rx 1	Rx 2	Rx 3	Rx 4
9/24/2010	0.0	0.0	0.0	0.0	0.0
9/25/2010	0.0	0.0	0.0	0.0	0.0
9/26/2010	0.0	0.0	0.0	0.0	0.0
9/27/2010	3.0	2.2	1.9	2.2	1.6
9/28/2010	3.5	2.8	2.4	2.7	2.3
SUM	6.5	5.0	4.3	4.9	3.9
REDUCTION		23%	33%	25%	41%

Table 9. Changes in excess mortality during the heat event of June 2008 in District 6.

Date	Actual	Rx 1	Rx 2	Rx 3	Rx 4
6/19/2008	0.0	0.0	0.0	0.0	0.0
6/20/2008	0.0	0.0	0.0	0.0	0.0
6/21/2008	0.2	0.1	0.0	0.1	0.0
6/22/2008	0.6	0.5	0.2	0.5	0.2
SUM	0.91	0.59	0.23	0.59	0.18
REDUCTION		35%	75%	35%	80%

For virtually all of the scenarios, we could not find any air mass changes taking place within any of the cases. We attributed this to the assumption we made regarding no tree cover or albedo changes for the remainder of the County outside of the district under evaluation, which is a conservative approach to a study of this type. Nevertheless, considering the robust results generally noted, a more liberal approach would certainly yield even more encouraging findings.

The variation in results is one of the most compelling portions of this evaluation. In general, findings were intuitive, with lower-income, more densely-populated districts and communities with more people of color showing the greatest mortality risk during heat waves, and the greatest numbers of lives potentially saved under the various prescriptions of tree canopy and albedo. The hottest events produced the greatest excess mortality numbers. The most aggressive cases, with the largest tree cover and albedo increases, showed the greatest reductions, with one to two out of every four lives currently lost to heat saved due to land cover changes. For example, districts 1, 6, and 11, all high-density, high minority districts, demonstrated the highest mortality during the modeled heat waves and often also had the greatest reductions. Districts 12, 14, and 18, low-density districts with relatively higher income, exemplified situations with less robust results, with low percentages of decrease in mortality and/or low excess mortality numbers. Thus, we have a good quantitative comparison of how the different districts, and their unique socio-economic characteristics will behave during various types of heat waves studied.

In general, findings were intuitive, with lower-income, more densely-populated districts and communities with more people of color showing the greatest mortality risk during heat waves, and the greatest numbers of lives potentially saved under the various prescriptions of tree canopy and albedo. The most aggressive cases, with the largest tree cover and albedo increases, showed the greatest reductions, with one to two out of every four lives currently lost to heat saved due to land cover changes.

However, not all results were intuitive. Although the low-density higher income District 18 expectedly demonstrated non-significant results, District 10, which is a high-density, high-poverty district, showed non-significant findings in. District 10 is socio-economically similar to District 11 (the most vulnerable district with the most encouraging results), as well as districts 1 and 6, which are also similar socio-economically similar and showed the potential for significant numbers of lives saved. District 10 did not respond like any of these other districts and stands out as the most glaring non-intuitive result, and points to the possibility that there may be social or other factors at work which make this a more heat-resilient district. This finding warrants further investigation, which we will seek to pursue in a future phase of this project.

Overall, our research found that many lives can be saved during a particularly hot summer, and during a typical decade, and increasing tree canopy and albedo cover can vastly improve the health conditions in lower-income districts of the County during heat waves.

CLIMATE CHANGE PROJECTIONS

A typical approach to evaluating the impact of climate change upon excess mortality is to apply climate models to mortality algorithms and determine how many additional deaths would occur under the various emissions scenarios.[36] In this study, we departed from the norm and attempted something quite different in the hopes of producing an alternative approach to quantifying the impacts of land cover choices on localized climate. We attempted to determine how many years of climate change-caused warming we could potentially delay if cooling prescriptions were implemented. We modeled the four prescriptions under both business-as-usual and moderate mitigation scenarios at the Los Angeles County level (the data are too coarse for a more granular analysis). We used Representative Concentration Pathways (RCP) models 8.5 and 4.5, approved by the Intergovernmental Panel on Climate Change (IPCC). The results are intuitive and allow us to accept our hypothesis that these cooling scenarios can potentially delay climate change by a number of years and even decades.
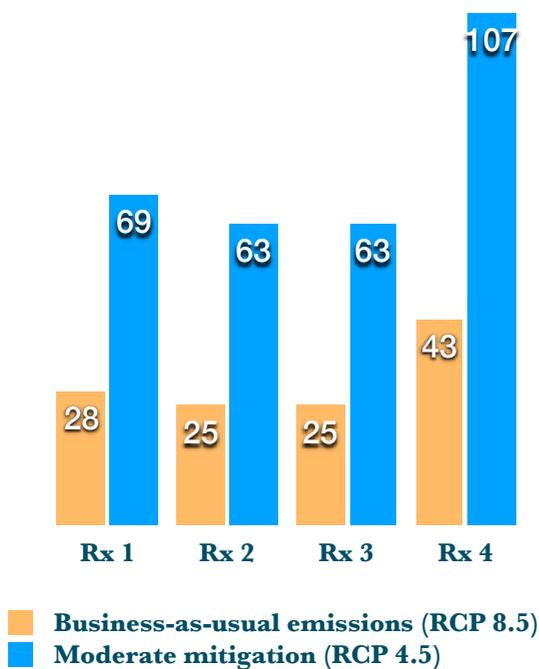
To do this, we initially determined the mean reductions in maximum temperature for Los Angeles County, using the same tree cover/albedo prescriptions that we used in the rest of the study. The mean reduction for each case is slightly more than 1°C (1.8°F) for Rx 1, slightly less than 1°C for Rx 2 and Rx 3, and a significant 1.71°C (3°F) for Rx 4. We looked at the 90th percentile of daily maximum temperature for the entire year and then just for summer (May through October). Using modeled data for the years 1950 to 2099, we determined the average temperature increases under the business-as-usual and moderate mitigation scenarios (+0.034°C and +0.015°C per year, respectively). We then divided the average temperature reduction of the four tree cover and albedo prescriptions by those average annual temperature increases to determine how many years of warming could be delayed (Figure 3).

For example, implementing Rx 4 (High Tree Cover + High Solar Reflectance) would reduce temperatures by an average 1.7°C, so we find that 1.7 / 0.034 = 50 years of possible delay. This means that climate change-caused warming could be potentially delayed 50 years relative to a business-as-usual emissions scenario (RCP8.5) if tree cover and albedo were to be increased aggressively. In this example, Angelenos could enjoy a climate in the year 2070 that is like the climate in year 2020.

YEARS OF DELAY

Business-as-usual emissions (RCP 8.5)
Moderate mitigation (RCP 4.5)

Figure 3. Years of delay of climate change-induced warming under tree cover/albedo prescriptions.

For the moderate mitigation scenario (RCP4.5), the delays would be greater, mainly because the lesser slope will need more years to equal the cooling. Assuming the Rx 1 example above, the 1.09°C (nearly 2°F) decrease would delay the warming by 69 years (1.09/0.0159), since the slope of the RCP4.5 model is less than half of RCP8.5. Thus, if we could meet the emissions demands of RCP4.5, the effectiveness of the cooling will yield an even greater delay in climate change-caused warming.

We believe this is a novel way to evaluate how urban cooling approaches can potentially mitigate climate change using land cover changes involving tree cover and albedo, and that this approach can be effective in allowing stakeholders to understand that the localized impacts of the global phenomenon of climate change can be delayed by a considerable amount of time through means that are within local control.

33

Climate change-caused warming could be potentially delayed 50 years relative to a business-as-usual emissions scenario if tree cover and albedo were to be increased using Rx 4, representing high tree cover and high albedo implementation. In this example, Angelenos could enjoy a climate in the year 2070 that is like the climate in year 2020.

TOWARD HEAT MITIGATION POLICY AND IMPLEMENTATION

TOWARD HEAT MITIGATION POLICY AND IMPLEMENTATION

SOCIAL IMPLICATIONS OF HEAT MITIGATION IN LOS ANGELES

Is air conditioning our lives into comfort really the solution when it is an inherently inequitable proposition available only to those who can afford it, and one that aggravates the problem by emitting climate-changing greenhouse gases? What if, while adapting to increasing temperatures, we could mitigate extreme heat at the level of parcels, neighborhoods, and even cities? What if the threat could be reduced equitably, while improving quality of life and reducing energy use? These questions — and the intent of advancing equitable solutions through applied research — motivated LAUCC's work on this study.

