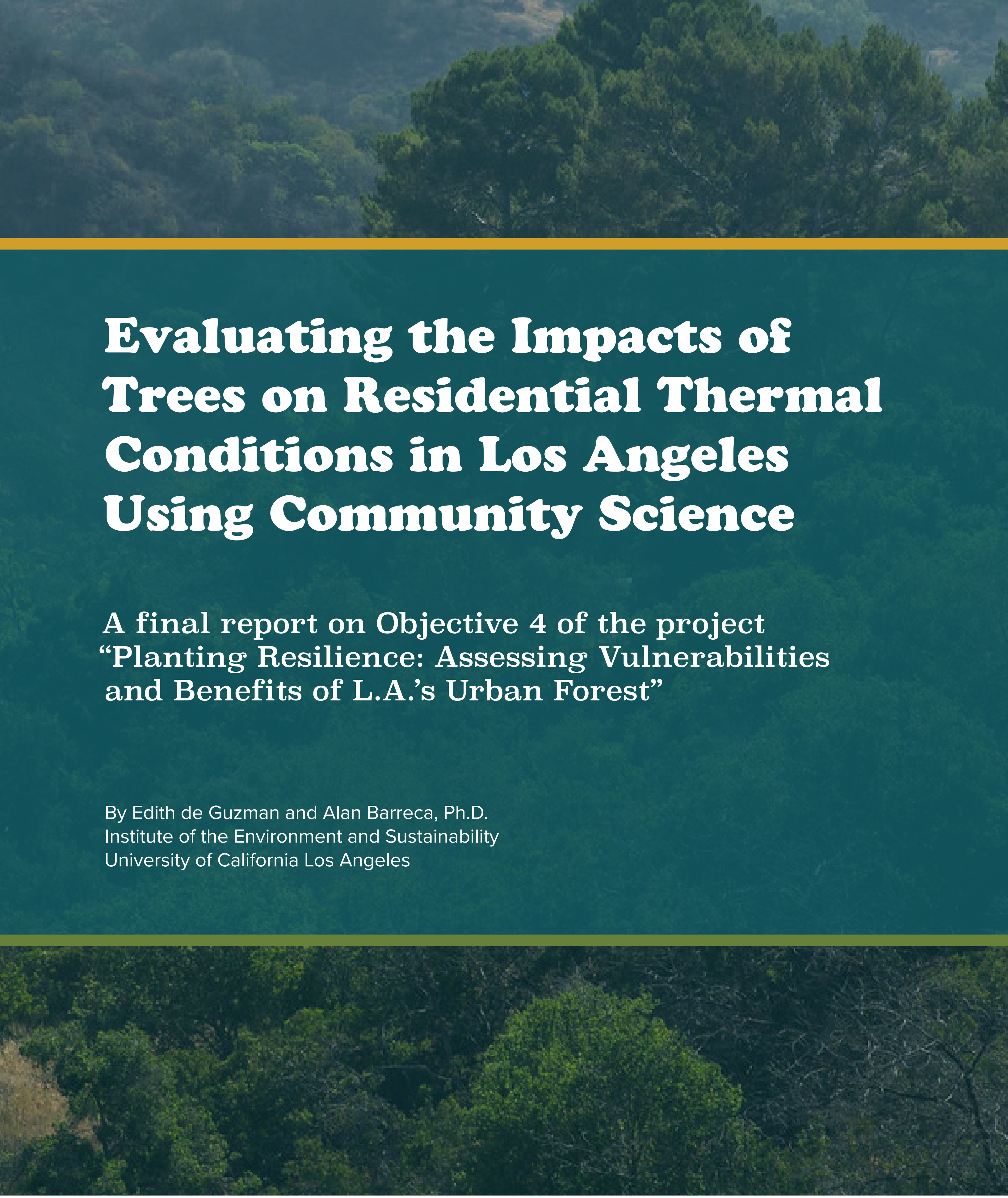


Evaluating the Impacts of Trees on Residential Thermal Conditions in Los Angeles Using Community Science

A final report on Objective 4 of the project "Planting Resilience: Assessing Vulnerabilities and Benefits of L.A.'s Urban Forest"

By Edith de Guzman and Alan Barreca, Ph.D.
Institute of the Environment and Sustainability
University of California Los Angeles

UCLA Institute of the Environment & Sustainability ARLA TreePeople

Authors
Edith de Guzman, UCLA
Dr. Alan Barreca, UCLA

Editor
Dr. Yujuan Chen, TreePeople and USC School of Architecture

Graphic Designer
Bliss Parsons, TreePeople

Photography
Adam Corey Thomas, TreePeople
James Kellogg

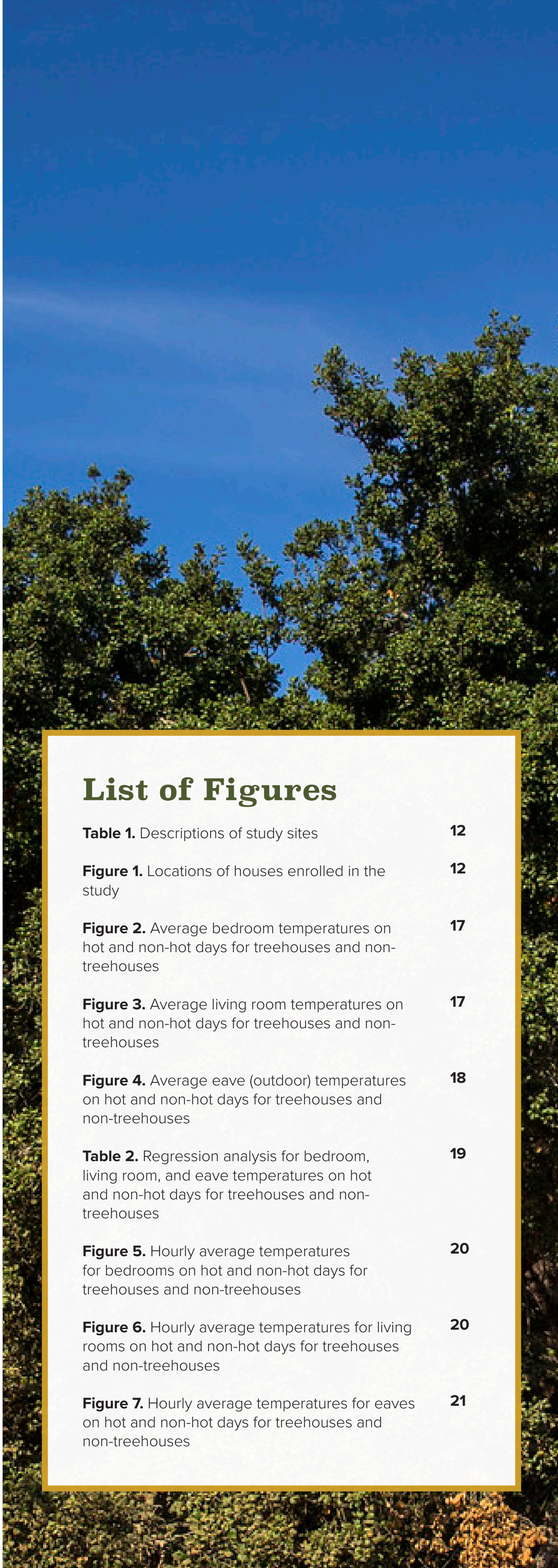
Recommended Citation
de Guzman, E. and A. Barreca. Evaluating the Impacts of Trees on Residential Thermal Conditions in Los Angeles Using Community Science. Y. Chen (Ed). TreePeople. 2021.

Funding Agency
Accelerate Resilience L.A. (ARLA),
a sponsored project of Rockefeller Philanthropy Advisors

ARLA

TreePeople
12601 Mulholland Drive | Beverly Hills, CA 90210
www.treepeople.org

Table of Contents



List of Figures

Executive Summary

As the planet warms, heat-vulnerable communities in Los Angeles and in cities around the world face increased risks of heat-related problems including lost productivity, reduced learning outcomes, illness, and even death. Despite the growing threat of heat, effective approaches to alleviate urban heat do exist, ranging from risk mitigation strategies designed to facilitate response during extreme heat events, to built environment strategies that focus on reducing urban temperatures. Tree planting is a heat mitigation strategy that has received investment in a growing number of cities around the world, but there are significant gaps in knowledge that stand in the way of optimizing the cooling potential of trees in the urban context.

The purpose of this study is to provide empirical evidence of the impacts of trees on indoor and outdoor thermal conditions in residential sites. We engaged residents in southeast Los Angeles County as “community scientists” during the COVID-19 pandemic in 2020. Participants in seven homes installed and maintained a thermal sensor network, contributing continuous half-hourly readings for indoor (bedroom and living room) and outdoor (eave) temperatures for a period of 11 weeks. Using a difference-in-differences approach we compare two groups of homes — “treehouses” with moderate to high tree cover and “non-treehouses” with no or low tree cover — on hot days exceeding 90°F and non-hot days below 90°F. We find that on average, indoor temperatures in treehouses warm 1.1°F less on hot days compared to non-treehouses. Averages by hour of day show that on hot days living rooms in treehouses are cooler than those in non-treehouses during the hottest times of the day.

These findings contribute new empirically-derived, spatially and temporally granular data supporting the daytime heat-protective function of trees in an urban environment during hot weather. However, we also find that trees provide relatively less benefit at night, a finding that is consistent with other studies but warrants further investigation for its potential impact on public health. Finally, we find that exposure to extreme heat can and does reach dangerous levels in older residences without trees or air conditioning. On September 6, 2020 — the day Los Angeles County’s hottest-ever temperature of 121°F was recorded — temperatures at a non-treehouse with no air conditioning reached 99.7°F in the bedroom and 107.4°F in the living room. Sustained exposure to such temperatures is a reality for many residents of Los Angeles and other cities who lack access to coping strategies, pointing to the need for swift action to protect heat-vulnerable communities.

Background

As Los Angeles heats up, public health risks rise and solutions are needed

The Los Angeles region faces a range of challenges induced or exacerbated by climate change. Of all of the changes anticipated for the region, extreme heat has the potential to impact the largest number of people, because many of the region's residents lack the resources necessary to cope (Li et al., 2020; Chakraborty et al., 2019). Continued warming is projected to increase average temperatures 4-5°F by mid-century, and by 5-8°F by the end of the century, with temperature extremes expected to be expressed both in the rising number of extremely hot days, and heat extremes growing by up to 10°F compared to today's hottest days (Hall et al., 2018). 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 (Hall et al., 2018).

Heat causes a host of health problems — ranging from those directly caused by heat exposure, such as heat exhaustion and heat stroke, to underlying conditions that become exacerbated by high temperatures, such as diabetes or cardiovascular diseases — and instances of these problems are expected to rise in California (Ostro et al., 2011). Consecutive days of intense summer heat in Los Angeles can see a significant rise in all-cause mortality — deaths from all causes combined — occasionally increasing these deaths by 30% (Kalkstein et al., 2014). Escalating back-to-back extreme heat days are expected to occur more frequently in the future, setting the stage for potentially devastating heat waves (Sheridan, et al. 2012).

Like many shifts brought on or exacerbated by climate change, heat raises equity concerns, as the burden of extreme heat disproportionately affects low-income urban populations and people of color (Jesdale et al., 2013). These communities often live in neighborhoods of denser development that have older, lower-quality building stock, less urban forest cover, and fewer buildings with air conditioning — living conditions which contribute to a pronounced urban heat-island, and which create a feedback loop of heating effects. Residents of neighborhoods that were formerly redlined under Federal policies that favored investment in non-minority neighborhoods currently experience higher surface temperatures (on average +4.7°F and up to +12.6°F) compared to their non-redlined counterparts, even more than 50 years after the end of redlining policy (Hoffman et al., 2020). In such environments, the absence of nighttime relief from the heat can increase health risk even more than high daytime temperatures (Dousset, et al. 2011).

