URBAN HEAT ISLANDS AND COOLING STRATEGIES: A COMPREHENSIVE ASSESSMENT OF CHARLOTTE, NC AND NATIONAL COMPARISONS

by

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ABSTRACT

VERONICA WESTENDORFF. Urban Heat Islands and Cooling Strategies: A Comprehensive Assessment of Charlotte, NC and National Comparisons (Under the direction of DR. JY WU).

The increasing threats posed by climate change and urbanization have elevated the importance of addressing Urban Heat Island (UHI) phenomenon, a critical concern impacting cities across the United States. This dissertation comprises three articles that collectively investigate the effectiveness of trees and greenspaces in managing UHI, creating a Heat Health Score (HHS) to identify areas experiencing UHI effects and investigates the perceived effectiveness of policies and programs aimed at reducing UHI in cities, while providing recommendations for Charlotte, NC in particular. Article 1 shows that urban greenspaces consisting of trees can help reduce the UHI effect by creating shade and cooling spaces, potentially reducing energy costs, improving human living conditions, providing food and habitat to wildlife and improving aesthetics and land values. In article 2, measures to mitigate the effect of UHI are evaluated from select cities and a ratio of daily average high temperature between locations and the corresponding difference in land cover of tree and shrub areas, create the Heat Health Score (HHS) (a unique metric) which allows municipalities and community groups to gauge the heat health between locations. These results show that most urban locations remain hotter and with lower vegetative cover than their suburban or rural counter parts, however, changes in tree and shrub cover can impact these results in a positive way. Results from article 3 elucidate the perceived successes and challenges of current policies through a qualitative survey. These responses offer practical recommendations for policymakers across the US but for Charlotte, NC in particular.

These results draw from the real-world experiences and lessons uncovered in the three articles, in aggregate, these provide a valuable resource for city leaders and policymakers striving to create a more sustainable and climate resilient city. It stresses the importance of urban greenspaces and urban trees in particular, provides community leadership with an easily accessible, not previously defined tool to discern urban heat health through the use of free, open-source data to score heat health, and provides insight to the perceived effectiveness of policies and programs used to mitigate UHI in cities in the United States.

Keywords
Ecosystem services, green spaces, heat health, policy, resilience, sustainability, tree ordinance, tree protection, urban green spaces, Urban Heat Island, urban planning

Statement of Original Authorship

I hereby certify that I am the sole author of this thesis. To the best of my knowledge this thesis contains no material previously published by any other person except where due acknowledgement has been made.

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LIST OF ABBREVIATIONS:

ACEEE	American Council for Energy Efficient Economies
ASLA	American Society of Landscape Architects
dbh	diameter at breast height
EAB	Emerald Ash Borer
ES	Ecosystem Services
GI	Green Infrastructure
GIS	Geographical Information System
HHS	Heat Health Score
ISH	Integrated Surface Global Hourly data
LEED	Leadership in Energy and Environmental Design
LiDAR	Light Detection and Ranging
LST	Land Surface Temperature
LUESA	Land Use and Environmental Service Agency
LULC	Land Use/ Land Cover
NCDC	National Climatic Data Center
NREL	National Renewable Energy Laboratory
NSRD	National Solar Radiation Database
RV	Replacement Value
SITES AP	SITES Initiative, Accredited Practitioner
TMY	Typical Meteorological Year
UDO	Unified Development Ordinance
UES	Urban Ecosystem Services
UHI	Urban Heat Island
US EPA	United States Environmental Protection Agency
USGBC	U.S. Green Building Council
VMT	Vehicle Miles Travelled

Chapter 1: Introduction

The effects of climate change across the United States have increased over the past decade. These issues bring a host of challenges to the city, ranging from increased heat, increased energy usage, poor air quality, more severe weather events, drought, and human health issues that at their worst result in increased mortality from heat. To better understand these climate change impacts, this paper explores the benefits of different urban ecosystem services (UES), how these relate to the urban heat island (UHI) phenomenon and an examination of synergies between types of urban land cover and temperature. This paper will review the current tree canopy in the greater metropolitan area of Charlotte, NC using i-Tree Canopy software to identify the percent of land covers in a designated area. Google Earth mapping provides for current satellite image of different areas and random points are provided through i-Tree to determine the percent coverage of grass/herbaceous, impervious building, impervious other, impervious road, soil/bare ground, tree/shrub and water.

The role of trees in mitigating Urban Heat Island in the Charlotte region is examined in chapter 2 through the identification of key benefits derived from UES and determination of which land uses offer these UES within Charlotte. The distribution of UES through the existing requirements of greenspaces in building codes and landscape ordinances can create an uneven and fragmented network of greenspaces that may also reflect the social inequity of the city. Mapping and GIS applications can be used to identify and classify different land use/land cover across Charlotte, NC to identify areas for improvement, allowing available resources to focus on areas of priority with an overall goal of improving access to UES, while creating a comprehensive design unifying UES for greatest impact.

Urban Heat Health Score (HHS) is used to compare the heat health of different locations in the United States. Calculating an urban HHS to compare the heat health of different locations in the United States uses differences in temperature between urban and the adjoining suburban or rural areas and the difference in land use/land cover category of trees and shrubs. This comparison creates a value that serves as a continuum to reflect the heat health of an urban location compared to its counterparts in suburban and rural situations.