Is air conditioning our lives into comfort really the solution when it is an inherently inequitable proposition available only to those who can afford it, and one that aggravates the problem by emitting climate-changing greenhouse gases? What if, while adapting to increasing temperatures, we could mitigate extreme heat at the level of parcels, neighborhoods, and even cities?

Los Angeles County is richly diverse from a sociocultural, geographic and climatological, and economic perspective. As a region with great disparities in income, housing condition, and neighborhood ecology, extreme heat affects Angelenos in very different ways. In some neighborhoods, residents have well-insulated homes with central air conditioning and the disposable incomes to use it as desired. Many of L.A.'s higher-income neighborhoods have access to trees, swimming pools, and other strategies for coping with extreme heat, and some of the region's wealthiest neighborhoods are located along the coast, with cooler year-round temperatures. In many of L.A.'s densely-populated, inland neighborhoods, residents face a constellation of conditions that raise heat-health risk. Residents in these neighborhoods may live in substandard housing, have limited access to air conditioning, lack the means to afford the electricity to run air conditioning, enjoy little shade from trees, and rely on public transit — leaving them to walk, stand, or work in dangerous conditions when outdoors, and offering limited respite when indoors. LAUCC's work is focused on responding to extreme heat through equitable, neighborhood-scale mitigation strategies focused on cooling homes, schools, public spaces, and streets through approaches that can benefit L.A.'s most vulnerable communities.

The focus on linking research to implementation raises some key questions. How does a city or county make decisions about where people are most vulnerable to extreme heat? How do decision-makers determine where to concentrate resources and efforts to maximize reductions in heat-related morbidity and mortality? How can relevant government agencies and nonprofit organizations work together with community groups and residents to select and implement mitigation strategies that will work to cool neighborhoods and also fit culturally with community needs and desires? The methodology outlined in this report, and plans for subsequent related projects, describe a process to effectively engage public-private-academic partnerships to produce the data necessary for community leaders and government agencies to work with residents in a collaborative and data-driven fashion.

The social implications for this project break from the norm: using a data-driven process to select not the hottest but rather the most heat-vulnerable communities in the region, government agencies can team up with relevant nonprofit organizations, neighborhood councils, and community groups to engage the public in selecting heat mitigation strategies that are right for place-based unique needs and aesthetics, and implement strategies as a collective whole at a neighborhood-scale, benefitting residents equitably while literally saving lives.

Rather than finding the most vulnerable areas (where interventions are assumed to be the most beneficial), our research allows decision-makers to identify and quantify where their interventions will deliver the most benefits. This is a subtle but important difference, and we offer this approach as a tool to add to the larger toolkit of heat mitigation.

NATIONAL RELEVANCE OF THE LOS ANGELES STUDY

Many cities are currently evaluating urban cooling strategies and, in almost every case, they face the challenge of identifying particular neighborhoods to focus their efforts in order to work within limited budgets and resource constraints. For example, New York City has focused its efforts on three highly heat-vulnerable communities, rather than taking a broader, but potentially less effective approach across the city. Other cities, such as Louisville, Kentucky and San Antonio, Texas, are using heat and heat vulnerability maps to target incentives and awareness-raising efforts.

This project is an analysis of the effect urban cooling strategies could have at a community scale, and though it focuses on Los Angeles, the intent of the study is to inform approaches that other cities or regions may choose to take. This project is unique in that it lays out a methodology to allow a decision-maker to take a different approach to the challenge of extreme heat. Rather than finding the most vulnerable areas (where interventions are assumed to be the most beneficial), the research allows decision-makers to identify and quantify where their interventions will deliver the most benefits. This is a subtle but important difference, and we offer this approach as a tool to add to the larger toolkit of heat mitigation.

Toward this end, the Los Angeles Urban Cooling Collaborative convened a daylong heat mitigation workshop held at the Science Museum of Minnesota, in St. Paul, using this study methodology. The workshop was held on October 15, 2019 and brought together three dozen representatives from governmental, non-governmental, academic, and community-based entities in the Twin Cities region. The goal of the workshop was to lay the groundwork for a holistic, multi-phase project to understand the relationships between extreme heat, public health, and land cover in Hennepin and Ramsey counties.

A post-workshop evaluation was conducted to determine the workshop's effectiveness in meeting the goal. The evaluation took the form of telephone interviews with about one-third of the workshop's participants. The evaluation revealed numerous issues of concern around the topic of heat mitigation, including insufficient public awareness, inadequate infrastructure, and the challenge of alleviating the bulk of heat vulnerability being borne by individuals who are low-income, elderly, and/or socially isolated. Eighty-three percent of interviewees expressed that the LAUCC workshop had positive impacts for collaboration in the Twin Cities region around the issue of extreme urban heat. Participants described feeling energized, engaged, and with renewed collaborative discussion around extreme heat. For some, the collaboration inherent in the event was the most significant benefit they received from the Workshop. The workshop was organized in such a way to foster collaboration between agencies that often were not in the same room with one another, and to do so in an interactive way so that everyone could share their perspectives, projects, and needs. As reported in interviews, the result of this type of workshop was that people could effectively come together in new or unusual ways, not only to learn about the LAUCC approach in Los Angeles, but also to transfer and build local knowledge. Interviewees reported an 11 percent increase in their level of collaboration. Respondents also shared early indicators of using the LAUCC Workshop participant body for future collaboration.

LAUCC also engaged with other cities to share progress on the research throughout the study. We briefed cities in several city-to-city networks, including C40 Cities of Climate Leadership, Urban Sustainability Directors Network, the Mediterranean City Climate Change Consortium, and the National League of Cities. It is our intent to continue to disseminate the methods and findings of this study, and to expand and improve upon the research that this project has started.

LAUCC's research is just one among many heat mitigation efforts around the world. In the next section, we highlight approaches that other cities are taking to combat extreme heat. We offer a glimpse of the many avenues available to cities and their residents to mitigate heat, and encourage readers of this report to remain engaged in this rapidly-changing field.

WHAT OTHER CITIES ARE DOING TO ADDRESS HEAT

Cities around the world have adopted and are implementing policy tools — from incentives and codes, to awareness raising and changes to municipal operations — to spur the deployment of heat mitigation measures. Some cities choose to implement a single activity while others combine a number of approaches to address excess heat. In this section, we break out policy activities into five categories. We discuss and offer examples within each of these categories in the following pages.
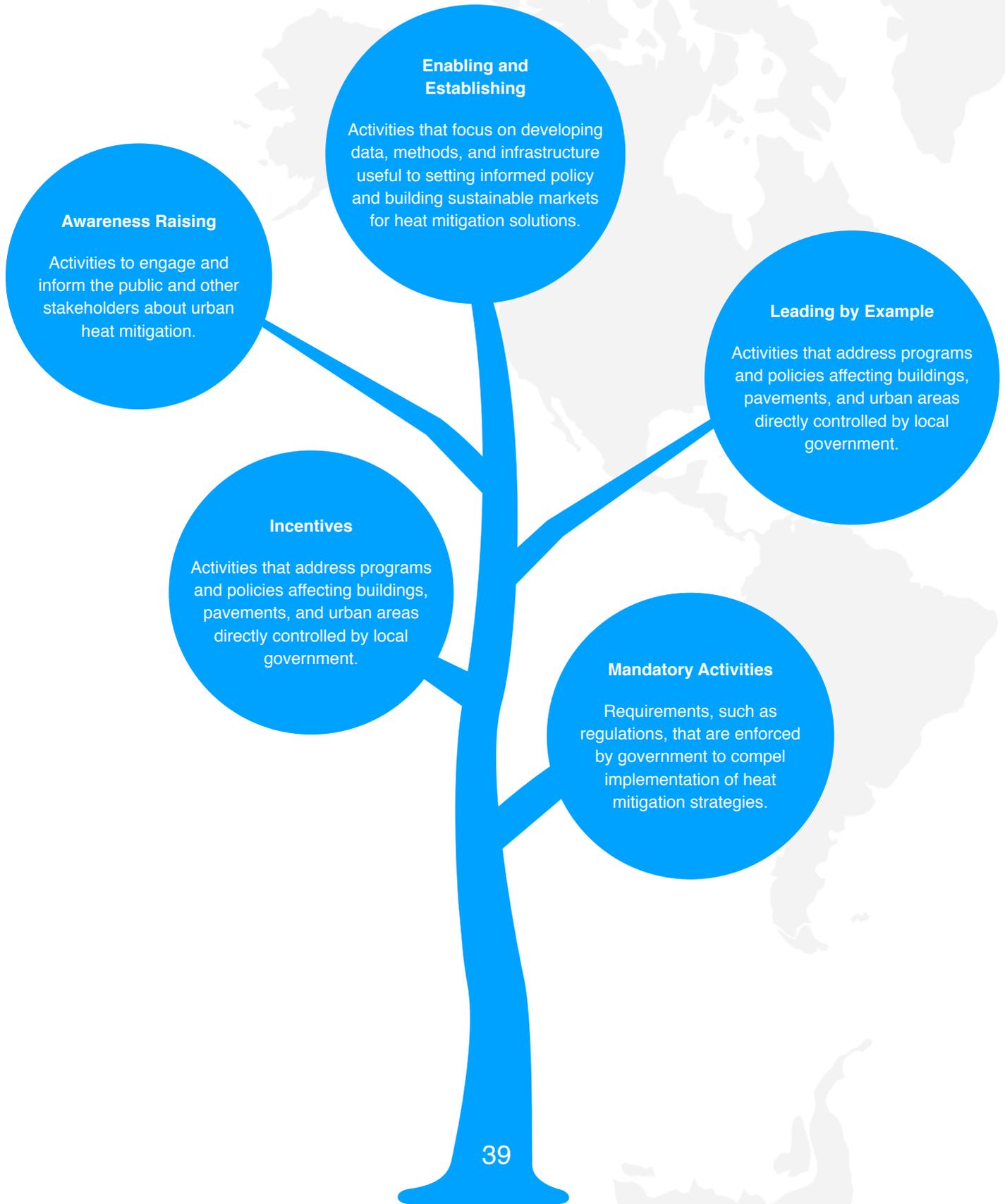
Enabling and Establishing