Inequitable heat impacts among low-income communities of color mean that these communities are likely to see some of the largest increases in mortality as the climate warms (Kalkstein et al., 2014). Black Americans are 52% more likely than the general population to live in areas where a high risk for heat-related health problems exists, while Latino communities are 21% more likely to live under such conditions (Jesdale et al., 2013). During extended heat waves in L.A., today mortality already increases about fivefold from the first to the fifth consecutive day; after the fifth day, mortality risk increases 46% in Latino communities and 48% in elderly Black communities (Kalkstein et al., 2014). As the planet warms, heavily urbanized areas are heating up at a faster rate than non-urban areas, placing in question the habitability of many cities and their most vulnerable neighborhoods, and highlighting the importance of better understanding the issue in order to provide a fitting response (Estrada et al., 2017).

Heat-health risk can be mitigated by trees, but there are critical gaps in knowledge

Despite the growing threat of heat, effective approaches to alleviate urban heat do exist. These include risk mitigation strategies designed to facilitate institutional response during extreme heat events, as well as built environment strategies that focus on reducing urban temperatures through measures such as increasing vegetation, improving building standards, and increasing access to air conditioning (Keith et al., 2020). Air conditioning access is a remarkably effective approach to protecting health, but it is not a sustainable strategy in its current form because it generates climate-changing emissions and is often prohibitively costly for low-income households to operate (Barreca et al., 2016). Tree planting is a heat mitigation strategy that has received investment in a growing number of cities around the world (Keith et al., 2020). Investments in urban forest cover are understood to provide a range of benefits to urban communities: a 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; provision of wildlife habitat; enhanced community cohesion; and improved human health and well-being (USEPA, 2011).

However, there are significant gaps in knowledge that stand in the way of cities optimizing the cooling potential of trees. One such area is understanding the effects that trees can have on indoor thermal conditions, and specifically on a room-by-room basis at different times of day. This matters because people spend more than 85% of their time indoors (Kleipeis et al., 2001), and when and where indoor activities happen in the home affects heat exposure and risk (Sailor et al., 2015). Understanding thermal conditions in a bedroom, for example, is critically important during nighttime hours, when residents are most likely to be sleeping and when the body attempts to rest and recover.

With this study, we seek to provide new knowledge on this topic and address some of these existing gaps.

The Los Angeles Urban Cooling Collaborative (LAUCC) is a multi-disciplinary partnership of universities, climate researchers, and nonprofit organizations that includes TreePeople and UCLA. LAUCC used meteorological and public health data to quantify how increases in urban forest cover and solar reflectance of roofs (or albedo) and pavements in Los Angeles could reduce summer temperatures, decrease the number of oppressive air mass days leading to higher heat-health risks, and prevent heat-related deaths. For L.A. County as a whole, results show temperature reductions of up to 3.6°F, leading to reducing mortality between 10 to 30%, depending on the tree/albedo scenario (de Guzman et al., 2020). A district-level analysis used the conservative assumption that tree/albedo increases would only occur in each district while the rest of the county's land cover remained unchanged. That analysis indicated that mortality reductions between 20 and 40% were a common outcome under various scenarios, and that the most lives would be saved in low-income communities of color.

The LAUCC study uses theoretical and modeling assumptions, a characteristic that is shared with much of the existing research about the impacts of trees on climate. Empirical research relying on in-the-field observations and measurements contributes a small proportion of what is known. There are advantages and drawbacks to different types of research ranging from theoretical to empirical approaches, and in order to increase the understanding of researchers and practitioners, we must collectively rely on what has already been established while exploring new avenues to make contributions to the field. Modeling such as that conducted by LAUCC provides a glimpse into the potential of large-scale planting efforts could impact conditions at a city and regional level. However, this approach stops short of yielding information about more granular interventions at the parcel or neighborhood level, begging the question of how we can translate encouraging city-scale modeling results into effective implementation at the level of parcels and neighborhoods. Engaging in both meso or macro scale modeling and in micro scale empirical research can generate critical insights about the advantages and potential disadvantages of varied approaches to urban greening to support cooling.

How trees affect microclimates, and what some of the tradeoffs are

At the neighborhood scale, trees change local climate conditions through shading and evapotranspiration, for instance contributing to decreases in park air temperatures by up to 11°F in comparison to surrounding streets (Vanos et al., 2012). Studies modeling projected benefits of tree canopy (defined as the amount of land covered by trees when seen from above) in reducing temperatures demonstrate that maturing tree canopies promote cooling in urban areas (Taha, 2013). In Los Angeles, city blocks that have more than 30% tree cover are about 5°F cooler than blocks without trees (Pincetl et al., 2013). In L.A., the percentage of shaded tree cover over the city's streets accounts for more than 60% of land surface temperature variations, compared with only 30% of variation explained by factors such as topography and distance to the coast (Pincetl et al., 2013).

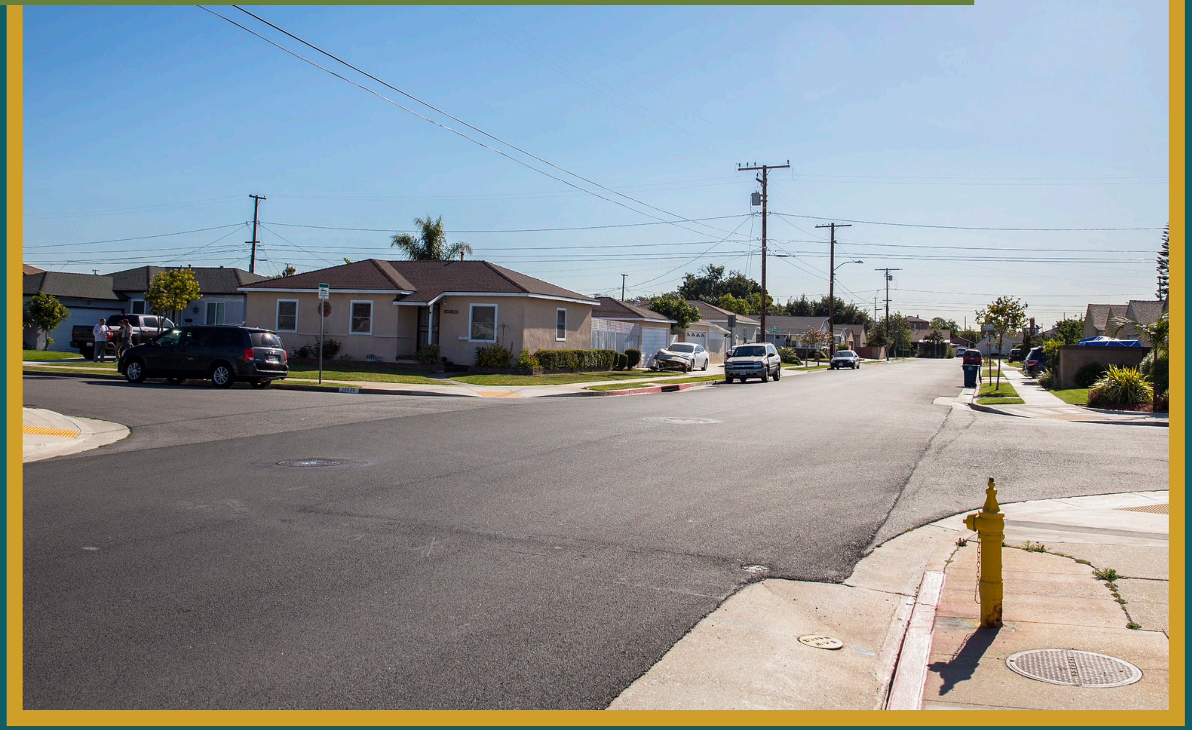
On a parcel scale, trees reduce temperature by providing shade, intercepting solar radiation, modifying wind patterns, and increasing humidity through transpiration (Streiling & Matzarakis, 2003; Steven et al., 1986). Cooling at the micro scale also impacts energy demand because tree shade reduces building heat gain and shaded air conditioners work more efficiently. A tree in Los Angeles avoids the combustion of 18 kg of carbon annually, exceeding the 4.5-11 kgs it sequesters during the same period (Akbari, 2002). The daily average temperature at which air conditioning use begins in shaded houses is generally higher than in unshaded houses (Akbari, 1997; Berry et al., 2013).

Tree placement and configuration have an impact on these functions at both the parcel and neighborhood scale. Abreu-Harbich et al. (2015) use a combined empirical-theoretical approach to find that tree characteristics such as lower tree height (closer to ground level where humans dwell) and canopy size and shape produce greater thermal comfort benefits. They also find that tree-planting configurations of two rows of trees, with minimally five to 10 trees per row, increase thermal comfort. Other modeling efforts support these findings and show that trees planted in higher-density configurations are more effective at improving outdoor thermal comfort, and that a dense canopy and large crown are some of the most advantageous characteristics (Kong et al., 2017). Based on a global study of 245 cities, trees can reduce maximum air temperatures by 0.9-3.6°F in summer (McDonald et al., 2016), though the impacts on nighttime cooling vary (Ruiz et al., 2017).

However, the energy, ecosystem, and health protection services that trees provide are not free from tradeoffs, and it is important to think strategically about how and where to plant to maximize benefit and reduce risk. For instance, when considering the microclimate effects of trees in urban areas, trees can provide cooling through shading of buildings during hot weather but can increase the need for wintertime heating and can also have a wind shielding effect that reduces mixing and dilution of pollutants — potentially contributing to poor air quality (Taha, 2013). In hot weather, cooling impacts from shade and transpiration peak during summer afternoons, when evaporation levels are at their highest — an important function on hot days (McPherson and Simpson, 2003). However, lower wind speed by trees can produce more conductive heat gain on surfaces in the built environment — a phenomenon that can be beneficial in cool weather but detrimental during hot weather (Huang et al., 1990). While shading and reduction of solar radiation by building-adjacent trees and vegetation reduce temperature, trees can raise indoor humidity (Huang, 1987; Akbari, 2002). Increased humidity in dry climates or during dry heat waves can promote improved thermal comfort, but it can have the opposite effect in humid climates or during humid heat waves (Zhou et al., 2020).

Understanding how to address these tradeoffs requires exploring the topic holistically, but much of the existing literature explores the benefit of trees solely on outdoor conditions. Studies on the indoor impacts of trees make up a smaller portion of the literature compared to studies on outdoor impacts. This is relevant because outdoor conditions may not be a good predictor of indoor conditions as a multitude of factors in the built environment contribute to indoor heat exposure and to when and for how long that heat exposure occurs. Fewer still are studies that look at impacts on the micro scale rather than the meso or macro scale, and those that use empirical observations rather than modeling (Wang et al., 2014). Of the studies that explore the impacts of trees on indoor thermal comfort, a very few consider thermal conditions by room or by likely time-of-day activity.

Among the few studies that investigate both outdoor and indoor thermal conditions is a study of two buildings in Nigeria that combined field measurements and simulations. The researchers found lower indoor temperatures in the tree-shaded building compared to the unshaded building, but also found that simulated results overestimated the cooling effects by as much as 2.7°F over observed measurements (Morakinyo et al., 2016). The same team conducted a similar study investigating the effects of trees on indoor and outdoor air and wall temperature and found that shaded buildings had indoor-outdoor temperature differences of no more than 4.3°F for the shaded building, while the unshaded building differences went up to 9.7°F (Morakinyo et al., 2013). Indoor air temperatures in the unshaded building were found to be consistently higher for longer. Another study, in Manchester, UK, looked at indoor thermal comfort during a heat wave using field measurements combined with modeling. Considering both existing and hypothetical conditions, the researchers found that by adding 17% more trees to the site, indoor thermal comfort was improved by over 20%, and outdoor air temperature decreased by 1.98°F (Taleghani et al., 2019). The present study seeks to contribute to this limited body of knowledge by providing empirical evidence of how trees impact indoor thermal conditions, adding to existing literature by yielding new insights that include analyses on thermal condition by room and time-of-day relative to tree cover and outdoor temperature.



Methods

Difference-in-differences approach

Simple comparison of (indoor) temperatures between houses with trees and houses without trees is complicated by the likelihood that these two groups of houses differ on other dimensions that might affect temperatures independent of trees. For example, houses that have tree canopy might also have greater wealth and are, therefore, more likely to live in a newer and better-insulated home. Physical factors that are often fortuitous can also influence thermal conditions, such as a home's configuration and the amount of solar exposure that it happens to receive relative to the cardinal direction it predominantly faces. While randomized experiments are one way to better control for confounding factors, such studies are costly and difficult to design and execute because such an experiment would need to plant mature trees that provide shade immediately. Young trees take time to grow and realize cooling benefits, so households randomized into the treatment group might migrate and as new residents move in, the experiment would be contaminated in non-random ways such as adaptive investments being made — for example, as a new air conditioning system.