In chapter 4, the effectiveness of policies and programs aimed at reducing UHI is evaluated. A qualitative survey of cities listed by the American Council for Energy Efficient Economies (ACEEE) provides the basis for evaluating the types of policies and programs for success and applicability to cities in the United States, particularly Charlotte, NC. The responses given by planning departments in cities listed in the ACEEE are evaluated through the opinions of those who work closely administering the policies.

Final conclusions are presented in chapter 5 with recommendations on key issues in creating resilient and sustainable ecosystems and landscapes in cities.

1.1 Literature Review

Urbanization impacts ecosystem services (ES), which are vital to sustainability of the world but especially in cities as they are growing in number and size (Taylor, 2006; Dobbs, Kendal & Nitschke, 2014). Land is used for buildings, infrastructure and resources, resulting in the destruction and fragmentation of habitat, soil degradation, and pollution from increased demand of energy relying on fossil fuels, increased air and water pollution, increased heat, loss of species diversity and conditions that are harmful to human health (Jennings et al., 2017). Literature on ES has been increasing in recent years, however less research has been on UES.

Research on UES is minimal, primarily focused on natural systems that do not include human needs (Derkzen et al., 2015; Gomez-Baggethun & Barton, 2013; Escobedo et al., 2010; Elmqvist et al., 2015). Most studies look more directly at ES in rural or "natural" systems (Luederitz et al., 2015; Oh, 2012). The current literature around urban ES is primarily focused on large, primary cities as evidenced in studies of Barcelona (Langemeyer et al., 2015), Rome (Marando et al., 2019), Philadelphia (Heckert & Mennis, 2012), Washington D.C and Baltimore (Loughner et al., 2012; Zhang, et al., 2018), Washington D.C. and New York City (Hicks, Callahan & Hoekzema, 2010), 64 different large cities (Hertel et al, 2014) and Berlin (Bertram & Rehdanz, 2015). As a result, more studies need to include "secondary cities" (population less than 5 million) as these are expected to account for 50% of future growth (Miner et al., 2016) and "cities are a crucial center of demand for ecosystem services and sources of environmental impacts", (Elmqvist et al., 2015).

ES and UES include provisioning, regulating, supporting and cultural services. Each of these groups of services are important to the sustainability and resilience of cities and can be achieved in several different ways, such as urban parks, greenspace criteria, undeveloped lands, rooftop, wall and planter spaces and both urban forests and individual tree plantings (Escobedo et al., 2010). Of these choices, street trees are an important type of greenspace/UES that provide many benefits to cities (Norton et al., 2015; Dobbs, Kendal & Nitschke, 2014; Gomez-Baggethun & Barton, 2013; Loughner et al., 2012; Coseo & Larsen, 2015) in particular cooling through shade (Norton et al., 2015), evapotranspiration and connectivity (Derkzen, van Teeffelen & Verburg, 2015; Cosoe & Larsen, 2015; Jennings et al., 2017). They offer the benefit of ease of installation, availability, aesthetics and the provision of more than a single ecosystem service for the location.

There is increasing support for remedying the uneven dispersal of greenspaces in cities, starting with the recognition that ecosystem services provide a wide range of human well-being benefits (Luederitz et al, 2014). Locating and classifying existing greenspaces and providing greenspaces equitably in the land planning may enhance the economic value of spaces in the city (Conway et al., 2010; Perino et al., 2014), but that monetary value is not well understood (Gomez-Baggethun & Barton, 2013; Elmqvist et al., 2015). The American Society of Landscape Architects (ASLA) has created a Sustainability committee as well as a Diversity, Equity and Inclusion committee to address these concerns along with additional climate change impacts (ASLA.org, 2020). The U.S. Green Building Council provides different certifications including one specific to the sustainability of projects, SITES AP, similar to LEED but includes sites that may or may not contain structures. SITES AP was developed to address the need of restoring ES to design projects including urban areas. Increasing the use and implementation of green and interconnected networks of green spaces that support conservation efforts begin rebuilding ecosystems throughout the city to help combat fragmentation and improve equity and accessibility for all communities (SITES, 2020; ASLA.org, 2020; Jennings et al, 2017).

Methods that have been used to analyze UES mostly refer to larger cities such as Washington D.C. New York, Philadelphia, etc. and include greenspace locations (GIS, maps) and temperature data (Landsat, WeatherUnderground, National Weather Association) that can be transferred to secondary and smaller cities to identify areas of UHI, and how trees can be used to mitigate these effects for the different scales of cities (Hertel et al., 2014; Eastin et al., 2017; Miner et al., 2016; Dobbs, Kendal & Nitschke, 2014; Loughner et al., 2012; Jennings et al., 2017).

The current state of literature looks at the many benefits of UES and acknowledges that there are disservices that should also be considered when determining the type of UES and location. Disservices include damage to property from limbs, roots and broken branches, pollen and leaf litter, both of which can cause allergies and exacerbate asthma. Trees may block views and signage, create safety issues and places for hidden persons (boogeyman bushes) and requiring maintenance costs. They also provide habitat to insects, pests, squirrels, birds and other creatures which compete for human resources as well as each other's. And finally, there are carbon costs associated with planting, maintaining and ultimately removing trees. However, there are challenges to assigning a value to non-monetary aspects of UES such as aesthetics, long term benefits, human health and wellness (Elmqvist et al., 2015).