Activities that focus on developing data, methods, and infrastructure useful to setting informed policy and building sustainable markets for heat mitigation solutions.

Awareness Raising

Activities to engage and inform the public and other stakeholders about urban heat mitigation.

Leading by Example

Activities that address programs and policies affecting buildings, pavements, and urban areas directly controlled by local government.

Incentives

Activities that address programs and policies affecting buildings, pavements, and urban areas directly controlled by local government.

Mandatory Activities

Requirements, such as regulations, that are enforced by government to compel implementation of heat mitigation strategies.

39

Table 10. Policies and programs to reduce excess heat in cities.

CATEGORY	POLICIES & PROGRAMS	EXAMPLE CITIES
Enabling and Establishing	Data collection and mapping (e.g., heat, tree/green infrastructure, flooding, urban fabric)	London, Barcelona, Tokyo, Singapore
	Heat vulnerability mapping	Durban, Washington
	Product testing and rating schemes	N/A
	Demonstrations in heat vulnerable areas	Nairobi, Pretoria, Hyderabad
	Strategic planning	Washington
Awareness Raising	Guidelines, toolkits, design guides, handbooks	New York, Melbourne
	Heat health alerts	Seoul, Paris, Athens
	Demonstrations in heat vulnerable areas	Nairobi, Pretoria, Hyderabad
	Strategic planning	Washington
	Tree giveaways	Los Angeles, Durban, Washington
Leading by Example	Demonstrations in heat vulnerable areas	N/A
	Strategic planning	Washington, Singapore
	Heat action planning	Ahmedebad
	Tree planting and maintenance	Singapore
	Park development	Seoul
	Heat-sensitive urban planning	Tokyo, Singapore
	Municipal govt. procurement specifications	Los Angeles, Toronto
Incentives	Cool roof rebates	Austin, Athens, Toronto
	Property tax reductions*	New York
	Tree giveaways	Los Angeles, Durban, Washington
	Increased floor are ratios for green space provision	Seattle
	Fastbtracking for permit approvals	New York
	Stormwater credits	Washington
	Stormwater fee discount	Philadelphia, Minneapolis
Mandatory	Stormwater credits	Washington
	Cool/green roof regulations and enforcement	Los Angeles, Paris, New Delhi, Chicago
	Tree ordinances	Melbourne

* indicates an activity that may involve/require regional or national authority

ENABLING AND ESTABLISHING

While the activities in this section are not necessarily required to establish policy, they are valuable in ensuring that effective policies are set; sustainable markets are developed for urban cooling solutions; innovative cooling technologies are encouraged; and policy goals are trackable.

Heat data collection and mapping

Heat data collection and mapping establishes where hot spots currently exist within the city. As a first step, cities may use aerial/satellite imagery to identify elevated surface temperatures. Though useful, relying solely on imagery has several limitations. The imagery may be only periodically available and may not include readings from the hottest time of the day. Such data often do not include nighttime temperatures, and nighttime temperatures are important for assessing health outcomes from excess heat. Finally, the connection between surface and air temperatures is not quite direct, so a focus on surface heat islands may miss heat pockets that are causing more damage to health.

To supplement surface temperature maps, temperatures collected via sensor networks and vehicular transects can support and deepen a city's understanding of community-scale heat vulnerabilities. Mapping multiple hazards (e.g., heat and flood risk) will highlight areas where urban cooling strategies can be coupled with other goals to provide multiple benefits. For example, when detailed vegetation maps for a city are overlaid with other spatial data, including population density, policy-makers can identify where in the city tree planting will yield the highest returns on investment in terms of ambient air temperature reductions.

Heat Vulnerability Mapping

Vulnerability mapping is an additional overlay to heat mapping that visualizes the human health risk of heat and the opportunities to mitigate it. Vulnerability encompasses a wide variety of factors. Demographic data such as population age, race/ethnicity, income, and housing stock are highly correlated with heat vulnerability, as are populations with health conditions that are aggravated by heat.

Enabling and Establishing

Awareness Raising

AWARENESS RAISING

The programs and policies in this category are intended to increase public knowledge of the risks of excess heat, encourage heat risk reduction behaviors, call attention to new related city policies and programs, and promote private implementation of urban cooling solutions. For a municipality, communication channels to the general public include public advertisements, announcements, media outreach, training events, community meetings, and mayoral statements.

Guidelines, toolkits, and handbooks

These materials are typically technical in nature and targeted to specific audiences that implement urban cooling solutions. Design guidelines provide a connection between general planning policies and implementing regulations, such as zoning codes and subdivision regulations. Green guides, such as Melbourne's *Growing Green Guide*, help landscape architects and developers plan appropriate plantings to help the city achieve its canopy and green infrastructure targets. Cities such as New York publish design guides with information on heat-mitigating roofing options, installation, appropriate use cases, and the effects of installing cool roofs on the building and the surrounding community. These guides are written for an audience of architects, developers, and construction industry representatives.

Heat health alerts

Heat alerts are emergent communications to the public to warn them of excess heat conditions. Cities use a variety of metrics and thresholds to trigger emergency communications. Some examples include days with daytime maximum temperatures above a given degree, days with maximum apparent temperatures above a certain level (an approximation of people's perception of heat derived from the combined effect of temperature and humidity), or number of days above a certain daytime maximum temperature. Municipal communications are useful, but may not effectively reach or be highly trusted by the most at-risk audiences. In an attempt to address this limitation, New York City launched a training program in 2018 for home health care aides to help them recognize the early stages of heat stress in their clients and to further share information with them on how to reduce their risk during extreme heat conditions. Cities may also make similar indirect public outreach efforts to local community groups and religious institutions.

Demonstrations

Demonstrations of urban cooling strategies help gather important performance data for policymaking and serve as a tangible example to raise public awareness. Demonstration projects may take place in public parks, schools, and other public facilities as well on private property and in informal settlements. Demonstrations may be for a single measure, such as a cool roof on a dwelling, or include multiple measures to evaluate their combined ability to cool buildings and air temperatures. Based on existing field studies, a community-scale pilot may be sufficient to generate a meaningful cooling response to inform broader-scale action.

Cities may also play a supportive role in demonstrations by other entities. This may be particularly useful for technologies such as district cooling or waste heat recovery that are often developed by public-private partnerships. Cities can make available municipal land for demonstration purposes, or provide funding incentives to encourage pilots.

Leading by Example

LEADING BY EXAMPLE

The activities under this category include efforts that in most cases only the municipal government can undertake to support heat mitigation and adoption of more efficient space cooling options. These include planning processes that establish heat mitigation as a priority for a city and create frameworks within which heat mitigation can be implemented (e.g., heat action/emergency plans). They also include opportunities to lead by example in municipally controlled buildings and spaces, including through procurement requirements to promote heat mitigating strategies, using energy-efficient buildings and cooling equipment, and encouraging or requiring municipal contractors to consider what effect their activities have on excess heat. Municipal governments can certainly also undertake a number of activities included in other sections here (e.g., demonstration projects) but this section focuses on those efforts that fall exclusively within government's purview to undertake.