The study we present seeks to isolate the causal effects of tree canopy on indoor temperatures using a non-experimental approach. We estimate a difference-in-differences (DD) approach that captures the spirit of differential changes over time across two groups, where one group is more exposed to a particular treatment at a given point in time (Angrist & Pischke, 2008). In our case, the two groups are residences with low or no tree canopy cover (the control group, which we dub "non-treehouses") and residences with moderate or high canopy cover (the treatment group, which we dub "treehouses"). We calculate the differences in indoor and outdoor temperatures in each group between hot days (≥90°F) and non-hot days (<90°F). The model assumes that homes with trees experience a relatively larger cooling effect from trees on hot days and, therefore, have a relatively smaller increase in indoor temperatures on hot days compared to control sites.

A key modeling assumption is that the baseline temperature on non-hot days is not influenced by the tree canopy. There is reason to believe that this assumption might be violated because tree canopy can trap heat in cooler temperatures under certain conditions. Though the magnitude of this warming effect may be small, it would likely lead to overestimating the benefits of trees since it would lead to finding a relatively smaller differential between hot and non-hot days in treatment homes relative to control homes. We attempt to address the magnitude of this bias by considering the mechanics of cooling and warming by trees, and how these are influenced by time of day. Trees provide cooling through the processes of shading and transpiration, both of which are maximized during daylight hours, when temperatures tend to be highest (Rahman & Ennos, 2016). Conversely, trees can have a warming effect at night, as wind is reduced and shielded, preventing dispersion of accumulated heat (Huang et al., 1990). However, the magnitude of daytime cooling is understood to exceed that of nighttime warming, with one study finding that trees provide up to 8.1°F of daytime cooling while providing only 1.8°F of nighttime warming (Taha et al., 1990). We therefore expect any warming effects to have a minimal influence compared to the cooling impacts observed over the course of the study.

Community scientist recruitment

The original scope of this project was written before the COVID-19 pandemic and called for interested community members to host thermal sensors in their homes and allow study personnel to visit their home to install the sensors and download the data several times during the project period. Due to the pandemic, the scope was modified to accommodate necessary social distancing requirements.
Rather than recruit community members at-large,

recruitment occurred among TreePeople volunteers who had volunteered with the organization multiple times and showed a consistent commitment to organizational activities. This model demanded a more hands-on "community science" approach requiring participants to install sensors, download and transmit data, and potentially troubleshoot sensor issues. This more active level of involvement warranted recruitment of vetted TreePeople volunteers.

Recruitment took place in July and August 2020 with the assistance of TreePeople's community engagement staff, which maintain lists of past volunteers and contact information for representatives of community organizations with whom TreePeople has partnered. An email explaining the study and the requirements for participation was sent to individuals who live in two areas: Watts (south central Los Angeles County) and the Gateway Cities (southeast Los Angeles County). These neighborhoods were selected for two reasons. First, relative to other parts of the County, residents of these areas have limited resilience to heat waves, with low tree canopy and lower-than-average air conditioning availability (Galvin et al., 2019; Fraser et al., 2017). Second, TreePeople has active programs in these areas, with viable contacts at the community and policy-making levels.

Interested individuals were asked to fill out an application (see appendices A and B). Twenty-nine applications were screened and eight households were ultimately selected, though one of the participating households was ultimately excluded for neglecting to install the sensors. Selection criteria included:

- **Parcel tree canopy amount**[1] - half of selected participants had tree canopy lower than the L.A. County average of 18%, while the other half had moderate or high canopy. Tree canopy was determined by using the Los Angeles Tree Canopy Map Viewer.
- **Year structure was built** - we sought older buildings built prior to the adoption of the 1978 Title 24 building energy efficiency standards.
- **Existence of and reported use of air conditioning** - to minimize the potential of "noisy" data readings that would be skewed by the use of air conditioning, we sought homes that either had no air conditioning, or homes with window units but no central air conditioning. We asked applicants with window units how often they typically use AC when very hot out (never, rarely, sometimes, always), and we sought participants who reported never, rarely, or sometimes.
- **Geographic location** - we sought homes that were clustered in a heat-vulnerable part of the county to allow for use of one official reference weather station.
- **Tech-savvy participant** - we asked applicants to rate their technological savvy as we wanted to select participants who would be able to easily install the sensors and download and transmit collected data.

Participating households were provided detailed instructions on how and where to install the sensors (see Appendix C). Study personnel requested data downloads from the participants every two weeks in order to be able to identify any data collection issues such as a unit malfunction or battery problems. The project received an exemption from UCLA's Institutional Review Board to ensure the protection of study participants. Participants were asked to sign a consent and agreement form advising them of the voluntary nature of the project, and they were offered an incentive of a $100 gift card at the conclusion of the project.

Data collection occurred in homes in Southeast Los Angeles (see Figure 1). Relative to other parts of L.A. County, this region has some of the highest concentrations of impervious surfaces coupled with low tree canopy cover. This is a working-class area that is approximately 70% Latino, 7% Black, and 7% Asian, and has an average annual household income ranging between $40,000 for Maywood and Huntington Park to about $60,000 in Downey (LA Times, 2021). CalEnviroScreen assigns this area a pollution burden of between the 65th percentile in parts of Downey and the 95th to 100th percentile for parts of Maywood, South Gate, and Huntington Park (OEHHA, 2020).

Study site	Neighborhood	Decade built	Parcel tree cover	Neighborhood tree cover	Housing type
Non-treehouse 1	Central-Alameda	1910s	10%	13%	Duplex
Non-treehouse 2	Bell Gardens	1940s	4%	11%	Single-family home
Non-treehouse 3	Huntington Park	1960s	7%	12%	Single-family home
Non-treehouse 4	South Gate	1940s	9%	13%	Duplex
Treehouse 5	Huntington Park	1960s	23%	12%	Duplex
	Tree mix: a mix of mature fruit trees exceeding 20-25' in height				
Treehouse 6	Downey	1940s	72%	16%	Single-family home
	Tree mix: predominantly mature broadleaf deciduous exceeding 35' in height; mature fruit trees and shrubs				
Treehouse 7	Maywood	1930s	40%	12%	Multi-unit apartment building
	Tree mix: predominantly mature broadleaf deciduous exceeding 35' in height				

Table 1. *Descriptions of study sites*

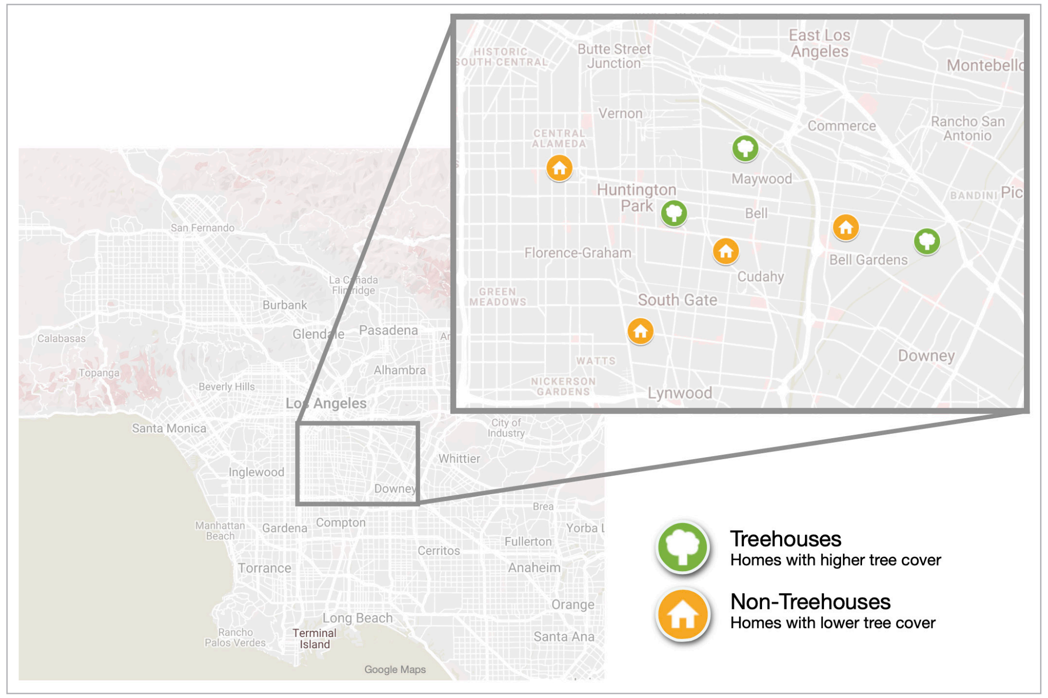


Figure 1. *Locations of houses enrolled in the study. Map shows only approximate locations. Icons have been moved slightly and randomly in order to protect participant anonymity.*

---

[1] *The L.A. County Tree Canopy Map Viewer is accessible at tinyurl.com/treeviewer.*

Data collection

Each participating household was given three Kestrel DROP thermal data loggers with instructions for installing the sensors, connecting them to an iOS or Android device via the Kestrel LINK app, and downloading and transmitting the data. Kestrel DROP sensors have been successfully used in other research studies, including: a study on the spatial-temporal dynamics of people's interaction with the urban environment (Li et al., 2019); a study that measured above-canopy meteorological profiles using unmanned aerial systems (Prior et al., 2019); and a comparative study of personal temperature exposure assessments (Bailey et al., 2020). Our study used Kestrel DROP D2HS Heat Stress Monitors for indoor installations and Kestrel DROP D3FW Fire Weather Monitors outdoors.

Three devices were installed as follows: one in the bedroom, one in the living room, and one on the exterior of the home, attached under an eave. Instructions for installation were written based on a literature review of similar studies using weather sensors, and included directions such as: placing the sensor 40-50 inches above the floor; on an interior wall that is not exterior-facing and does not have a window or door leading out; and away from sources of heat, sources of light, direct sunlight, or heating/cooling vents. Homes considered to have moderate to high tree canopy were given a fourth data logger to install in a tree, but in order to treat each site equally tree data were ultimately excluded from analysis. Participants were instructed to install outdoor sensors in fully shaded locations. As a precaution, all outdoor sensors were placed in a small, light-colored upside down paper cup to shield them in the event of direct sun exposure.

Data were collected between September 1, 2020 and November 15, 2020, for a total of 76 days of data collection. Readings were collected every half hour for a total of 48 readings per sensor per day, and included temperature, relative humidity, heat stress index, and dew point. The total number of half-hourly readings across all sites was over 20,000 per site category (for all bedroom sensors, etc.). The sensor network was in place in time to capture the hottest day ever recorded in Los Angeles County, which occurred on Sept. 6, 2020.

Daily highs for the study region were obtained from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information. The reference weather station used for the study is at Downtown/USC located just west of the study area.

> Data collection occurred for 76 days between September 1 and November 15, 2020. Readings were collected every half hour both indoors (bedroom and living room) and outdoors.