1.2 Case Study Charlotte, NC

Charlotte is the largest city in North Carolina with a population of 808,830 in the city and 1,011,770 in Mecklenburg County (The Demographic Statistical Atlas of the United States, 2020). Located in the south-central portion of North Carolina on the east coast of the United States, the city is the 17th largest city in the United States. Charlotte has annual average high temperatures of 21.7ºC (71º F) and low temperatures are 9.4ºC (49º F), 1.05 meters (41.63 inches) of average annual precipitation and 0.1 meters (4 inches) average annual snow fall. Over the last 30 years, the number of days over 35º Celsius (95º F) has increased dramatically, and this trend is expected to continue. Charlotte, NC shows a projected increase from 2040-2070 above the median increase of 30-45 more days per year over 95º Fahrenheit (Melillo et al, 2014).

Charlotte has a long history of recognizing the value of trees. In the 1900's, Charlotte was referred to as the "Tree City" (Markovich, 2017). John Nolan, a peer of Fredrick Law

Olmstead, founder of the title landscape architect, and fellow graduate of the Harvard Design School, was hired to create landscape plans for Myers Park in the 1910's-1920's, one of the iconic neighborhoods in Charlotte. Nolan's designs included native trees, dug from the many creek beds in the area and planted along street edges and large medians. Poplars, Oaks, Elms and Plane Trees (Sycamore) provided the basis of the plantings (Markovich, 2017). Sixty years later, the neighborhood lined with mature trees continued to experience high demand despite the aging homes. By the 2000s, the trees are nearing one hundred years old and experiencing decline from age, climate conditions and pests.

Recognizing the importance of trees early on, Charlotte passed the City Code of Ordinances in 1978 to direct development and included tree preservation, heritage tree designation, and tree save areas. Mitigation off site, restoration on site and payment-in-lieu were provided as options for developers to replace removed trees. In 2008 Mecklenburg County and the city of Charlotte conducted a tree study spanning the years of 1985-2008 to understand the changes that were taking place. Over this period, Charlotte experienced a 33% decrease in tree canopy, 2.8% decrease in open space and a 60% increase in impervious area (Markovich, 2017). In 2011, Charlotte, in partnership with a public-private group, TreesCharlotte, set a goal to achieve a 50% tree cover across the city by 2050 (Sustain Charlotte, 2020). An assessment of the tree canopy in 2012 showed that the current canopy cover in Charlotte-Mecklenburg County was at 49%, however, from 2012-2018 the tree canopy declined 4% due to age, pests, storm damage and an increase in development (Sustain Charlotte, 2020). Prior to the passing of the new Unified Development Ordinance, Charlotte's tree requirements included (Code of Ordinances City of Charlotte*,* 2020):

- Trees minimum 2" caliper diameter at breast height (dbh).

- Plant list and diversity of plant species requirements
- Large maturing street trees spaced at 1 tree every 40’, small maturing trees are planted with 1 tree every 30’
- Trees required within 60’ of every parking space in parking lots of a certain size, and as buffer and perimeter plantings.

This gap between required tree save areas and new plantings, and tree canopy coverage to reduce the impacts of UHI, reflects the basis for this dissertation.

Chapter 2

Article 1:

The Role of Trees in Mitigating Urban Heat Island in Charlotte, NC

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ABSTRACT

Urban Heat Island (UHI) is a complex phenomenon experienced by cities around the globe, resulting in increased heat retained by dark, often impervious surfaces which gain and hold heat during the day, and slowly release heat over the nighttime. The result is higher nighttime surface temperatures which start the city at higher temperatures the following morning. These increased nighttime temperatures affect plant growth, agriculture, habitat, animal life and even human health and well-being. As daily temperatures rise worldwide, this effect has been increasing, although the factors which can impact the intensity of UHI are not well understood. Managing UHI plays an important role in the future success of sustainable cities. Trees provide moderation of UHI as well as many other benefits to human health and climate change management, and as a result can be part of the plans for policy development that will influence the future design of our cities. Results show that Charlotte is experiencing areas of UHI and that these areas also reflect lack of tree cover. Urban greenspaces consisting of trees help reduce the UHI effect and impact social equity by reducing energy costs, improving human living conditions, providing food and habitat to wildlife and improving aesthetics and land values.

Charlotte's ordinances help to preserve and improve tree canopy cover but not to the extent that is needed, therefore recommendations to improve the strength and reach of the ordinances are provided..

Keywords: Urban Heat Island, green infrastructure, ecosystem services, sustainability, urban planning, policy, urban green spaces

2.1 Introduction

Cities are the largest consumers of ecosystem services, relying on land for housing, business, transportation, waste disposal and providing resources for energy, water and food. While cities offer many opportunities for a better life, their current growth patterns are not sustainable and are adding to the climate crisis across the globe. Valuable resources and ecosystem services are being lost and the implication for human health and wellbeing is more apparent as time passes. This paper will explore the role that "greening" of urban spaces plays in the creation of sustainable and improved cities through a review of literature and analysis of the relationship between land cover, and Urban Heat Island effect. The introduction of green spaces in urban areas through green infrastructure, streetscapes, green roof and walls, street trees, urban forests and restored ecosystem services will improve the sustainability of cities and provide benefits to both humans and ecosystems. Changes to the green fabric of a city provide benefits and this study may offer planners the tools to support policy changes and prioritization of works to increase the sustainability of cities.