Strategic planning

Strategic planning is generally a multi-stakeholder process to establish goals and the basic pathways for achieving them. Strategic plans may be adopted by a mayor, city manager or local legislative body and may set forth policies, goals, and objectives within the planning jurisdiction. Strategic plans generally have a broad scope and long-term vision. Some cities have adopted temperature reduction targets as the guiding goal for urban cooling activities. Los Angeles has adopted a 0.9°C (1.6°F) reduction in the difference between urban and nearby rural temperatures by 2025, while Melbourne has an aspirational goal to reduce urban temperatures by 4°C (7.2°F), in line with the city's average urban heat-island intensity.

Heat action planning

Heat action planning is a similar exercise to strategic planning that is focused on preparing for and responding to extreme heat hazards. Ideally, such plans are coordinated between multiple departments to ensure smooth, coordinated responses to hazardous heat. As part of this, cities and counties may make "cooling centers" available to the public — publicly-accessible, air conditioned spaces such as libraries and community centers — and publish lists or maps to encourage community members to find cool spaces in their neighborhood. Through public-private partnerships, cooling centers can also be expanded beyond government-owned facilities to private spaces, such as shopping areas.

Heat action plans typically include a public outreach component to improve residents' ability to respond to a heat wave. Heat action planning may also include the establishment of early warning systems for heat waves and an opportunity to build awareness of heat illnesses amongst health care professionals. Cities like Ahmedabad, India have developed plans incorporating all of these elements and go through an annual update process to ensure that information and contacts are properly updated and included.

43

Tree planting and maintenance

Municipal tree programs expand the number of street trees, increase tree cover in existing parks, and help ensure that the appropriate species are planted and that the urban forest remains healthy. Within cities, there is substantial variation in the variables that affect the ability of trees to remove particulate matter, mitigate ambient air temperatures, and thus deliver on the return on investment in terms of ecosystem services. Maintenance is also very important for retaining existing cover. Maintenance may include periodic scheduled assessments of individual trees, responses to comments from the public, or be based on sophisticated tree monitoring sensor networks. To maximize the cooling potential of trees, prioritizing planting in areas that receive high volumes of pedestrian, cyclist, and transit rider traffic can be a way of creating "cool corridors" — paths that offer shade and evapotranspiration benefits during heat waves. Paris, France offers an example of a city that has created cool corridors in order to ensure residents have ways to travel to cool refuges during a heat wave.

Park development

Parks are another way to increase permeable green space in cities and to create cool islands. Park development includes improvements to the health and robustness of existing park space, as well as the creation of new park spaces. Depending on space or funding constraints, cities may create multiple small park areas rather than finding space for fewer new medium or large

parks. Pocket parks are small-area green spaces that can be created when roads are closed, parking lanes are reorganized or areas such as parking spaces or parking lots are reclaimed. While not as effective for neighborhood-scale urban cooling as large parks, pocket parks provide localized cooling via shading, and, with sufficient vegetation, via evapotranspiration. Seoul, South Korea recently added 1,000 new parks and forests within city limits, primarily by developing pocket parks. Cities may also choose to install water features that provide cooling services for residents during heat waves and aesthetic value at other times.

Heat-sensitive urban design

Cities should consider the effect of new developments on excess urban heat when making site development or zoning decisions. These regulations generally dictate function, building height and bulk, population density, and parking requirements for an area. Zoning codes can increase the use of urban cooling strategies by requiring their use in new developments or redevelopments.

Incentives

INCENTIVES

Incentives encourage adoption of urban cooling solutions in both the public and private sector. Incentives may take many forms and may not all be financial in nature.

Rebates

Rebates help defray the cost premium that still exists for some urban cooling strategies such as cool roofs, green roofs, and energy-efficient space cooling units. Rebate programs for cooler building materials are similar to other technology rebates, so experience with one would be helpful when implementing the other. Rebates may be funded by municipalities (e.g., Louisville, Kentucky and Toronto, Ontario) or by utilities (e.g., Los Angeles Department of Water and Power, Pacific Gas and Electric, Sacramento Municipal Utility District, and Progress Energy Florida). The Cool Roof Rating Council lists a large number of municipal and state government programs that subsidize cool roofs as part of broader residential and commercial energy performance programs.

Low-interest loans

Low-interest loans may be used to reduce the first cost burden of deploying urban heat mitigation solutions and have been used extensively to fund other energy efficiency measures. Governments with sufficient credit worthiness may use their own borrowing power, administer funding from other sources (e.g., utilities, regional or national governments) or provide a guarantee to secure the lower rates.

Tax credits have also been used extensively in energy efficiency financing and are often applicable to building-based urban heat mitigation measures. In the U.S., a federal tax credit was enacted in 2009 for new roofs that meet Energy Star requirements for solar reflectance that provided for a tax credit for 30 percent of material costs up to a total credit worth $1500.

Tree giveaways

Municipal governments may provide the seeds, saplings, or young trees directly to residents or offer a rebate to reduce the first cost of purchasing the tree. Giveaway programs are self-selecting, meaning that often the trees end up being planted by individuals who are more likely to maintain and care for the tree. Community participation is important because most urban trees are not under public jurisdiction (for example, in the City of Los Angeles, 90 percent of tree canopy is on residential parcels). Giveaways should be paired with training on how to properly plant and care for the tree for the establishment period of two or more years to improve survival and encourage maximum health and growth potential. It may be helpful to include communications via phone, email, or occasional visits to ensure maintenance is happening and support the resident in the event that any tree care questions come up.

In order for trees to be most effective at improving thermal comfort, the appropriate tree must be selected and it must be planted in the appropriate place. For example, the mature height of the tree should be considered to ensure that it is sufficient to provide adequate shade and that the tree is placed in the best location for residential shading. To help overcome these challenges, public shade tree programs may require participating households to receive a home visit from a trained arborist or forester who helps them choose the appropriate location for the tree. Alternatively, public maintenance and care guides can be developed and distributed to participating households. Tree giveaway programs have also been used in cities such as Durban, South Africa to advance social and economic uplift goals. Durban's municipal government provides residents with seedlings or young trees and pays residents to plant and care for them in areas with high heat or stormwater management risks. Residents form small nurseries and provide maintenance services for trees in their community. The results have brought cost savings to the municipal operating budget, improved tree health and survivability, and new economic opportunities for under-resourced communities.

Developer incentives

Incentives to developers typically improve the construction permitting process for developers willing to install heat mitigation solutions in their project. The incentives of this type may include fast-tracking for permit approvals to reduce project downtime or waiving certain permitting or planning fees. Developer incentives may also allow certain permitting regulations to be loosened, such as increasing floor area ratios to allow more buildable space on a particular site, in exchange for installing energy-efficient or green infrastructure.

Stormwater credits and fee discounts

These incentives are intended to encourage the installation of green infrastructure but have the added benefit of improving cities' response to excess heat. Cities may provide discounts on stormwater fees when building owners commit to install and maintain green infrastructure to retain and manage stormwater.

This set of activities covers requirements established by the municipal government (or in some cases the regional or national government) to compel adoption of urban cooling solutions.

<u>Cool roof and green roof regulations</u>

Cool and green roof requirements have been included in building codes for over two decades. Cities such as Chicago, New York, Denver, Los Angeles, Paris, and New Delhi each have some form of cool or green roof requirement. Model codes such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) codes 90.1 and 90.2, be adopted by cities to require that new or substantially repaired roofs be highly solar reflective or vegetated. Regulations vary, but are typically aimed at low-slope (i.e., flat) roofs and buildings of a particular size. Cities like Los Angeles, however, also require new roofs on steep slope and residential buildings to be highly solar reflective.

Cool and green wall regulations are becoming more common and may be included in codes as a credit or offset to another requirement. Several recent Chinese building energy efficiency standards assign reflective roofs and walls a thermal resistance value that can reduce the requirement for physical wall insulation. Some offer this trade-off only for very solar reflective walls (those with a reflectance of at least 0.80), while others provide a thermal resistance benefit that scales with wall solar reflectance. The reflectance tradeoffs may also offset exterior shading requirements. For example, ASHRAE 90.1-2016: Energy Standard for Buildings Except Low-Rise Residential Buildings permits east- and west-facing walls to be unshaded in ASHRAE climate zone 0 (hot & tropical conditions) if they have a solar reflectance index (SRI) not less than 29, which would typically correspond to an albedo of at least 0.28.