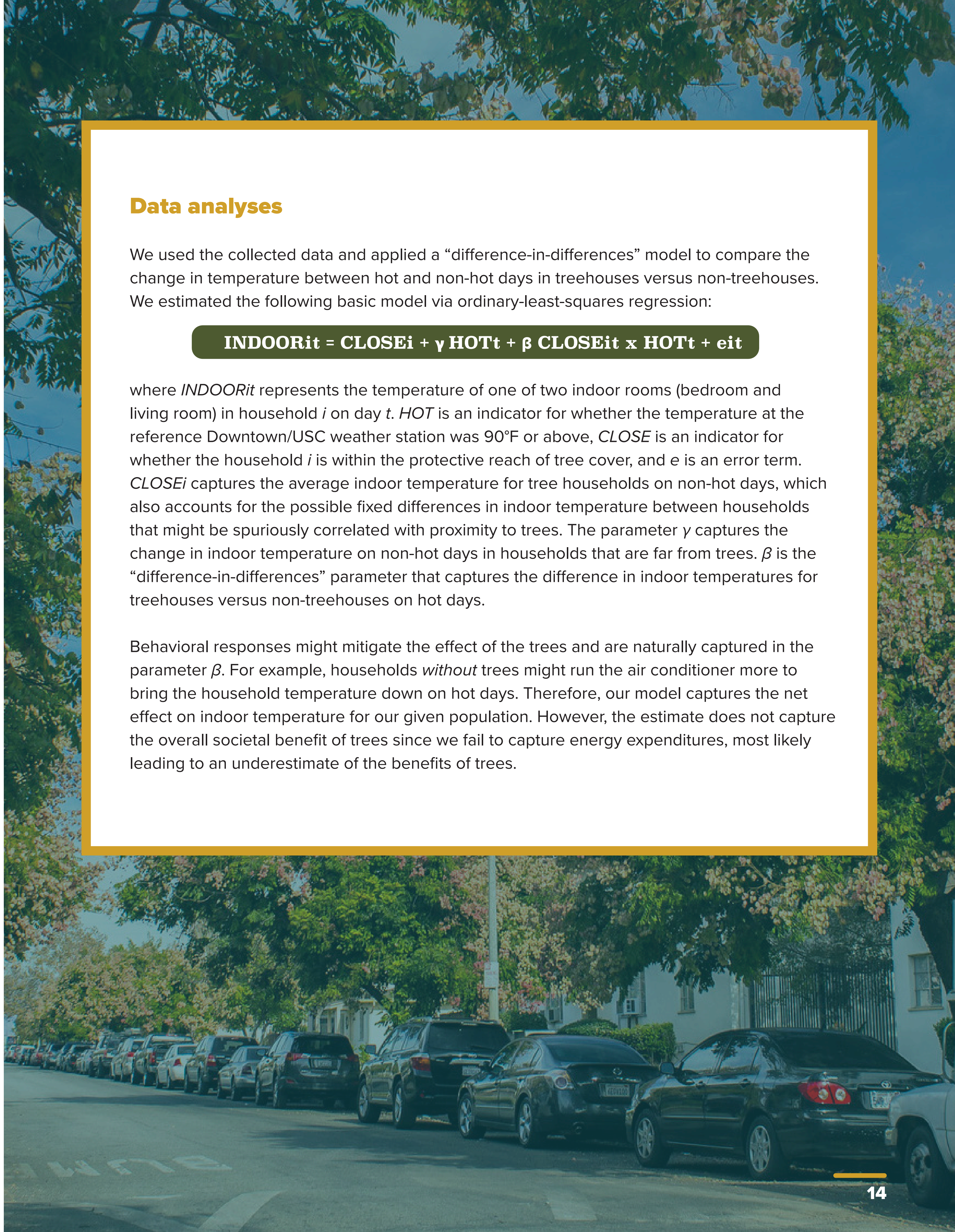
Study Definitions

Treehouse = A participating residence whose parcel tree canopy cover exceeds L.A. County's average canopy cover of 18%

Non-treehouse = A participating residence whose parcel tree canopy cover falls below L.A. County's average canopy cover of 18%

Hot day = A day with a maximum daily temperature at or above 90°F as recorded at the National Weather Service Los Angeles Downtown/USC weather station

Non-hot day = A day with a maximum daily temperature below 90°F as recorded at the National Weather Service Los Angeles Downtown/USC weather station



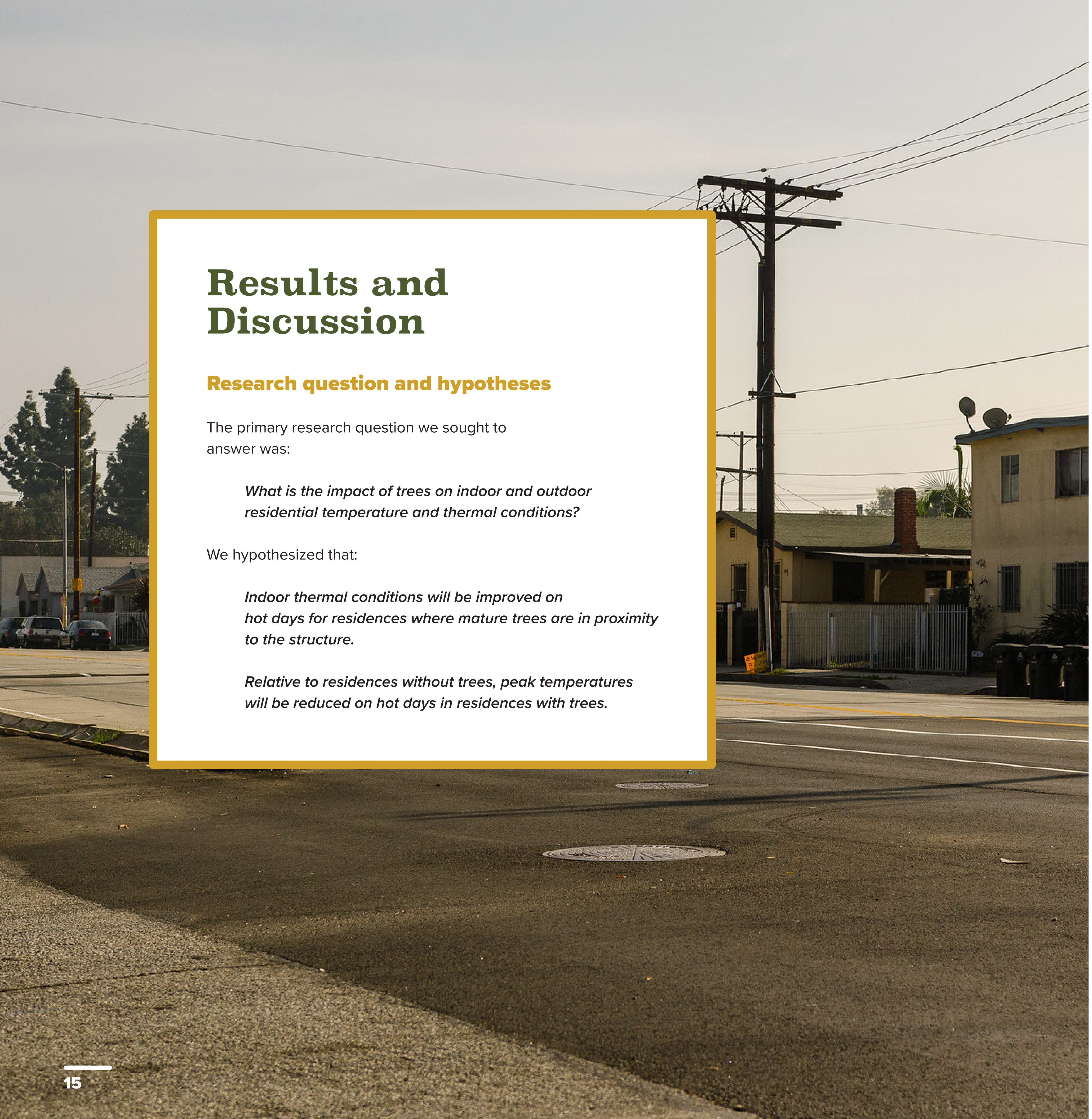
Data analyses

We used the collected data and applied a "difference-in-differences" model to compare the change in temperature between hot and non-hot days in treehouses versus non-treehouses. We estimated the following basic model via ordinary-least-squares regression:

$$\text{INDOORit} = \text{CLOSEi} + \gamma\ \text{HOTt} + \beta\ \text{CLOSEit} \text{ x } \text{HOTt} + \text{eit}$$

where *INDOORit* represents the temperature of one of two indoor rooms (bedroom and living room) in household *i* on day *t*. *HOT* is an indicator for whether the temperature at the reference Downtown/USC weather station was 90°F or above, *CLOSE* is an indicator for whether the household *i* is within the protective reach of tree cover, and *e* is an error term. *CLOSEi* captures the average indoor temperature for tree households on non-hot days, which also accounts for the possible fixed differences in indoor temperature between households that might be spuriously correlated with proximity to trees. The parameter *γ* captures the change in indoor temperature on non-hot days in households that are far from trees. *β* is the "difference-in-differences" parameter that captures the difference in indoor temperatures for treehouses versus non-treehouses on hot days.

Behavioral responses might mitigate the effect of the trees and are naturally captured in the parameter *β*. For example, households *without* trees might run the air conditioner more to bring the household temperature down on hot days. Therefore, our model captures the net effect on indoor temperature for our given population. However, the estimate does not capture the overall societal benefit of trees since we fail to capture energy expenditures, most likely leading to an underestimate of the benefits of trees.



Results and Discussion

Research question and hypotheses

The primary research question we sought to answer was:

> *What is the impact of trees on indoor and outdoor residential temperature and thermal conditions?*

We hypothesized that:

> *Indoor thermal conditions will be improved on hot days for residences where mature trees are in proximity to the structure.*
>
> *Relative to residences without trees, peak temperatures will be reduced on hot days in residences with trees.*

Average temperatures comparing treehouses and non-treehouses on hot and non-hot days

Bedroom Average Temperatures

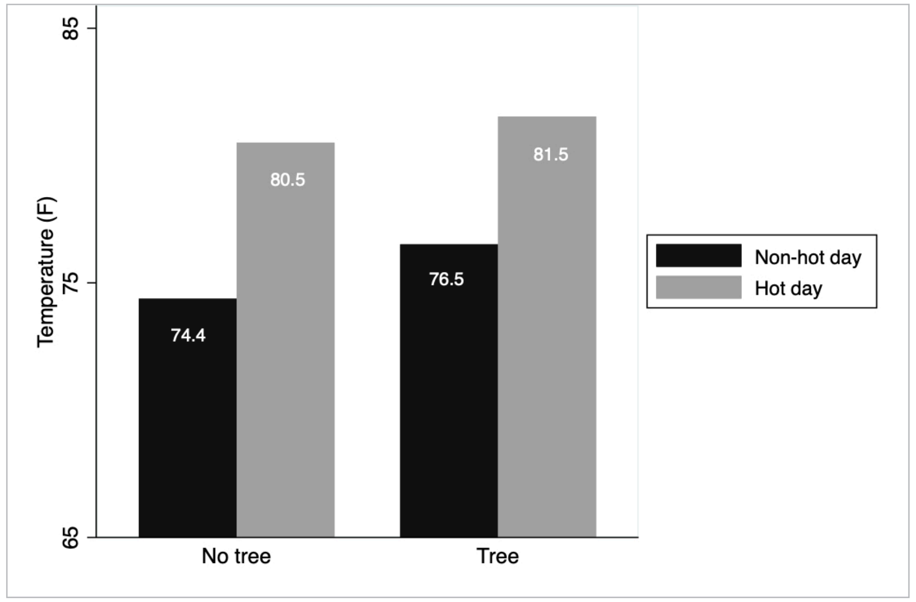


Figure 2. *Average bedroom temperatures on hot and non-hot days for treehouses and non-treehouses*

Figure 2 presents the graphical version of our difference-in-differences estimate for bedroom temperatures. It shows that over the study period, bedrooms in treehouses actually experienced 2.1°F higher average temperatures on the baseline non-hot days (days below 90°F). There are a host of reasons why this could be the case, including building materials and sun exposure as a function of the orientation of the bedroom relative to the rest of the house. This fact alone does not diminish the potential of urban cooling by trees, and it underscores the aptness of our difference-in-differences research design. The data show that on average, bedrooms in treehouses are 5.0°F warmer on hot days than on non-hot days, and that bedrooms in non-treehouses are 6.1°F warmer on hot days than on non-hot days. The difference between the two groups of homes being 2.1°F on non-hot days and shrinking down to 1.0°F on hot days suggests that trees have a 1.1°F dampening effect during extreme heat conditions. Without trees, we would expect that treehouses would be hotter and expose residents to higher temperatures.