Urban environments are experiencing higher temperatures due to increased infrastructure, development, impervious area, deforestation and climate change. Urban areas range from 1.8-5.4 degrees Fahrenheit above those of surrounding rural areas in the daytime, to 22 degrees Fahrenheit higher at night (Benefits of Trees, 2012). UHI occurs in urban areas due to the high area of impervious areas especially dark surfaces that hold heat, and can disrupt the health, well-being and effective functioning of a city (US EPA, 2014) with long term consequences to climate change, health and sustainability of cities. Energy usage increases within these urban areas by 1.5-2% per degree Fahrenheit increase above 68-77 degrees Fahrenheit for cooling (US EPA, 2014). This has a huge effect on social costs beyond the rising cost and stressors on the electric grid. These costs include threats to human health from increasing temperatures, lung disease from increased pollutants, and increased insect populations including mosquitoes that carry diseases that impact human populations (Melillo, 2014).

2.2 Objective

The objective of this chapter is to explore the role trees play in improving the UHI effect and the sustainability of cities and recommend supporting policies directed by municipalities for green space and for street tree plantings and planting areas to reduce UHI and ensure better survival of plant species. Planning departments for municipalities hold a key role in managing the urban environment to reduce the impacts of climate change. Urban green space, particularly trees, bring benefits to the urban environment, such as shade and moisture which combined can create microclimates that reduce the heat effects of urban areas (ASLA.org, 2019). New development creates environments that are often hostile to supporting plant material. Green spaces are one of the last pieces of projects to be installed, and face cut budgets that create less than ideal conditions for successful results. Looking at the relationship between UHI and land cover types including street trees and urban green space, would help support the implementation of policies to mitigate UHI and improve climate regulation in urban areas.

This paper also seeks to use free, open-source data to research these concepts to create a method of determining Land Use/Land Cover benefits to be accessible to any city, regardless of budget or size to assist in determining the best land covers, best ecosystem services, appropriate mitigation options and greatest benefits to the citizens. This is especially important because each city has a unique UHI characteristic (Eastin et al, 2017) and needs to evaluate their location independently from other cities to evaluate policies for funding and placement of green spaces. A one size all approach is not effective for managing ecosystem services like UHI reduction, and a solution that is accessible to all is vital.

2.3 Methodology

Green spaces in the context of urban settings provide multiple services from ecosystem services like air quality, water quality, habitat, erosion control, food provisioning (TEEB 2017) to mental health, physical health, wellbeing, aesthetics and cultural and spiritual benefits (Langemeyer et al, 2015). UHI is one of the main climate issues faced by urban areas (Marando et al, 2019). To understand the impact of green spaces on reducing UHI in cities, a literature review, followed by a specific methodology described in 2.4 Analysis section of this chapter to analyze the correlation of land cover and UHI was used with Charlotte, NC as the case study for this research.

2.3.1 Literature Review

UHI is characterized by a rise in temperatures of urban areas due to greenhouse gas emissions, increased numbers and sizes of buildings, transportation, and heat adsorption by these surfaces (Gomez-Baggethum and Barton, 2013). These changes in urbanization create urban climates which absorb and hold heat from daylight hours and release this heat slowly over the night, resulting in higher nighttime temperatures in the cities versus rural or even suburban areas (Norton et al, 2015) Larger and more populous cities are feeling the effects of UHI and now there is more research available to document how these changes affect not only humans and animals (Marando et al, 2019) but also building efficiency and equipment longevity and functioning (Miner, 2017).

William Hertel (2014) published a review of UHI for 64 cities across the globe. This method of identifying variables that influence urban heat island offers an understanding of the effects each variable has on UHI in cities with differing characteristics. The use of multiple cites allows a broad exploration of climate and geographical features that increases the understanding of which variables have the greatest impact on UHI. This analysis also informs best choices for mitigation strategies that work for conditions specific to individual cities. These data come from the Integrated Surface Global Hourly data set (ISH) retrieved from the National Climatic Data Center (NCDC), which has either hourly or 3-hour spaced data on climatic conditions including temperatures, dew point, wind speed and direction, pressure and sky cover.

Washington, D.C. has several interesting programs and ordinances directed at reducing UHI. Sustainability D.C. documents the plans that DC has developed starting in 2011 to improve sustainability through community involvement, targets, goals and implementation strategies (Sustainability D.C., 2011). Changes to parking requirements reduce paved areas through zoning changes and move to requiring underground parking. Washington, D.C. also (requires all new construction to adhere to green building codes. A connectivity map will help guide development to ensure green corridors and areas of connected habitat have trees and green spaces all new developments.

Stuttgart, Germany, is a model for “cool city” principles which are directly related to reducing UHI effects (Rehan, 2016). These include reducing the volume of global emissions, creating smart growth and cool community scenarios. Stuttgart’s policies support the implementation of green infrastructure and green spaces, using trees and vegetation to shade buildings, decreasing demand for cooling AC, maintaining pavements through tree canopy shading and promoting cooling in urban environments.