Green building and energy codes may reduce the warming impact of space cooling in cities with a high penetration of conditioned buildings. In cities where air conditioning use is rapidly growing, such codes will help reduce the warming and energy consumption of the new cooling units.

Mandatory Activities

Tree ordinances

Tree ordinances are a common tool used by local governments to ensure public safety, protect trees or views, and provide shade. Ordinances may require direct developer/property owner action, or require developers to pay a fee to exempt themselves from certain requirements. Three types of ordinances, in particular, are most useful from an urban cooling perspective: tree protection, street trees, and parking lot shade.

Tree protection ordinances restrict the removal or pruning of trees without a permit. Often, these ordinances apply only to native trees or trees with historical significance. The effectiveness of this type of provision depends on enforcement and how strict the requirements are for granting tree removal permits. Some ordinances protect not only trees but also the ground under the crown area of a tree to prevent root damage. In addition to permitting, Melbourne, Australia values the total ecosystem services provided by individual trees and calculates a holistic value as the amount of payment required to remove the tree. The process funds other municipal tree promotion and maintenance programs.

Street tree ordinances generally govern how to plant, care, and, when necessary, remove trees along public rights-of-way and land that is privately owned but accessible to the public. At a minimum, these ordinances designate the numbers or types of trees that should be planted. More effective street tree policies include guidelines on tree selection, installation, and maintenance to lengthen a street tree's life and minimize conflicts with pavement, powerlines, and buildings. Seattle, Washington requires a street use permit before landscaping in a planting strip in a public right-of-way. For street trees, the planting strip must be at least 5 feet wide, unless specific approval from the city's arborist is received. A guide is available to help property owners select and plant trees in accordance with the city's requirements.

Some cities or neighborhoods require parking lots be shaded to cool the pavement and cars, which improves comfort, reduces the heat-island effect, and lowers evaporative emissions from parked cars which would otherwise off-gas when heated by sun exposure. For example, since 1983, an ordinance in Sacramento's zoning code has required that enough trees be planted to shade 50 percent of new, or significantly altered, parking lots after 15 years of tree growth.

48

Recommendations for Heat Vulnerable Cities and Regions

RECOMMENDATIONS FOR HEAT-VULNERABLE CITIES AND REGIONS

BUILD A PROJECT TEAM THAT IS INTERDISCIPLINARY AND CROSS-SECTORAL

The Los Angeles Urban Cooling Collaborative brings together a range of organizations with differing areas of expertise as part of the team. The core study team was composed of academic researchers, expert practitioners, and policy experts from the non-governmental sector. The team received input at various stages of the project from community representatives, local and state government entities, and from private enterprise with expertise developing cool city technologies. The interdisciplinary nature of the team was rather distinctive and may provide a framework for other such projects demanding specific levels of project management and research expertise. In addition, such collaboration ensured that each decision along the project's path is made with multiple perspectives in mind. Where LAUCC's modeling experts might otherwise have proceeded with executing a technical scope using pre-defined specifications, LAUCC instead engaged in an iterative process filled with robust discussions, often based on questions that might have been considered outside the scope of the project had the team been composed solely of researchers and technical personnel. This collaboration allowed for further insight among team members, all of whom gained deeper understanding on the holistic nature of the project, ultimately producing a more robust process and outcomes.

Having multiple perspectives also means that our team, as a whole, holds a research-to-implementation view of the study; thus, the results of our research are presented and designed primarily for application. The non-governmental partners on the team frequently suggested adjustments to the approach to ensure that results would lend themselves to post-study application. For example, whenever possible, the districts created were designated so they included jurisdictional demarcations at which change could be implemented, something that could be easily overlooked if only hard-science researchers were the sole members of the team. With this perspective, a government decision-maker can advocate for policies and programs within their specific jurisdiction, which can provide a cleaner path toward implementation.

50

FRAME THE PROBLEM IN TERMS OF SOLUTIONS

Extreme heat already kills more people in an average year than all other weather-related causes combined — an accurate statistic even before factoring in increased intensity or frequency of heat waves due to climate change.[37] Climate change is widely considered the existential challenge of our time, with increased heat threatening to render many parts of the world uninhabitable.[38] The enormity and complexity of the issue can be downright paralyzing for those interested in addressing it, and indeed much research and reporting on the topic is done via a lens of quantifying risks. The risk quantification approach answering questions such as how much hotter a given geographic area is likely to get, when the impacts might be expected, or how (and how many) people are projected to be impacted.

We opted to frame the work in terms of positive changes that could be undertaken in order to not only adapt to but actually mitigate extreme heat and its impacts on urban dwellers. Our research is meant to inform local, coordinated action that can provide protection to communities most at risk.

While these are fundamental questions without which solutions could not be effectively built, LAUCC's approach presents a complement to framing research-to-action efforts. We opted to frame the work in terms of positive changes that could be undertaken in order to not only adapt to but actually mitigate extreme heat and its impacts on urban dwellers. Our research is meant to inform local, coordinated action that can provide protection to communities most at risk. Furthermore, this work is inherently optimistic about humankind's collective ability to have a positive influence on climate outcomes, even as we contend with our own species' destructive tendencies that led us to this critical juncture in the first place.

COLLECT THE NECESSARY HEALTH AND SPATIAL DATA

Various data requirements must be met in order to enable analyses of the sort that were completed for this study. On the health side, general data requirements are patient level data for a municipality or state over multiple years. These data can be either mortality data (deaths) or morbidity data (episodes of illness, impairment of degradation of health usually operationalized as a hospitalization, emergency room visit or ambulance transportation), or both.

For hospitalization analyses, it is useful to exclude hospital-to-hospital transfers and transfers within a hospital. Spatial data on tree canopy and albedo are also needed, and should be at the same geographic scale as the health data (e.g., zip code level). In the absence of off-the-shelf spatial data, tools such as i-Tree Canopy can be used to derive those data. See the section titled "How Tree Canopy and Albedo Scenarios Were Developed" for details.

51

ENSURE YOUR EFFORTS ARE REPLICABLE AND RELEVANT BEYOND YOUR CITY (CASE STUDY: TWIN CITIES)

The interdisciplinary nature of LAUCC's approach had the natural result of bringing a range of stakeholders to the table representing community, academic, government, and private sector perspectives. We engaged other cities to share progress on the research during the course of the project, briefing cities in several city-to-city networks, such as C40 Cities of Climate Leadership, Urban Sustainability Directors Network, the Mediterranean City Climate Change Consortium, and the National League of Cities.

It was critical to LAUCC and to the project's primary funder — the USDA Forest Service — that the study be relevant beyond Los Angeles to other cities and regions along the multiple dimensions of scientific modeling, policy-making, urban planning, and community engagement. To test replicability of the project's approach, LAUCC sought to select a heat-vulnerable city or region for a partnership designed around technology transfer and capacity building. We considered several possible heat-vulnerable locales in the United States, and based on factors such as existing contacts in the region and a desire on the part of the region's representatives to engage around the topic of heat mitigation, we chose the Twin Cities region in Minnesota (a region that is indeed vulnerable to heat-health risk despite being cold much of the year).

LAUCC worked with an array of entities — including the City of Minneapolis, the Metropolitan Council of the Twin Cities, the Science Museum of Minnesota, and the University of Minnesota — to coordinate and deliver a day-long workshop which was attended by about three dozen participants representing more than 20 entities. Participants came together and learned about LAUCC research, discussed how heat impacts the Twin Cities region, identified a preliminary list of heat mitigation threats and opportunities, and took the first step toward forging a collaborative partnership to reduce impacts of extreme heat in the Twin Cities areas. The goal of the workshop was to lay the groundwork for a holistic, multi-phase project to understand the relationships between extreme heat, public health, and land cover in the region. A post-workshop evaluation, conducted in the form of participant interviews, found that the workshop was effective at meeting its goal (see "National Relevance of the Los Angeles Study" section for further details). Participants described feeling energized, engaged, and with a renewed collaborative spirit around extreme heat, and for some, the collaboration inherent in the event was the most significant benefit they received from the workshop. The result of this type of workshop was that people could effectively come together in new or unusual ways, not only to learn about the LAUCC approach in Los Angeles, but also to transfer and build local knowledge.