Living Room Average Temperatures

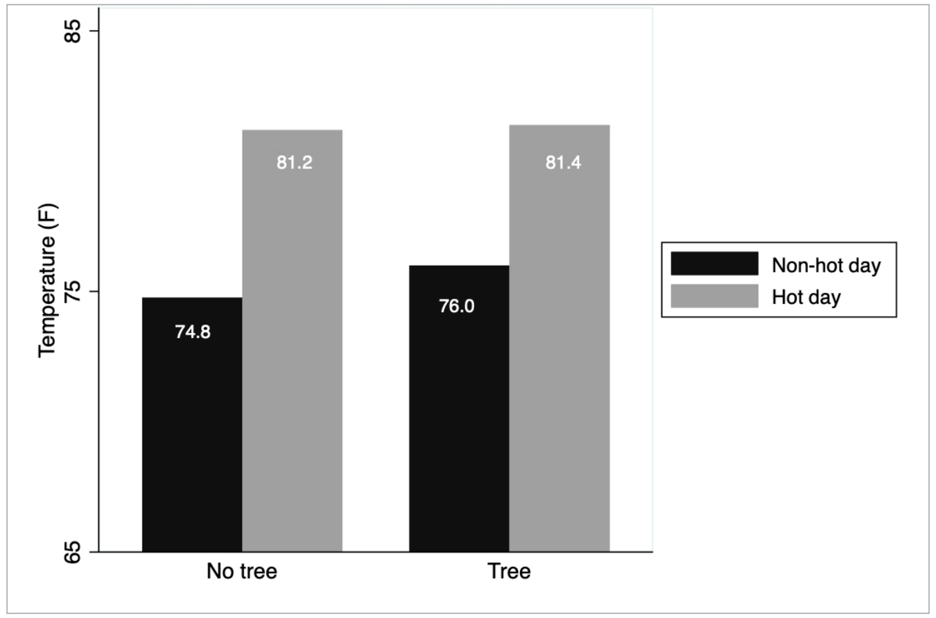


Figure 3. *Average living room temperatures on hot and non-hot days for treehouses and non-treehouses*

Figure 3 illustrates that the effects of trees on living room temperatures are similar to those in the bedroom. Living rooms in treehouses are 1.2°F warmer on non-hot days and 0.2°F warmer on hot days relative to non-treehouses, implying a difference-in-differences of approximately 1.0°F. The estimated effect for the living room is similar to our estimate for the bedroom, indicating the benefits of trees are not confined to one area of the house.

SEPTEMBER 6, 2020: L.A.'S ALL-TIME HOTTEST DAY

On Sept. 6, 2020, L.A.'s Woodland Hills neighborhood hit 121°F, the highest temperature ever recorded in L.A. County, surpassing the previous record of 119°F set during California's historic 2006 heat wave (Wigglesworth & Cosgrove, 2020). The daily high for our study's reference weather station at Downtown/USC was 111°F, and the hottest of our study sites — a residence in Huntington Park with no trees or air conditioning — topped out at:

- Eave: 110.3°F at 2:00pm
- Living room: 107.4°F at 4:00pm
- Bedroom: 99.7°F at 6:00pm

Such extreme temperatures are dangerous even for healthy people, and sustained exposure can prove deadly. As the planet warms and Los Angeles becomes more prone to hotter and longer heat waves, heat-protection strategies are needed to prevent more Angelenos from being in harm's way.

Living Room Average Temperatures

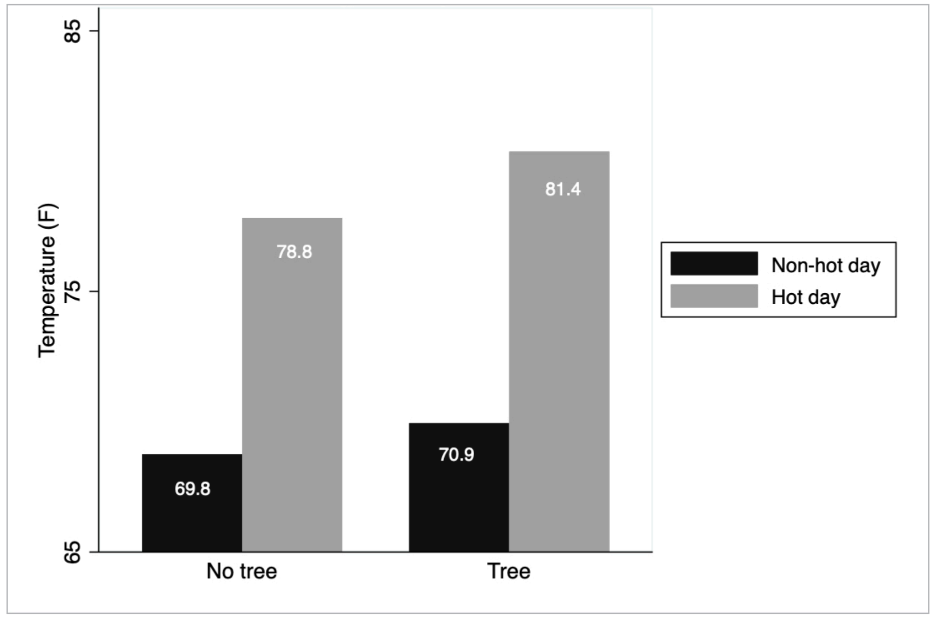


Figure 4. *Average eave (outdoor) temperatures on hot and non-hot days for treehouses and non-treehouses*

Figure 4 shows that, averaged over the study period, treehouse temperatures are actually warmer outdoors than at non-treehouses. In contrast with indoor temperatures, we see that eave temperatures in treehouses actually rise by a greater amount than eaves in non-treehouses during hot weather. On average, eaves at treehouses are 10.5°F warmer on hot days than on non-hot days, whereas non-treehouse eaves are 9°F warmer on hot days than on non-hot days. The difference between the two kinds of sites is 1.1°F on non-hot days and grows to 2.6°F on hot days, suggesting that tree houses are actually warming 1.5°F more outside on hot days. There are a variety of site-specific reasons that could account for this unexpected phenomenon, and while we cannot conclusively ascribe this differential to any specific factors given the data at hand, we expect that average eave temperatures in treehouses would grow even more significantly if trees were absent. This fact suggests that our findings above, which already support a cooling benefit of trees, might even be understated.

> Among the homes in the study, trees keep indoor temperatures an average of 1°F cooler compared with homes that have little to no tree cover. If homes in heat-vulnerable parts of Los Angeles were 1°F cooler we could reduce heat-related deaths by 10-20%, and with additional tree canopy and solar reflectance increases the number of lives saved could grow to 30% or more (de Guzman et al., 2020).

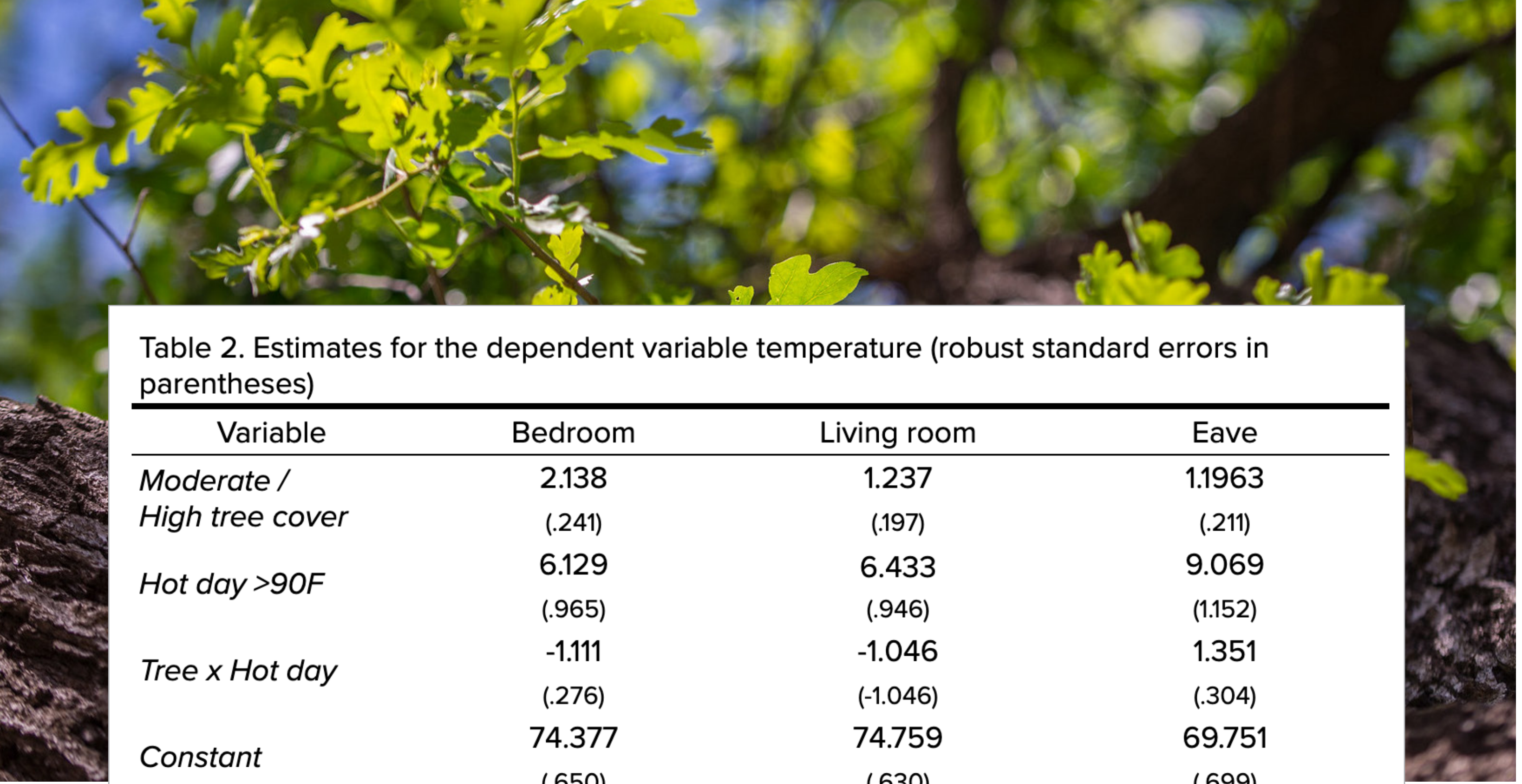


Table 2. Estimates for the dependent variable temperature (robust standard errors in parentheses)

Variable	Bedroom	Living room	Eave
Moderate / High tree cover	2.138	1.237	1.1963
	(.241)	(.197)	(.211)
Hot day >90F	6.129	6.433	9.069
	(.965)	(.946)	(1.152)
Tree x Hot day	-1.111	-1.046	1.351
	(.276)	(-1.046)	(.304)
Constant	74.377	74.759	69.751
	(.650)	(.630)	(.699)
Sample size	25,596	25,326	20,695

Table 2. *Regression analysis for bedroom, living room, and eave temperatures on hot and non-hot days for treehouses and non-treehouses*

Regression analyses

Table 2 replicates the prior figures in table format and presents estimates that are identical to those previously shown, with the regression analysis including standard error calculation in parentheses. Bedrooms in non-treehouses are 6.1°F warmer on hot days than non-hot days *(Hot day >90F)*. Bedrooms in treehouses are an average 2.1°F warmer than non-treehouses on non-hot days *(Moderate / High tree cover)*, but temperatures in treehouse bedrooms increase by 1.1°F less than they do in non-treehouses *(Tree x Hot day)*, once again pointing to indoor temperature modulation impacts of trees. Given the standard error of 0.28, the estimates are statistically significant (p = 0.0000). The number of observations varies due to variations in thermal sensor performance over the 76-day study period. The community scientist nature of the project led to data downloads occurring sporadically, at times causing a delay in identifying and troubleshooting sensor issues.

While a difference-in-differences of 1.1°F is small, we note that this study was intentionally conducted in neighborhoods that have low tree cover in order to yield data about the parcel-level function of trees while excluding potential neighborhood-level tree cover influence. Even where the parcel had high tree cover, as is especially the case with treehouse 6 and 7, we expect no additional tree cover benefit to come from neighborhood-level tree cover, because all neighborhoods have less than the L.A. County average of 18% tree cover. As such, our study will naturally understate the benefit of large scale planting efforts, as documented in the LAUCC study.