The European Union encourages the use of Green Infrastructure (GI) as a nature-based solution to managing and mitigating UHI in urban areas (Marando et al, 2019). GI includes using plants including trees, shrubs, ground covers, bioswales, urban forests, green roofs and green walls to manage storm water, reduce flooding, create cool areas, reduce energy demand and enhance human well-being (Jennings et al, 2017). These natural connective networks of green spaces provide many ecosystem services (ES) that reduce pollution and reduce UHI impacts on human health (Marando et al, 2019). Trees and urban forests overall reduce temperatures in cities by blocking solar radiation, adsorbing this radiation, and through evapotranspiration from the leaves which lowers the overall canopy temperature as well as the surrounding area surface temperatures. Marando's study of Rome, Italy showed a difference in land surface temperatures in both summer and winters seasons, with average differences between urban and rural areas ranging from 1 to 4 degrees Celsius, with a strong correlation between surface type and temperature. Land Surface Temperatures (LST) in Rome were shown to be highly influenced by the presence of vegetation, especially in the hot summers (Marando et al, 2019).

Open green space (not lawn), tree canopy, green roofs and vertical greening screens all provide some benefit to reducing UHI, but overhead vegetation, mainly tree canopies provides one of the best options for mitigations of UHI (Norton et al, 2015). Marando (2019) found canopy cover in green spaces increased their ability to regulate urban climates and reduce UHI and Elmqvist et al (2015) found that a 10% increase in tree cover can create a reduction of 3-4 degrees Celsius in ambient air temperatures. This decrease in temperature then reduced the energy usage from air conditioning, which further reduced consumption of fossil fuels to create the energy needed for cooling, creating a chain effect of reduction that improves air quality in cities and reduces UHI. Trees can sequester carbon which helps regulate climate (Gomez-

Baggethum and Barton, 2013). Decreasing UHI also decreases the number of heat related illnesses and mortality (Escabedo, 2011).

Understanding the plant physiology and morphology i.e. “horticultural limitations” is extremely important in ensuring the desired results from the investment in green spaces and urban trees (Norton et al, 2015). For the benefits to be received, the plants must survive. Efforts and precautions to increase the health and longevity of the trees and other plants used in the green spaces are needed in order to reap the benefits to UHI mitigation. Typical life expectancy of an urban street tree is less than 10 years (Elmqvist et al, 2015) and the true benefits of trees in UHI reduction come with the growth and maturity of the tree. Time is an essential factor in determining and using street trees to reduce UHI and improve the city’s health, especially in vulnerable areas that lack the funding for replacement plants. If vegetation and GI are to work successfully, they must be installed and maintained properly to achieve long term growth and benefits. Not all vegetation is equal; however, some trees and plants release biogenic hydrocarbons when the hydrocarbons emitted from the leaves bind with nitrogen oxides and add to air pollution, and not all have the high leaf area index with the greatest capacity to remove air quality contaminants (Jennings et al, 2017). There are also a number of other disservices which should be considered when evaluating the benefits of specific green spaces to reduce UHI in cities. These include damage to buildings and infrastructure from roots, limbs falling or storm damage, allergies and asthma from pollen and leaf litter, view and sign blockages, safety and fear issues from overgrown vegetation, and habitat competition from insects, rats, squirrels and pests (Gomez-Baggethun et al, 2013). These disservices are often neglected in planning and cost analysis of urban green spaces (Escobedo et al, 2015) and should be included when looking at policies and cost benefit analysis of green spaces.

In Barcelona, Spain researchers looked at cultural value as an ecosystem service of greenspaces (Langemeyer et al, 2015). Land use maps and management data bases, planning documents and local experts were used to classify the green spaces as cultural facilities, parks and gardens, semi-natural or sport facility. Norton et al (2015) collected satellite or airborne sensed data, visual surveys, LiDAR, and GIS data to determine land cover types and compare these to temperature data. This was used to identify urban areas that were referred to as "hot spots" and then to prioritize those areas for the use of GI to mitigate UHI. Open space (non-lawn), shade trees, green roofs, vertical greening were all evaluated, with overhead vegetation and canopy cover from street trees one of the most beneficial at reducing UHI.

UHI has many complicated influences that include meteorological conditions, the form of the urban spaces, and human action. Biomes, wind conditions, cloud cover, pollution levels, humidity, location of water bodies, season of the year, location, topography, and existing policies are unique to each city and impact UHI (Eastin et al, 2017). In Rome, Marando (2019) used remotely sensed Land Surface Temperatures (LST) from LANDSAT-8 OLI/TIRS images for summer and winter day and nighttime temperatures for 2013-2017. Hertel (2014) employed data from the Integrated Surface Global Hourly data set (ISH) retrieved from the National Climatic Data Center (NCDC) including temperatures, dew point, wind speed and direction, pressure and sky cover. Spatial satellite imagery was used to analyze the urban forms of different cities, looking at patch shape, fragmentation, and proportion of open space. These data can be used to expand our understanding of urban ecology to include human health benefits and social justice concerns. Higher levels of biological diversity in an ecosystem have been linked to greater restoration value from green spaces. And this diversity of species is less apparent in disadvantaged communities (Norton et al, 2015).