This case study offers just one path for forging new partnerships around heat mitigation by bringing multiple perspectives together. Myriad other methods exist that may support that inclusion of multiple perspectives, and we encourage you to try various approaches. Whichever path(s) are chosen, it is critical to ensure inclusion of representatives from multiple sectors that can speak to a multitude of issues, including public health, environmental justice, urban planning, urban forestry, transportation, housing, community engagement and empowerment, climate science, and other areas.

ENGAGE NON-GOVERNMENTAL ORGANIZATIONS
TO CONDUCT EVIDENCE-BASED ADVOCACY

The diverse array of sectors represented in LAUCC allowed for the non-governmental partners in the collaborative (Climate Resolve, Global Cool Cities Alliance, and TreePeople) to advocate for the advancement of heat mitigation programs and policies in real-time. For instance, Climate Resolve and TreePeople worked with the Los Angeles City Council to author a motion directing the formation of a committee on cooling and urban heat impacts tasked with forging a path for heat mitigation. The group, which includes representation from city and county government, academia, and non-governmental organizations, began to meet during the course of this project, convened and facilitated by Climate Resolve and TreePeople, in partnership with the City. At the same time, LAUCC's evidence-based recommendations informed targets in *Resilient Los Angeles* (which serves as the City's resilience strategy), L.A.'s *Green New Deal* (an update to the Sustainable City pLAn), and related policy-making efforts.

IMPLEMENT COOLING STRATEGIES THAT ALREADY EXIST TODAY

It is clear that the technology is presently available to cool vulnerable cities so that numerous lives can be saved during excessive heat events. From the simple act of planting a tree, to using highly-reflective paints, pavements, and roofing, we already have access to the necessary technologies today. And there is reason to be optimistic about the affordability and availability of materials in the future. In December 2013, Los Angeles became the first large city in the United States to pass a law to require all new and refurbished homes to have a cool roof. That decision had a ripple effect, resulting in the transformation of the cool roofing market over a relatively short period of time, both in terms of the number of products available and how quickly costs have come down, making many products cost-competitive with many traditional roofing materials.[39]

SUPPORT ACTION AT THE NEIGHBORHOOD SCALE

Urban heat mitigation calls for preparation before heat waves hit as much as it calls for taking protective actions during heat waves. Heat mitigation actions can and must occur at a variety of geographic levels — from the regional level of policy-making and government-level decision-making, down to the neighborhood level, where a variety of formal and informal actors can serve as agents of change.

Focusing on the neighborhood scale can start with demonstrating cool city technologies. For example, starting in 2017 the City of Los Angeles piloted cool street surfaces on residential blocks in each of the City's 15 council districts as a strategy toward achieving a citywide temperature reduction goal.[40] Though limited in geographic scope to a handful of streets, this program was leveraged successfully for awareness raising around cool city approaches. The City of Los Angeles cool streets pilot generated global news coverage and prompted inquiries from cities around the world for similar projects to be replicated.

BUILD AND IMPROVE UPON EXISTING RESEARCH AND IMPLEMENTATION EFFORTS

Cooling our cities will require broad coalitions with many voices and creative minds. We encourage individuals, households, communities, neighborhood groups, private industry, academia, and government agencies to learn about best practices for heat mitigation, and to then test and tailor cooling strategies to best fit each city and each neighborhood. Consider novel paths for engaging people on this topic, and reach out to non-traditional partners to combine forces. Share what you learn — including both the successes and challenges you encounter — so that other cities can build and improve upon collective efforts.

Next steps for LAUCC and its partners include conducting similar research by investigating the influence that extreme heat has on morbidity (illness) in addition to mortality (death). We expect that this research will yield new data to complement the findings shared in this publication, and that combining these with the mortality results will put us in a position to provide even more robust recommendations about which strategies and geographic areas in Los Angeles County should be prioritized. We are also engaged in various implementation efforts, including neighborhood-level heat mitigation demonstrations and policy-making ranging from local to international levels, and our partners will continue to share what we learn through presentations, publications, webinars, and via our institutions' web presence.
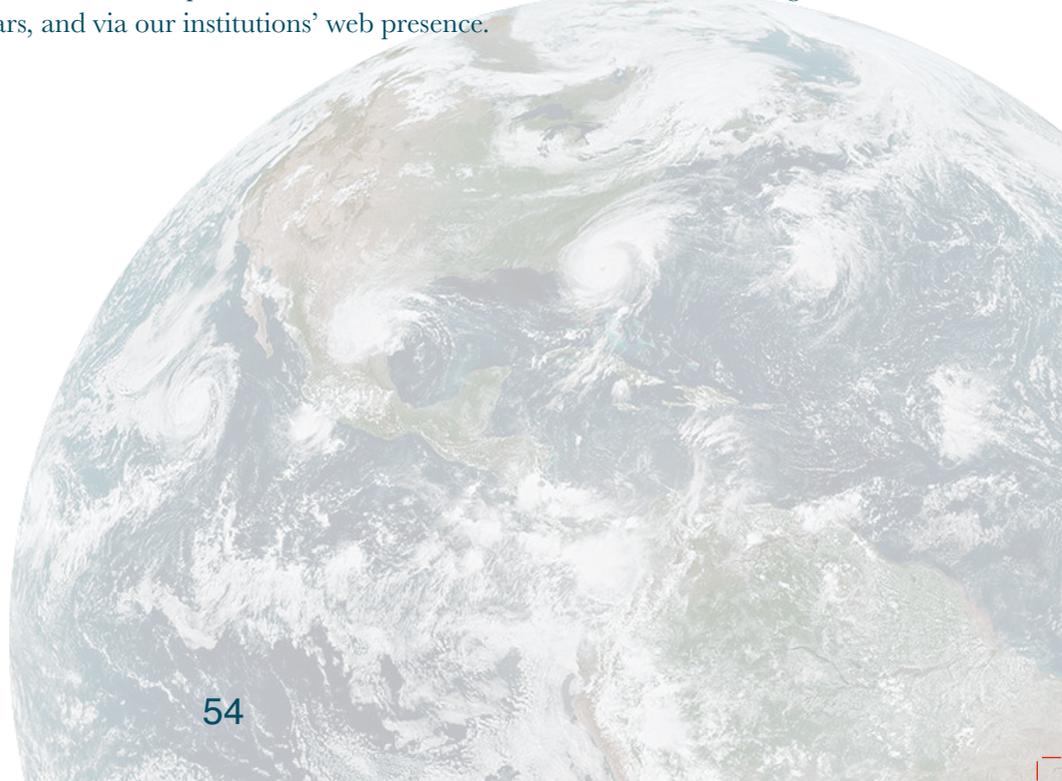
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APPENDICES

APPENDIX A - COUNTY-LEVEL MODELING APPROACH

For this study, we simulated Los Angeles County using three nested domains with the innermost domain covering the entire county with 156 by 156 grid cells of 500 meters on a side, and a total of 42 vertical levels. All results are then averaged over a suitably large array (nominally an area of 12.5 sq. km) of individual cells comprising each neighborhood.

The single layer urban canopy model was implemented using Weather Research and Forecasting (WRF) model, version 3.8.1, using default geometries for parameterized urban canyons in low density residential, high density residential, and commercial land use areas. The low, medium, and high intensity development categories used in the modeling are based on fraction of impervious surface as defined in the National Land Cover Database (NLCD).[41] Low intensity urban land cover corresponds to areas with a mix of constructed materials and vegetation, with impervious surfaces accounting for 20 to 49 percent of total cover (typically single-family housing units). The medium intensity urban land cover includes areas with 50 to 79 percent impervious surface cover (typically higher density housing). The high intensity classification is for areas with 80 to 100 percent impervious cover (typically commercial and industrial areas).

All simulation cases were provided atmospheric initial and boundary conditions from the NCEP North American Reanalysis (NARR) 3-hourly atmospheric data. Key model physics parameterizations included the Rapid Radiative Transfer Model (RRTM) with the Dudhia shortwave radiation scheme; Monin-Obukhov (Janjic Eta) similarity scheme for the surface layer, the Mellor-Yamada-Janjic TKE scheme for boundary layer physics, and the Noah Land Surface Model.

To ensure appropriate model spin-up, all simulations were conducted for a full 7 days prior to the onset of each modeled extreme heat event (EHE). Baseline simulations were conducted for each EHE and model performance was judged by comparing hourly temperature data from several National Weather Service airport weather stations within the domain (Ontario and LAX) with model output averaged over an array of 9 grid cells centered on the airport (e.g., 1.5km by 1.5km region). In general, model performance, as judged by visual inspection of the diurnal profiles, and by RMSE values (typically 2 - 4°C), was good. See Figure 4.