Average hourly temperatures

Figure 5 shows that on hot days we see that the difference in temperatures between treehouses and non-treehouses is smaller at all times of day than it is on non-hot days, suggesting a temperature attenuation effect by trees. The fact that the benefits extend to nighttime hours is particularly beneficial to public health, because while occupants are sleeping the body seeks to recuperate after the day's heat exposure. Indoor peak temperatures occur around 5:00pm, later than outdoor peak temperatures, as heat continues to be retained and conveyed even after outdoor temperatures begin to cool off.

Bedroom Average Hourly Temperatures

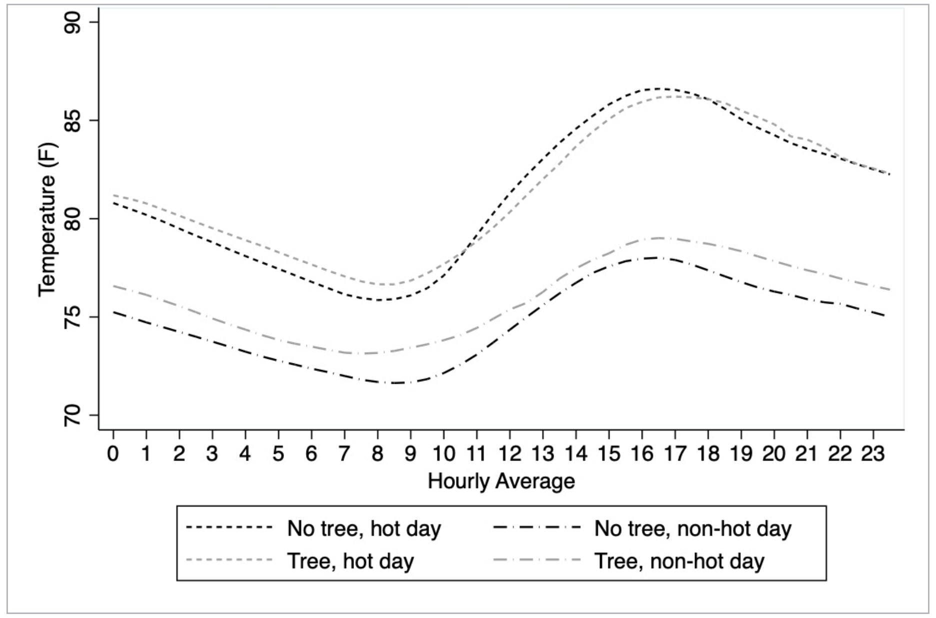


Figure 5. *Hourly average temperatures for bedrooms on hot and non-hot days for treehouses and non-treehouses*

Figure 6 shows that living rooms in non-treehouses are generally cooler, which we also see in the bar chart in Figure 3. However, we see that temperatures in treehouses increase by a lesser amount on hot days and that non-treehouse temperatures actually exceed those in treehouses as daily temperatures increase between about 11:00am and 6:00pm. This implies that trees have an even larger cooling effect in living rooms during hours when daily temperature is on the rise. This switch is not observed in bedrooms and could potentially be attributed to factors such as insulation quality and azimuth/cardinal direction of the living room relative to the rest of the house.

Living Room Hourly Average Temperatures

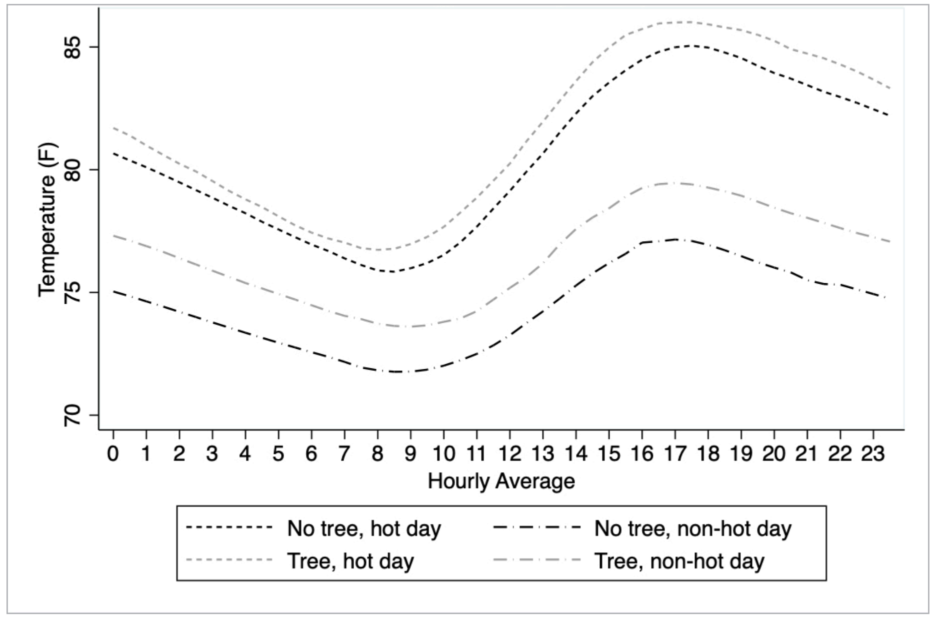


Figure 6. *Hourly average temperatures for living rooms on hot and non-hot days for treehouses and non-treehouses*

Eave Average Hourly Temperatures

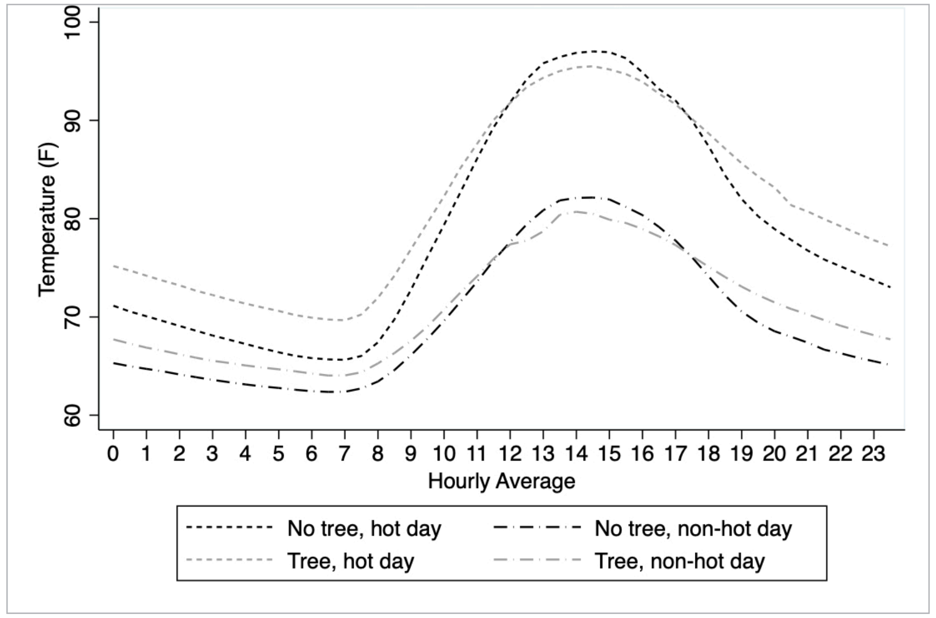


Figure 7. *Hourly average temperatures for eaves on hot and non-hot days for treehouses and non-treehouses*

Figure 7 shows that outdoor temperatures in treehouses are on average higher than those observed at non-treehouses during the cooler parts of the day. Importantly, we see that the relationship flips during peak temperature hours (between about 12:00pm and 5:00pm), when temperatures at treehouses are cooler. This occurs both during non-hot and hot days, though the differential at the coolest part of the day is larger on hot days. These observations suggest different possibilities: a) trees provide some, albeit relatively less, cooling at night than during the day, or b) trees trap heat and have a warming effect at night. Nighttime warming is attributable to wind shielding (Huang et al., 1990) and longwave radiation emitted from the ground being reflected by the tree back down to the ground due to limited sky view factor (Souch & Souch, 1993; Taha et al., 1991). Disentangling these two competing hypotheses is difficult with the limited data at hand. But the first hypothesis seems more likely since the theoretical benefits of trees are largest during the hottest part of hot days, suggesting that we would expect there to be even less difference between day and night for treehouses on hot days, which is what we observe.

Limitations

The grant that supported this research was written and awarded prior to the COVID-19 pandemic. Recruitment was originally meant to occur through door-to-door canvassing. With agreements in place, the plan was for study team personnel to enter each household to install the data loggers and then visit the homes approximately every two weeks to check on the devices, download collected data, and troubleshoot any issues. This plan was not possible given the realities of social distancing, and methods were changed. Instead, installation instructions were provided to residents who served as community scientists on the study. Study personnel were in frequent communication with residents to obtain photos of sensor installations and data downloads.

Community science, also known as citizen science or participatory monitoring, has gained popularity in recent years because it offers a cost-effective way to collect data across large spatial and temporal scales and brings positive experiences and learning opportunities for volunteers (Aceves-Bueno et al., 2017). In the case of this pandemic-era study, community science made it possible for the research to proceed. However, a community science approach raises questions about accuracy, and in the case of our study, it presented challenges around ensuring correct sensor placement and accurate data collection. Candidates interested in participating in the present study were screened to ensure they had a thermal sensor-compatible iOS or Android device and were asked how strongly they agree with the statement "I consider myself technologically savvy with the use of mobile applications." Selected participants were provided detailed instructions for installing the devices and downloading the data, and were asked to submit photos of the installed devices. Remote troubleshooting support was available to them from study personnel.

These and other measures rely on participants being committed and responsive. In practice, we learned that participants are not all equally committed and communicative. For instance, we learned too late that one of the participants failed to install any of the sensors they were given, even after signing a contract and receiving frequent communications via emailing and texting throughout the course of the study. This led to a sample of seven homes rather than eight.

Other limitations also exist. Adaptive responses, like use of air conditioning, were not closely accounted for in this study. Because houses without trees lacked cooling from trees, they may have responded with more air conditioning or fan use. This cooling effect suggests we might understate the benefit of trees in our analysis. To mitigate this concern, prospective study participants with central AC were excluded because of the relative ease and automation of controlling indoor climate with central systems, and we selected participants who either had no AC or had window or wall units only. To address this limitation, a future study could collect daily energy use data or otherwise monitor adaptive responses such as AC use.

Finally, the small sample size meant that we could not test whether site characteristics, such as housing type, tree type, and tree distance may have modified the benefit of trees. For example, houses where trees are planted on the west-facing wall or in front of windows would be expected to see larger benefits from trees, but with the limited sample size and high variability in built environment characteristics between study sites, aggregating observations into the two study groups (treehouses and non-treehouses) proved to be the most conservative and defensible approach. We acknowledge these limitations and offer this as a proof-of-concept study that can serve as the foundation for a larger future study.

Conclusions and Future Directions

This study contributes new empirically-derived support for the heat-protective function of trees in an urban environment. We find that on average, bedroom temperatures in treehouses warm 1.1°F lower on hot days compared to non-treehouses and 1.0°F lower in living rooms. These temperature benefits extend to all times of the day, which is critical from a public health perspective given nighttime vulnerability to heat exposure. These temperature reductions can help reduce heat-related public health costs among heat-vulnerable communities — a fact of critical importance as the study also finds that exposure to extreme heat can and does reach dangerously high levels in older residences without trees or air conditioning. On September 6, 2020 — the day Los Angeles County's hottest-ever temperature of 121°F was recorded — temperatures at a non-treehouse with no air conditioning reached 99.7°F in the bedroom and 107.4°F in the living room. Sustained exposure to such heat is a reality for many residents of Los Angeles and other cities who lack access to coping strategies, pointing to the need for swift action to protect heat-vulnerable communities.

Future directions for this research include a larger-scale study involving 100 to 200 homes segmented by neighborhood and site characteristics. This would enable a deeper exploration of tree and housing type characteristics. Incorporating household-level energy data for the study period would enable quantification of the impacts of trees on energy demand. Such an analysis could be linked both to in situ sensors, such as the ones used in this study, and remote-sensed land surface temperature data. Further investigation of the daytime vs. nighttime effects of trees on thermal conditions is another critical area that should be explored, especially in the context of how exposure to heat at different times of day and in different rooms of the house impacts public health outcomes.