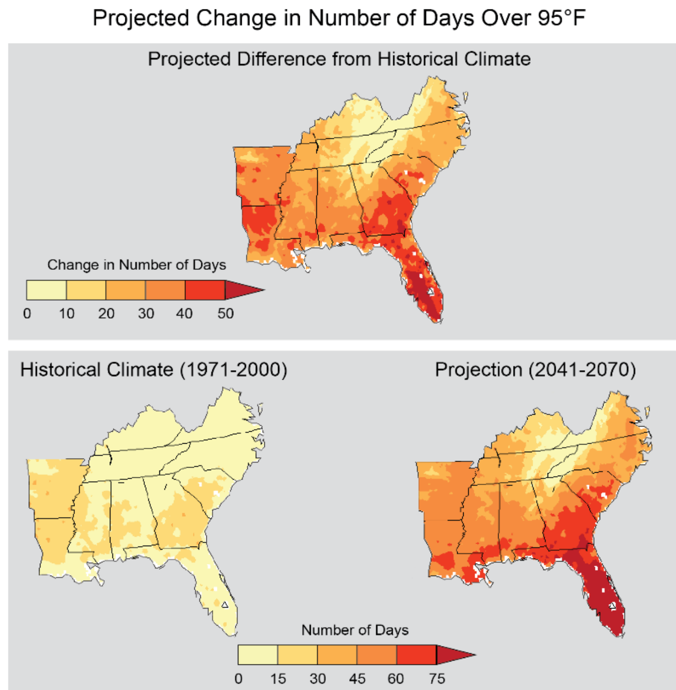

Figure 2.1:
The Third National Climate Assessment Report shows Charlotte, NC has an above median increase of 30-45 more days per year over 95º F. (Melillo et al, 2014).

2.3.2 Case Study Charlotte, NC

Charlotte, NC is the largest city in North Carolina with a population of 808,830 in the city and 1,011,770 in Mecklenburg County (The Demographic Statistical Atlas of the United States, 2020). Annual average high temperatures are 71 degrees F and low temperatures are 49 degrees F, with 41.63 inches of average annual precipitation and 4 inches average annual snow fall. Over the last 30 years, the number of days with temperatures over 95 degrees F has increased dramatically, and this trend is expected to continue (National Climate Assessment, 2019). Reviewing these data, Charlotte, NC is predicted to continue in the trend of increasing numbers of days over 95ºF in the future (figure 2.1).

2.4. Analysis

As a first step in this study, the base map using ArcGIS and data from the Multi Resolution Land Characteristics (MRLC) was created using the Open Street Mapping data for Mecklenburg County. Tree cover canopy density as a percent of coverage from Global Forest Watch for year 2000 was added, and finally Urban Heat Island relative heat severity for the summers of 2018-2019 from OpenStreetMap data from the Trust for Public Lands was included. Each layer was set to a transparency of 50% to allow the other layers to be visible (see figures 2.2 and 2.3). It is immediately apparent where the interstates 77, 85 and 485 are as well as the Charlotte Douglas International Airport and more dense and urban centers of the county. Impervious areas that absorb and hold heat can be seen in gradients labeled from 1-5 with 1 showing areas slightly above the mean for the city and 5 as a severe heat area significantly above the mean for the city. Impervious areas show up as the highest gradients, but other areas also show increased heat adsorption and retention. In comparison, when tree cover layers are added to the same maps, it emphasizes the impervious areas as having the highest temperatures. Roadways and heavily impervious and built out areas show the most intense temperature increases, but of more interest to this study, is what types of land covers are around areas that are impervious but cooler, and what land covers are in hot areas that are not impervious. For example, sections of I-85 located near wooded areas are cooler than stretches of the interstate that are treeless. New development with small or no street trees appears as hotter, while older areas with larger trees register as cooler.

Currently, the city of Charlotte and towns that make up Mecklenburg County have street tree requirements that support the planting of trees for shade and erosion control. Trees are required to be 2” caliper diameter at breast height (dbh). This allows for a large enough tree at installation without the risk of "shocking' the tree into an early demise. Streets without overhead utilities are planted with large maturing street trees spaced at 1 tree every 40'. Where there are limiting factors such as utilities overhead, small maturing trees are planted with 1 tree every 30' (Code of Ordinance, 2020). Tree save areas are required as part of new plans for approval and trees are required within 60' of every parking space in parking lots of a certain size, and as buffer and perimeter plantings. When trees provide cover of 40% or more, the streetscape is cooled more than the UHI created by the absorbed heat from impervious surfaces (Weston, 2019). This suggests that both quantity and canopy spread (age and health) are important factors in reducing the effects of rising urban temperatures. TreesCharlotte (2020), a local organization created to help Charlotte reach a tree canopy coverage of 50% by 2050, estimates that Charlotte currently has a 47% canopy cover. Despite this positive number, many of Charlotte's trees are declining in health while continued growth and development are impacting the existing tree canopy. The Charlotte Tree Ordinance planting requirements create a tree canopy in new developments in public areas (streets and parking) of approximately a 10% tree canopy area coverage (Chatham Park, 2019). 40% coverage of tree canopy to surface area has been shown to reduce the effect of UHI (Weston, 2019), so for Charlotte to impact the cooling effects of coverage by tree planting, the number of trees required in these public spaces will need to increase to 4 times the canopy coverage required from the Charlotte Tree Ordinance.