High albedo modifications were implemented by modifying the roof and pavement albedo values within the urban parameters input file. Vegetation increases were implemented by suitably modifying the urban vegetation coverage variables in the vegetation parameterization input file for WRF.

At the completion of each simulation (for each EHE and for each simulation case), hourly data from domain were exported for ~50 grid cells within each neighborhood (e.g., a 3.5 by 3.5 km area) using a specialized script. The hourly values of air temperature and dewpoint temperature perturbations were then provided for input to the previously developed heat/health relationships to estimate the effects of the projected changes on heat-related mortality.
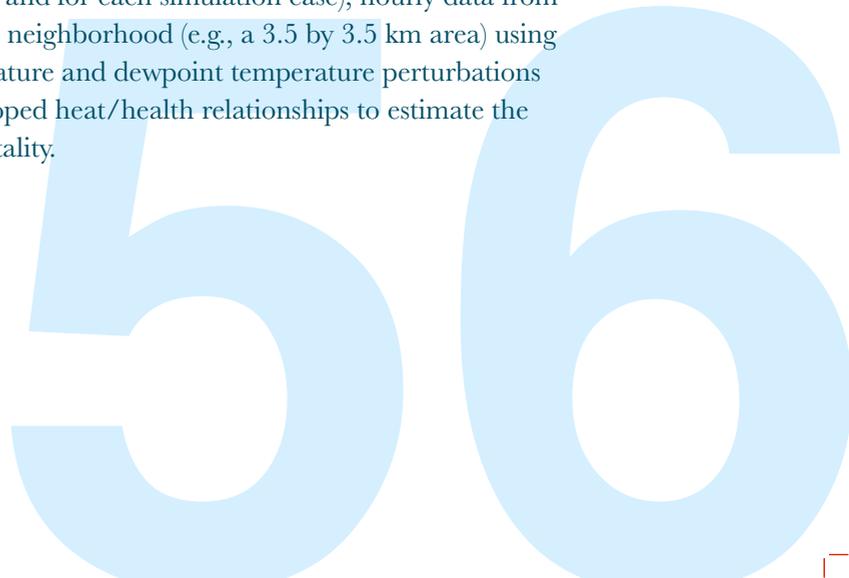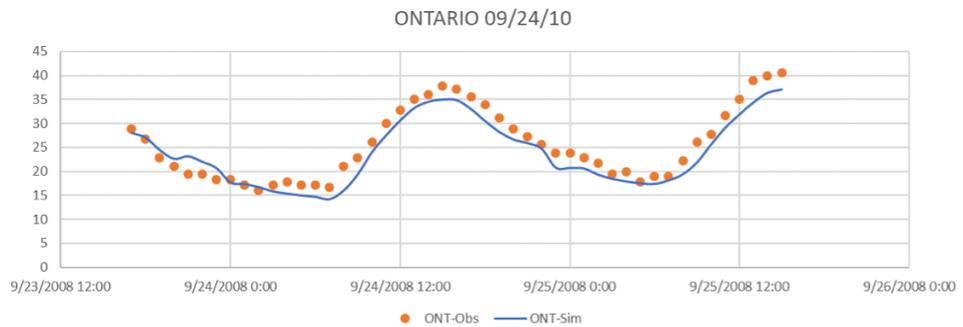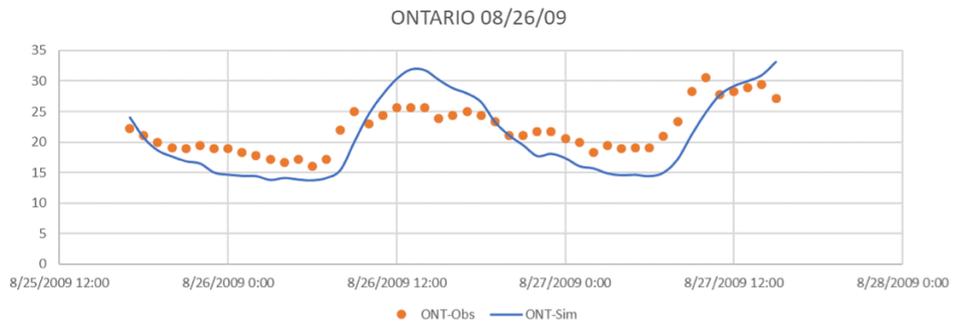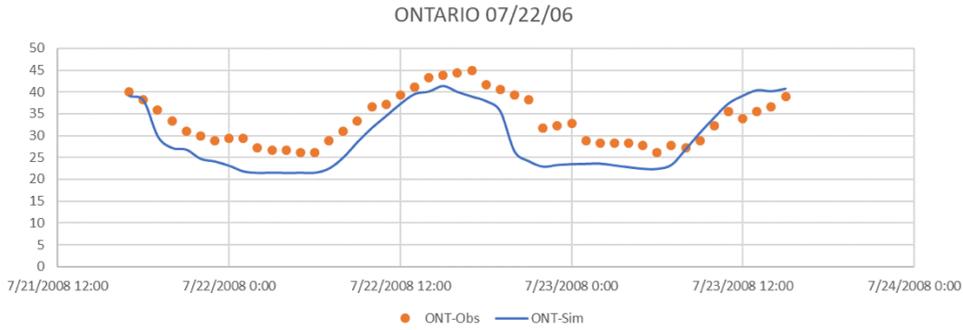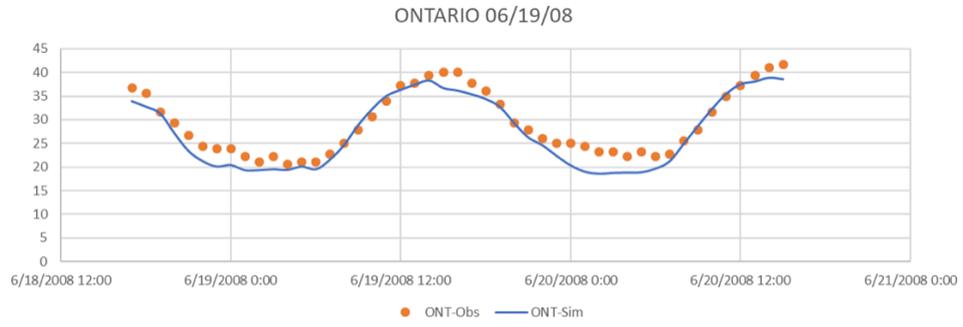
Figure 4. WRF model performance relative to the Ontario airport station for the first 2 days of each EHE.

APPENDIX B - DISCUSSION OF JULY 2006 AND AUGUST 2009 HEAT WAVE RESULTS FOR LOS ANGELES COUNTY

The July 2006 heat wave was hot and humid, with temperatures on the 22nd and 23rd approaching and exceeding 38°C (100°F) and dewpoints nearing 16°C (61°F). The results were somewhat similar to the two previous heat waves evaluated: the temperature decreases under the four scenarios were rather significant, with decreases ranging generally from 0.5 to 2°C (0.9-3.6°F) for Rx 1, 2, and 3, and generally 0.5 to 1.0°C (0.9-1.8°F) lower than that for Rx 4. Dewpoint simulations showed similar increases to other heat waves in the analysis, varying from slight decreases to increases up to 2°C (3.6°F). Notably, the greatest temperature decreases and dewpoint increases were observed at night. Results for this heat wave, which represents a monsoonal type of heat wave dominated by MT+ air masses, can be considered quite reasonable. Three of the five days during this heat event demonstrated some air mass change. For July 22 and 26, all four prescriptions resulted in changes from MT+ to MT, a more benign air mass. On July 25, we saw a change from MT+ to MT for Rx 4, our most aggressive scenario. Mortality percentages diminished, particularly for Rx 4.

The August 2009 heat wave had somewhat drier conditions. Unlike the 2006 event, there were some dry tropical (DT) and dry moderate (DM) days, and dewpoints were generally below 10°C (50°F). As is often the case when drier heat events are present, the results were more variable than the more humid events. Temperature decreases

usually exceeded 1.0°C (1.8°F), and frequently approached 2.0°C (3.6°F), especially for Rx 4. In this heat wave, we saw instances that exceeded 3°C (5.4°F) decrease, a very encouraging decrease. Drier air masses possess a lower "specific heat" than more moist air masses, which permits them to gain or lose energy at a faster rate. Thus, it is possible to see these more extreme results, with greater daily swings. This is particularly the case for dewpoint temperature, which shows up to an almost 8°C (14.4°F) swing between increases and decreases during the heat event. We have closely examined these large dewpoint swings, and there is nothing that we observed to consider that these are not correct, based upon the scenarios and modeling that we used. However, we think that results from this August 2009 heat wave should be observed with greater caution than the other heat waves because of the high variability in the results.