Acknowledgments

The Institute of the Environment and Sustainability at UCLA acknowledges our presence and the presence of the homes involved in this study on the traditional, ancestral and unceded territory of the Gabrielino/Tongva, Chumash, and Kizh peoples.

The study team wishes to thank:

The participants of this study and their families for their curiosity and commitment to growing our collective knowledge about the role of trees in making our neighborhoods more livable.

Andy Lipkis, Jen Bravo, Deborah Bloome, and Zenya Prowell at Accelerate Resilience L.A. (ARLA) for the partnership and support provided during this study.

Luis Rodriguez at TreePeople for his role co-managing the project and liaising with study participants, Dr. Yujuan Chen for her role co-managing the project, and Alejandro Fabian and Eileen Garcia for their help in recruiting participants.

Charlotte Schulman at Vassar College for compiling information on thermal sensor selection and placement.

Dr. V. Kelly Turner and Dr. Aradhna Tripati at UCLA for advising on research design.

References

Aceves-Bueno, E., Adeleye, A. S., Feraud, M., Huang, Y., Tao, M., Yang, Y., & Anderson, S. E. (2017). The accuracy of citizen science data: a quantitative review. *The Bulletin of the Ecological Society of America*, 98(4), 278-290.

Akbari, H. (2002). Shade trees reduce building energy use and CO2 emissions from power plants. *Environmental Pollution*, 116, S119-S126.

Angrist, J.D. & Pischke, J. (2008). *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton University Press.

Bailey, E., Fuhrmann, C., Runkle, J., Stevens, S., Brown, M., & Sugg, M. (2020). Wearable sensors for personal temperature exposure assessments: A comparative study. *Environmental Research*, 180, 108858.

Berry, R., Stephen, L. J., & Aye, L. (2013). Tree canopy shade impacts on solar irradiance received by building walls and their surface temperature. *Building and Environment*, 69, 91-100.

Chakraborty, T., Hsu, A., Manya, D., & Sheriff, G. (2019). Disproportionately higher exposure to urban heat in lower-income neighborhoods: a multi-city perspective. *Environmental Research Letters*, 14(10), 105003.

de Abreu-Harbich, L. V., Labaki, L.C., & Matzarakis A. (2015). Effect of tree planting design and tree species on human thermal comfort in the tropics. *Landscape and Urban Planning*, 138, 99-109.

de Guzman, E., Kalkstein, L.S., Sailor, D., Eisenman, D., Sheridan, S., Kirner, K., Maas, R., Shickman, K., Fink, D., Parfrey, J., & Chen., Y. (2020). Rx for Hot Cities: Climate Resilience Through Urban Greening and Cooling in Los Angeles. TreePeople. https://www.treepeople.org/wp-content/uploads/2020/09/RX-for-hot-cities-report.pdf

Dousset, B., Gourmelon, F., Laaidi, K., Zeghnoun, A., Giraudet, E., Bretin, P., ... & Vandentorren, S. (2011). Satellite monitoring of summer heat waves in the Paris metropolitan area. *International Journal of Climatology*, 31(2), 313-323.

Estrada, F., Botzen, W. & Tol, R. (2017). A global economic assessment of city policies to reduce climate change impacts. *Nature Climate Change 7*, 403–406. https://doi.org/10.1038/nclimate3301

Fraser, A.M., Chester, M.V., Eisenman, D., Hondula, D.M., Pincetl, S.S., English, P., & Bondank., E. (2017). Household accessibility to heat refuges: Residential air conditioning, public cooled space, and walkability. *Environment and Planning B: Urban Analytics and City Science*, (2017), 1036-1055, 44(6).

Galvin, M., O'Neil-Dunne, J., Locke, D., Romolini, M. (2019). Los Angeles County Tree Canopy Assessment. SavATree Consulting Group. https://www.treepeople.org/sites/default/files/pdf/tree-canopy-data/Tree%20Canopy%20LA%202016%20Report_FINAL%2020190425.pdf

Hall, A., Berg, N., & Reich, K. (2018). *Los Angeles Summary Report*. California's Fourth Climate Change Assessment. Publication number: SUM-CCCA4-2018-007.

Hoffman, J.S., Shandas, V., & Pendleton, N. (2020). The effects of historical housing policies on resident exposure to intra-urban heat: A study of 108 US urban areas. *Climate, 8*(1), 12. https://doi.org/10.3390/cli8010012

Huang, Y.J., Akbari, H., Taha, H., Rosenfeld, A.H. (1987). The potential of vegetation in reducing summer cooling loads in residential buildings. *Climate & Applied Meteorology, 26* (9), pp. 1103-1116.

Huang, Y. J., Akbari, H., & Taha, H. (1990). The wind-shielding and shading effects of trees on residential heating and cooling requirements. *ASHRAE Proceedings, 96*(pt. 1)

Huang, L., Li, J., Zhao, D., & Zhu, J. (2008). A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China. *Building and environment*, 43(1), 7-17.

Jesdale, B.M., Morello-Frosch, R. & Cushing, L. (2013). The Racial/Ethnic Distribution of Heat Risk-Related Land Cover in Relation to Residential Segregation. *Environmental Health Perspectives*, 121(7), 811–817. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3701995/

Kalkstein, L.S., Sheridan S.C., Kalkstein A.J., Vanos J.K., & Eisenman D.P. (2014). The Impact of Oppressive Weather On Mortality Across Demographic Groups in Los Angeles County and the Potential Impact of Climate Change. Prepared for Los Angeles County Department of Public Health.

Keith, L., Meerow, S., & Wagner, T. (2020). Planning for Extreme Heat: A Review. *Journal of Extreme Events*. 6. 2050003. 10.1142/S2345737620500037.

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., ... & Engelmann, W. H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J*ournal of Exposure Science & Environmental Epidemiology*, 11(3), 231-252.

Li, Z., Zhao, Q., Shah, D., Luo, W., Fischer, H., Solis, P., & Wentz, E. A. (2019). ActivityLog-HeatMappers: A Novel Research Data Collection Tool for Logging Activities, Locations and Environment Data. In *99th American Meteorological Society Annual Meeting*. AMS.

Li, D., Yuan, J., & Kopp, R. E. (2020). Escalating global exposure to compound heat-humidity extremes with warming. *Environmental Research Letters*, 15(6), 064003.

Los Angeles Times. 2021. Neighborhoods: Southeast LA. Accessed 03/22/21. <http://maps.latimes.com/neighborhoods/region/southeast/>

McDonald, R., Kroeger, T., Boucher, T., Longzhu, W., & Salem, R., (2016). Planting Healthy Air: A global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. The Nature Conservancy.

McPherson, E. G., & Simpson, J. R. (2003). Potential energy savings in buildings by an urban tree planting programme in California. *Urban Forestry & Urban Greening*, 2(2), 73-86.

Morakinyo, T. E., Balogun, A. A., & Adegun, O. B. (2013). Comparing the effect of trees on thermal conditions of two typical urban buildings. *Urban Climate*, 3, 76-93.

Morakinyo, T. E., Dahanayake, K. C., Adegun, O. B., & Balogun, A. A. (2016). Modelling the effect of tree-shading on summer indoor and outdoor thermal condition of two similar buildings in a Nigerian university. *Energy and Buildings*, 130, 721-732.

Office of Environmental Health Hazard Assessment (OEHHA). 2020. CalEnviroScreen 3.0. Accessed 08/20/20. <https://oehha.ca.gov/calenviroscreen/report/calenviro-screen-30>

Ostro, B., Rauch, S., & Green, S. (2011). Quantifying the health impacts of future changes in temperature in California. *Environmental Research* 111(8), 1258–1264. https://doi.org/10.1016/j.envres.2011.08.013

Pincetl, S., Gillespie, T., Pataki, D.E. Saatchi, S., & Saphores, J. D. (2013). Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. *GeoJournal*, 475-493, 78(3).

Prior, E. M., Brumbelow, K., & Miller, G. R. (2019). Measurement of above-canopy meteorological profiles using unmanned aerial systems. *Hydrological Processes*, 34(3).

Rahman, M. A., & Ennos, A. R. (2016). *What we know and don't know about the cooling benefits of urban trees*. Technical Report, Trees & Design Action Group. Accessed 07/01/21. <https://www.researchgate.net/publication/303868184_What_we_know_ and_don't_know_about_the_cooling_benefits_of_urban_ trees>

Ruiz, M.A., Sosa, M.B., Correa, E.N., & Canton, M.A. (2017). Design tool to improve daytime thermal comfort and nighttime cooling in urban canyons. *Landscape and Urban Planning*, 167, 249-256.

Sailor, D. J., Hu, H., Wilhelmi, O., & Banerjee, D. (2015). Indoor-outdoor environmental coupling and exposure risk to extreme heat and poor air quality during heat waves. In *Proceedings of the 9th International Conference on Urban Climate jointly with 12th Symposium on the Urban Environment* (pp. 20-24).

Sheridan, S. C., Lee, C. C., Allen, M. J., & Kalkstein, L. S. (2012). Future heat vulnerability in California, Part I: Projecting future weather types and heat events. *Climatic Change*, 115(2), 291-309. doi:10.1007/s10584-012-0436-2

Souch, C. A., & Souch, C. (1993). The effect of trees on summertime below canopy urban climates: a case study Bloomington, Indiana. *Journal of Arboriculture*, 19(5), 303-312.

Steven, M., Biscoe, P., Jaggard, K. & Paruntu, J. (1986). Foliage cover and radiation interception. *Field Crops Research*, 13, pp. 75-87.

Streiling, S & Matzarakis A. (2003). Influence of single and small clusters of trees on the bioclimate of a city: A case study. *Journal of Arboriculture*, 29, 309-316.

Taha, H., Akbari, H., & Rosenfeld, A. (1991). Heat island and oasis effects of vegetative canopies: micro-meteorological field-measurements. *Theoretical and Applied Climatology*, 44(2), 123-138.

Taha, H. (2013). Meteorological, emissions and air quality monitoring of heat island mitigation: Recent findings for California, USA. *International Journal of Low-Carbon Technologies* (10), 3-14.

Taleghani, M., Marshall, A., Fitton, R., & Swan, W. (2019). Renaturing a microclimate: The impact of greening a neighbourhood on indoor thermal comfort during a heatwave in Manchester, UK. *Solar Energy*, 182, 245-255.

United States Environmental Protection Agency (USEPA). (2011) Using trees and vegetation to reduce heat islands. Heat Islands. https://www.epa.gov/heat-islands/using-trees-and-vegetation-reduce-heat-islands

Vanos, J.K., Warland, J.S., Gillespie, T.J., Slater, G.A., Brown, R.D., & Kenny, N.A. (2012). Human energy budget modeling in urban parks in Toronto and applications to emergency heat stress preparedness. *Journal of Applied Meteorology & Climatology*, 51(9), 1639-165.

Wang, Y., Bakker, F., de Groot, R., & Wörtche, H. (2014). Effect of ecosystem services provided by urban green infrastructure on indoor environment: A literature review. *Building and Environment*, 77, 88-100.

Wigglesworth A. & Cosgrove J. (2020, Sept. 6). At 121 degrees, Woodland Hills hits all-time high temperature for L.A. County. *Los Angeles Times*. Accessed 06/22/21. <https://www.latimes.com/california/story/2020-09-06/southern-california-weather-forecast-sunday-los-angeles-record-breaking-heat>

Zhou, X., Carmeliet, J., Sulzer, M., & Derome, D. (2020). Energy-efficient mitigation measures for improving indoor thermal comfort during heat waves. *Applied Energy*, 278.

Recruitment Email

Dear [Name],

TreePeople, in partnership with UCLA, is conducting research on the benefits of trees on cooling indoor and outdoor spaces. We are looking for a small number of volunteers to participate in the study by hosting a few small environmental data loggers in their home (the loggers we are using are Kestrel Drop, and each sensor is about the size of a car alarm remote). Each data logger will collect temperature and humidity data. We anticipate 2-3 loggers will go inside the home and one will go outside the home. Loggers will hang on walls (living room, bedroom) from removable hooks. For houses with air conditioning, TreePeople may also ask participants to report their air conditioning use for a portion of the study. This is so that we can correctly interpret the data that the Kestrel Drop loggers will collect.