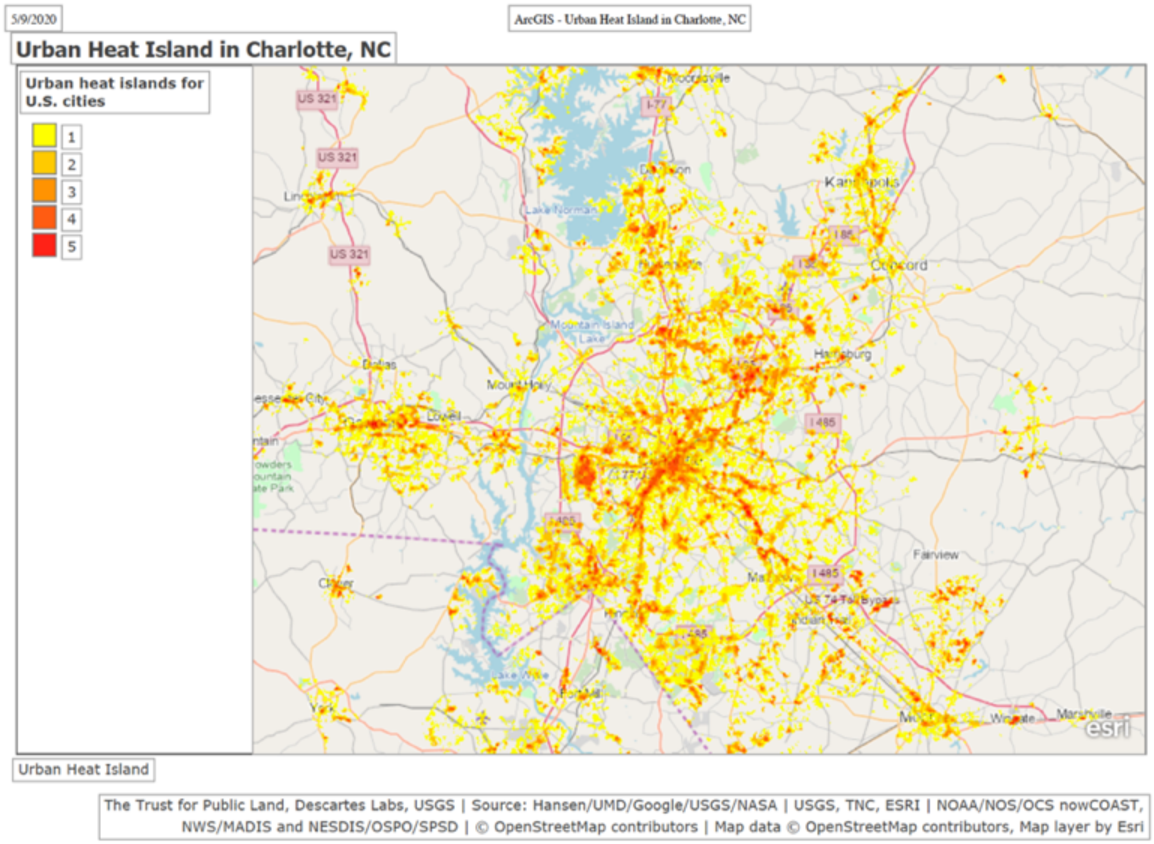

Figure 2.2: Urban Heat Island in Charlotte. Data is from The Trust for Public Lands 2020

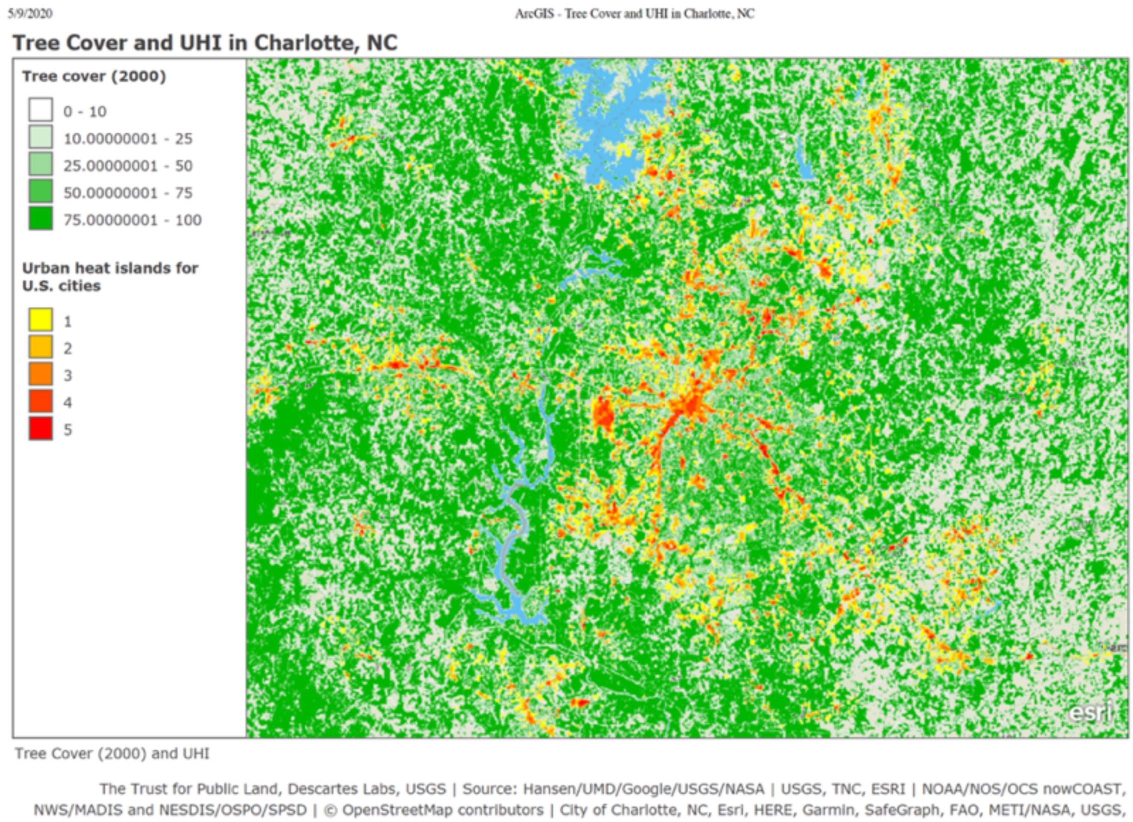

Figure 2.3: Urban Heat Island and Tree Cover in Charlotte. Data from The Trust for Public Lands 2020 and NOAA 2012 tree data.