For the 2009 heat wave, we also saw some air mass changes. Three MT days changed to DM, or dry moderate, a generally cooler and more comfortable air mass. There were also decreases in excess mortality percentage, but the increases in mortality were much smaller for this heat wave than for the other three events. Temperatures for this event were the lowest for all four heat waves evaluated, hence the lower mortality increases. Thus, the percentage decreases, though very large, are to be regarded with more caution than the other three heat waves.

58

APPENDIX C - DISTRICT-LEVEL MODELING:
DISTRICT DESIGNATION PROCESS AND CHALLENGES

We divided Los Angeles County into smaller districts in order to determine region-by-region variations in heat/health sensitivity and the effectiveness of tree cover/albedo increases within each district. Based upon past experience, we determined that each district should have a population of about 300,000 or greater, since smaller population sizes would contribute to variations in mortality that are more likely to be governed by local events not related to meteorology. The daily variations in mortality related to events such as heat waves are always better-determined when the areas being examined have substantial population sizes.

The process of building districts (called neighborhood typologies) began with conducting two forms of cluster analysis: K-means cluster analysis, which analyzed the data for clusters in dataspace (i.e., which values cluster together) and geographic cluster analysis, which analyzed how data values cluster across space (i.e., which clusters of data cluster together in real space across Los Angeles County). District typologies were initially built at the census tract level to ensure we captured the real sociocultural and economic diversity of Los Angeles County, and could compare this to the ways in which the typologies were represented at the zip code level (the scale necessary to work with the mortality data). Data were smoothed out at the zip code level, and study districts were generated that could be characterized as relatively homogenous on several factors: 1) density (a combination of household and population density); 2) ethnicity and race (as a proxy for sociocultural differentiation, as combined with the third factor); and 3) socioeconomic status. Los Angeles County was mapped according to this combined model, and then boundaries were selected (whenever possible)

that combined city or neighborhood council districts across contiguous similar areas to reach the threshold for statistical significance in the subsequent heat mortality analysis. Districts were then created for the study based on the demographic modeling so that they would have similar sociocultural, economic, and housing conditions. To the extent possible, each district was designed to meet the threshold of a minimum of 300,000 in population and contained meaningful political units in order to facilitate the adoption of heat mitigation through policy and program strategies.

We ultimately divided the County into 18 unique and rather homogeneous districts (Figure 2). These districts were developed to be completely inclusive of zip code areas, which represent the scale of our localized mortality data. A listing of the cities, neighborhoods, and zip codes included in each district is found in Appendix D.

We were able to maintain our 300,000 population minimum for most of the districts, although some were somewhat smaller. For example, the lowest population district was district 14, with a 2010 census population of 189,000. Several other districts exhibited population totals in the 200,000s. The largest population was found in district 4, exceeding 367,000.

Some of these districts proved to be problematic for one reason or another; for example, some had incomplete mortality datasets or possessed low population densities. Thus, we reduced the number of districts to be evaluated to a total of 11. These included districts 1, 5, 6, 8, 9, 10, 11, 12, 14, 16, and 18. Virtually all of the high-poverty districts were included within the evaluation.

The primary challenge in defining study districts was that they had to conform to a threshold population floor of approximately 300,000 in order to render statistically significant results for mortality data analysis. This was challenging because in order to generate study districts of that size, the data on sociocultural, economic, and population density must be smoothed out over a larger geographic space than is optimal for engaging residents and implementing mitigation strategies. Additionally, while the modeling process generates the data necessary to select the most vulnerable and relevant districts for study, engagement, and implementation, it is best to pair this with decision-makers on the research team who are familiar with the city/region in question on an ethnographic or personal level, which assists in identifying smaller-scale neighborhoods that may be highly vulnerable, interested in the project, or interesting for study but which may be subsumed by a greater surrounding homogeneity in the neighborhood typology methodological process. Primary recommendations for other cities/regions include:

✱ Combine K-means and geographic cluster analysis at a census tract level to optimize initial understanding of distribution and diversity in density, ethnicity/race, and socioeconomic status.

✱ Be attentive to neighborhood council district or other relevant political boundaries for creating study districts, because the final step of the project — implementation — cannot be completed without public and political engagement.

✱ Smooth data at the zip code level prior to selecting districts for modeling heat wave and mortality scenarios. Combine contiguous, homogenous neighborhoods. While this can be done largely through geographic data analysis, it helps to use ethnographic data to make final decisions on district boundaries.

✱ Select study districts that are likely to be vulnerable to extreme heat (i.e., high density and high poverty areas). However, you should also be attentive to meaningful contrast sets (i.e., a district that is low density and low poverty, to check baseline assumptions as well as comparing districts with similar density and poverty levels, but differing ethnic/racial demographics).

✱ When moving from the process of modeling future scenarios to engaging local neighborhoods for mitigation strategy selection and implementation, it is necessary to reduce the scale of study and engagement. There are two ways this can be done (and optimally, both should be used simultaneously):

  ● Primary method: Select smaller-scale, highly homogenous contiguous areas within a study district that map onto only one neighborhood council district (or a portion of one neighborhood council district). This should involve looking again at the data at the census tract level level to optimize homogeneity.

  ● Secondary method: Select one or more small-scale, interesting, highly diverse, potentially high-need (often high population density) neighborhoods. These can be selected through geographic analysis, but is best paired with ethnographic data.

APPENDIX D - DISTRICTS BY NEIGHBORHOOD/CITY AND ZIP CODE

District 1
City of Los Angeles: 90004, 90005, 90020, 90012, 90013, 90014, 90021, 90026, 90071, 90028, 90029, 90038

District 5
Inglewood: 90301,90302, 90305
City of Los Angeles: 90056, 90008, 90016, 90018, 90043, 90062

District 6
City of Los Angeles: 0044,90047,90061
Compton: 90220
Gardena: 90248, 90249
Carson: 90746, 90747

District 8
La Puente: 91744, 91746
West Covina: 91790, 91791, 91792
Baldwin Park: 91706
Covina: 91722, 91723

District 9
North Hollywood: 91605, 91606
Pacoima: 91331
San Fernando: 91340
Mission Hills: 91345
Sun Valley: 91352

District 10
City of Los Angeles: 90001, 90011, 90023, 90058
Huntington Park: 90255
Maywood: 90270

District 11
Compton: 90221, 90222
Lynwood: 90262
Paramount: 90723
Long Beach: 90805

District 12
Monterey Park: 91754, 91755
Rosemead: 91770
Alhambra: 91801, 91803
San Marino: 91108
El Monte: 91731
San Gabriel: 91775, 91776
Temple City: 91780

District 14
Redondo Beach: 90278
Torrance: 90501, 90503, 90505
Lomita: 90717

District 16
Van Nuys: 91401
North Hollywood: 91601, 91602
Valley Village: 91607
Burbank: 91502, 91504, 91505, 91506

District 18
Canoga Park: 91303, 91304
Winnetka: 91306
Northridge: 91324, 91325
Reseda: 91335
North Hills: 91343
Van Nuys: 91406

APPENDIX E - HEAT MITIGATION RESEARCH DATA: DISSEMINATION PREFERENCES

During the latter part of the project, LAUCC administered a survey that went out to approximately 400 individuals working in or otherwise interested in heat mitigation around the country. The aim of the survey was to understand how respondents expected they might use project findings and ask about preferences for dissemination of findings via various options such as an executive summary, webinar, infographic, or other materials and products. Survey responses informed what materials LAUCC produced to disseminate project methods and findings.

The survey received 98 responses, mostly from NGO, government, or academic sectors. Following are the questions asked, along with the responses received.

Q1: "How do you/would you use heat mitigation research findings in your work?" Up to 3 selections.

Q1 top answers by percent:

✱ Educating toward greater public awareness of short — and long — term heat mitigation actions that communities can take, such as but not limited to planting trees or installing a cool roof (67 percent)

✱ Advocating for stronger policies for heat mitigation (58 percent)

✱ Educating toward greater public awareness of the dangers of extreme heat (39 percent)

Q2: "What format is most useful for you to receive research findings?" Up to 3 selections.

Q2 top answers by percent:

✱ Infographic (44 percent)

✱ Executive summary report (38 percent)

✱ Downloadable presentation (38 percent)

✱ A packet of materials geared toward policy makers (38 percent)

✱ Webinar (36 percent)

✱ Technical report (36 percent)

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