The study will take place through the end of 2020 and will require volunteers to download a mobile application, communicate with TreePeople periodically, and send collected data every two weeks. We are therefore looking for participants who are comfortable using mobile phone apps, and who have one of the following devices (Android 4.3 or later; iPhone 5 or later; or iPad 5 or later). Our staff will be available to remotely help you set up the device and troubleshoot any issues that may come up.

TreePeople will offer each participating household a $100 e-gift card or prepaid credit card at the end of the study. At the end of the study we will request that the devices be returned to TreePeople.

Thank you.

TreePeople Research on Cooling Participant Form

TreePeople is conducting research on the benefits of trees on cooling indoor and outdoor spaces. We are looking for a small number of current TreePeople volunteers to participate in the study by hosting a few small environmental data loggers in their home (the loggers we are using are: Kestrel Drop). We anticipate 2-3 loggers will go inside the home and one will go outside the home. The study will take place starting in the next few weeks through the end of 2020 and will require volunteers to download a mobile application, communicate with TreePeople periodically, and send collected data every few weeks. Our staff will be available to help you set up the device and troubleshoot any issues that may come up. TreePeople will offer you a $100 e-gift card of your choice at the end of the study. At the end of the study you will return the device to TreePeople.

* Required

1. First Name *

2. Last Name *

3. Please provide your phone number or email address *

4. Which, if any, of the following devices do you have? Check all that apply.

Check all that apply.

☐ Android 4.3 or later
☐ iPhone 5 or later
☐ iPad 5 or later
☐ None of the above. (If none of the above, thank you for your time. Must have one of these devices in order to participate).

5. Please indicate how strongly you agree with the following statement: I consider myself technologically savvy with the use of mobile applications.

Check all that apply.

☐ Strongly agree
☐ Moderately agree
☐ Neither agree nor disagree
☐ Moderately disagree
☐ Strongly disagree

6. Please provide the Address, City, Zip of your home *

____
____
____
____
____

7. Do you live in a single-family home? (a freestanding home set alone on its own piece of property)

Check all that apply.

☐ Yes
☐ No

8. Do you know people on your street that you would be willing to ask to participate in this study?

____

____

____

____

____

9. Do you have a functioning air conditioning unit in your home? Check all that apply.

Check all that apply.

☐ YES, I have central air (forced air that comes out of the wall, ceiling ducts or floor ducts)
☐ YES, I have an individual unit(s) installed in a window or wall.
☐ NO

10. When it’s really hot outside, how often do you use AC?

Check all that apply.

☐ Never
☐ Rarely
☐ Sometimes
☐ Always

TreePeople

Research Study on Urban Heat and Trees

Overview

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. Trees can protect against heat because of the shade and cooling benefits they bring, but not enough is known about how they impact residential spaces, especially indoor temperature.

This collaborative project will engage residents of Los Angeles County in community research to contribute knowledge about how indoor and outdoor temperatures are impacted by the presence or absence of trees. Thank you for your participation as a community scientist!

General Purpose

TreePeople, in collaboration with UCLA, is conducting research on the benefits of trees on cooling indoor and outdoor residential spaces. We are recruiting voluntary participation in the study by inviting a small number of residents in the Southeast Los Angeles region to host thermal data loggers in their home for approximately 3 months. The data loggers used for this study are [Kestrel DROPs](), which are approximately the size of a car alarm remote. The data loggers automatically record temperature and humidity, and participating households will be asked to download and send the collected data to TreePeople via the [Kestrel LINK app]() (available for ioS/Android).

Project Details and Expectations

TreePeople staff will drop off the data loggers at your home, along with removable hooks and any other materials you will need for the temporary installation of the devices at your home. Batteries on the devices are designed to last several months and we anticipate that once the device is installed, it will automatically log data and participants will not have to do anything to maintain the device. The study will require participants to download the Kestrel LINK mobile application, communicate with TreePeople periodically, and send collected data. TreePeople staff will be available to help participants set up the device remotely and troubleshoot any issues that may come up.

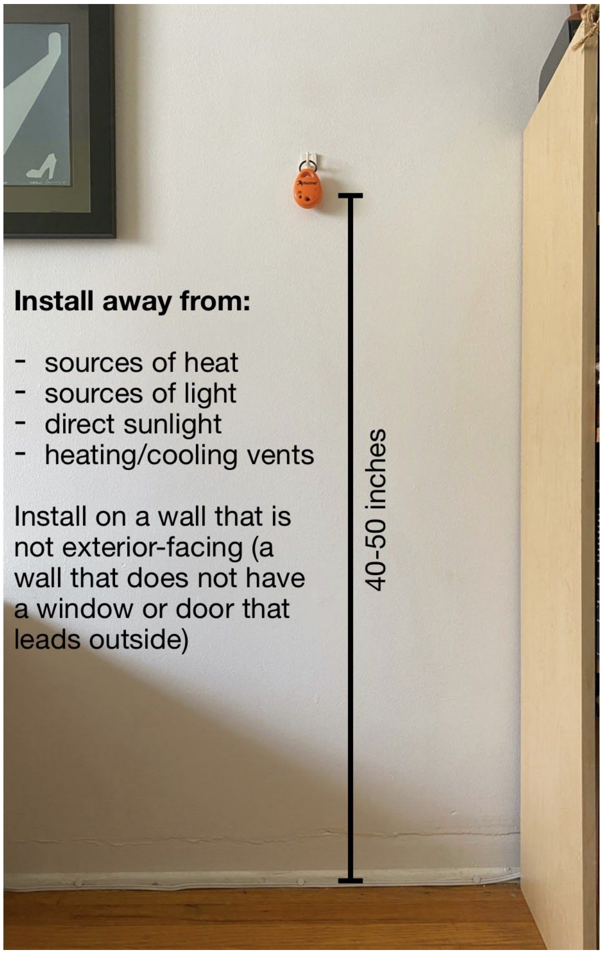
TreePeople will offer participants a $100 e-gift card or prepaid card of their choice at the end of the study. Participants will be asked to return the devices to TreePeople at the end of the study.

TreePeople commits to the following:

- Drop off Kestrel DROPs and hardware (removable hooks) for the loggers' temporary installation at your home at a mutually agreeable time.
- Provide remote assistance by telephone or virtual meeting platform to help you install the devices correctly in suitable locations and connect the devices to your iPhone, iPad or Android via Bluetooth.
- Provide remote assistance to troubleshoot any issues that may arise with connecting the Kestrel DROPs to your iOS or Android device and transferring data.
- Provide a $100 e-gift card or prepaid card of your choice at the end of the study.

Participants are asked to commit to the following:

- Temporarily install Kestrel DROPs at your home in a timely manner
- Place units as instructed by TreePeople: 2 units indoors to be placed in the living room and bedroom, and 1 to 2 units in shaded outdoor location.
- Keep the Kestrel DROPs at the same location for approximately 3 months.
- Download data and email it to TreePeople approximately every 2 weeks, or as requested by TreePeople staff.
- If you have and use air conditioning, TreePeople staff may ask you to report air conditioning use for a few days during the study using an online form. The intent is to correctly interpret indoor data readings in the event that Kestrel DROPs are located in a space that is cooled by air conditioning. Note: We urge participants NOT to modify their normal use of air conditioning because of this study; use air conditioning as you would if you were not participating in the study.



Install away from:

- sources of heat
- sources of light
- direct sunlight
- heating/cooling vents

Install on a wall that is not exterior-facing (a wall that does not have a window or door that leads outside)

Installation Instructions

Indoor units

- Find an indoor wall for which the other side is not outdoor-facing (e.g., a wall that does not have a window or a door that leads to the structure's outdoor facade).
- Install one of the removable hooks that was provided **40-50 inches** (100-125 cm) up the

wall as measured from the floor. Place the logger **away from sources of heat and light**, making especially sure that it will not be in direct sunlight.

- Place **one data logger in your bedroom** and **one in your living room**, for a total of 2 indoor data loggers.
- **Place away from vents** and make sure it is near or in the path of air conditioning or heating units or vents.

Outdoor units

- Find an **eave or other covered, fully shaded space** on the immediate exterior of your home. Note that removable hooks provided are not suitable for outdoor use.
- Using the metal ring and/or cord provided, **hang a data logger (with a paper cup on it)**. The paper cup will help regulate any influence that wind or light might cause. Make sure that the logger is placed where it will be fully shaded at all times of day. If it receives direct sunlight, the data readings will be impacted.
- If you were provided with 4 total data loggers, you will install a second outdoor logger:
    - Find a tree branch that is at least 3 feet (1 meter) away from any building.
    - Hang your 4th logger in the branches of a tree 40-60 inches (150-200 cm) off the ground.
    - Place in a well-shaded part of the tree so logger does not receive full sunlight.
    - Outdoor loggers should be installed within the provided paper cup.

Install within a paper cup, in a shaded location on the exterior of your home. Use the ring and/or twine provided if needed.

If you received 4 sensors, install one of them in a tree close to the exterior of your home. Place it in full shade, in a paper cup. Use the provided twine and/or ring as needed.

Once you have completed installing your data loggers, please take a photo of each location and send it to TreePeople. Make sure to step back a few feet to show where the data logger is within the space where it is installed!

PARTICIPANT AGREEMENT

The undersigned participant understands and agrees to install the data loggers as described above, and to have the units in place for approximately 3 months but no later than December 31, 2020. No party to this agreement shall be responsible for replacing or repairing any study equipment that is damaged or destroyed by an act of God (such as, but not limited to, fires, explosions, earthquakes, and floods).

I, the undersigned, certify that I am a resident of the property at the address below (“Resident”), and agree to the following:

1. To install the data loggers as described in the section “Installation Instructions” and allow for automatic data collection of temperature and other thermal data in my residence.
2. To photograph the placement of the data loggers and send photos documenting their placement to TreePeople.
3. To follow the instructions described in the sections “Project Details and Expectations” and “Installation Instructions”
4. To be in occasional communication with TreePeople, including to transmit downloaded data TreePeople and to respond to occasional inquiries from TreePeople pertaining to this project.
5. I further agree to exercise reasonable care to avoid damage to the data loggers and any associated attachments.
6. In consideration for the sections “Project Details and Expectations” and “Installation Instructions,” I, and on behalf of myself, my heirs, and assigns, hereby release and forever discharge TreePeople, and their representatives, agents, subcontractors, and consultants of all tiers from any liabilities or claims of any kind to the fullest extent permitted by law. This release includes all expenses associated with litigation, including attorney’s fees. The release includes loss of use or services, injuries to real or personal property, and all kinds of personal injuries, resulting from actions described in the sections “Project Details and Expectations” and “Installation Instructions” and associated data loggers, except to the extent that the liability or claim is the result of the sole negligence by TreePeople, or their agents.
7. I further agree to indemnify and hold harmless TreePeople and their representatives, agents, subcontractors, and consultants of all tiers from and against all claims asserted against them relating in any way to the actions described in “Project Details and Expectations” and “Installation Instructions,” except to the extent that the claim is the result of the sole negligence of TreePeople, or their agents, and to defend TreePeople and their agents from any suit or action arising from a claim for damage or loss related to the sections “Project Details and Expectations” and “Installation Instructions.”
8. Wherever possible, each provision of this agreement shall be interpreted in such a manner as to be valid under applicable law, but, if any provision of this agreement shall be invalid or prohibited there under, such provision shall be ineffective to the extent of such prohibition without invalidating the remainder of such provision or the remaining provisions of this agreement.

9. I further agree, promise, and covenant not to sue, assert, or otherwise maintain or assert any claim against TreePeople, or their agents, subcontractors, or consultants of all tiers for any injury, death, illness or disease, or damage to myself or to my property, arising from or connected with my participation as described in “Project Details and Expectations” and “Installation Instructions” or from any claim asserted against me by third parties, except to the extent that the claim is the result of the sole negligence of TreePeople or their agents.

Resident Signature:.. Date: ....

Printed Name: ....

Telephone number: ....

Address: ....

City: .... State: .... Zip: ....

TreePeople

12601 Mulholland Drive | Beverly Hills, CA 90210
www.treepeople.org