The City of Charlotte currently has programs and policies in place to support the use of trees in the city. The City of Charlotte Code of Ordinances dictates tree preservation, Heritage tree designation, tree save areas as a percentage of developed site area and mitigation options including off site mitigation, restoration and payment in lieu (Code of Ordinance, 2020). These policies acknowledge that trees are vital to the health of the city, and that there is a greater value to existing and larger trees that is not easily replaced by new plantings. Trees increase the shade coverage which helps reduce UHI, reduce energy costs, improve the quality of the air, increase evapotranspiration, which in turn cools the air. They also provide additional ecosystem services including habitat, erosion control, water quality, human health and aesthetics. New plantings are required to fulfill streetscape plans, perimeter parking and interior lot and parking plantings through section 21 of the Code of Ordinance. Perimeter screening of parking areas call for a minimum of 75% evergreen shrubs and require each parking space be within 40’ of a tree, or 60’ if there is a continuous planting strip. Urban zoning requirements adjust planting requirements to meet the needs of the increased impervious area on projects (Code of Ordinances section 9, 2020). These codes still include providing shrubs to screen parking and different uses, in addition to fencing for screening, giving value to the role green plays in improving the city. Street trees and streetscape per approved plans are also required, with the City of Charlotte providing direction on streetscape requirements on a neighborhood and project level.

Erosion Control in the Code of Ordinances (Section 17, 2020) provides protection from 10-year storms. Erosion control plans are required of any development greater than 1 acre. The length of time the soil remains disturbed is vital as bare soil during construction has a similar heat effect as impervious areas (Li et al, 2017). A post construction ordinance (Code of Ordinances section 18, 2020) is also in place to set requirements for developed sites after the construction is completed, which include maintaining buffers and existing vegetation. Incentives are provided for additional tree save areas and open space in the form of added density for development. In single family residential development, developers are encouraged to reduce yard size through reduced setbacks, density bonus, smaller lot sizes permitted and clear-cutting site prior to construction is discouraged.

The Charlotte Tree Ordinance directs tree plantings for new and existing development through required tree plans. It provides for tree protection and planting directions, updates the approved tree and shrub list, gives urban forestry tree planting and preservation standard notes. The City Arborist oversees the administration of the ordinance, including direction for the maintenance of the trees on private land as well as public right of way. When minimum planting tree save area requirements are not met, supplemental planting is required. Soil amendment requirements, approved tree and shrub list for public planting spaces, requirements of 50% native trees, minimum width of planting strips, spacing of street trees, tree pits, pavement cutouts on renovated sites, and 75% of trees as large maturing shade trees are examples of how the Code of Ordinances sets policy for the improvement of UHI. An updated code is in process, the Unified Development Ordinance (UDO) due to be completed by 2021, that will combine the multiple ordinances and policies, further streamlining the policies and programs in use in the City of Charlotte. This addition is part of the Charlotte Future 2040 plan and has a strong focus on smart growth and sustainability (DOEE, 2020).

Other programs outside of the City of Charlotte include Mecklenburg County's Land Use and Environmental Service Agency (LUESA) and a public/private partnership with Center City Partners which looks at ways to increase sustainability and circular economy in Charlotte. Non-profits like TreesCharlotte offer free trees to residents and planting in neighborhoods and school yards. Envision Charlotte, a public-private collaboration, works to reduce energy consumption, which plays a large role in increasing UHI, by commercial properties located in the urban core of Charlotte. Their programs collect data, define policies, and act as a living laboratory for change within Charlotte.

2.5 Conclusions and Implications:

Charlotte has taken the first steps toward improving ecosystem services and reducing the impacts of UHI through the current policies and programs, however, more effort is needed to adapt to the changing climate and fast paced growth that is impacting the green spaces of the city. Creation of a climate action plan that is integrated with the UDO in the Charlotte Future

2040 plans is necessary. In it, an overarching master plan of the trees, green spaces, green infrastructure, green corridors need to be documented and strategically added to and mapped out. For future work, the Mecklenburg County POLARIS website and on-site verification will supplement data and images as needed. The data can be used to map the different land cover types across the city over a period of time and compare those to daytime and nighttime temperatures across the city. Cells of identical size laid across the map show where most of the green spaces in Charlotte are located and identify areas with little to no coverage. Hot spots of UHI can be determined, and areas that coincide with high UHI temperatures signal a need for prioritization for programs, policy and funding to address the problem. This procedure will identify correlation, and areas of inequity and excessive heat. Initially, discerning the patterns of UHI can be established through a visual inspection of these layered maps to find hot spots of UHI, looking for tree cover, and later, land cover type (impervious, urban forest, green infrastructure, green space, bare earth etc.) under each hot area.

The US Environmental Protection Agency recommends focusing on three policies in particular to create impact to UHI: tree protection, parking lot ordinances, and street tree ordinances (US EPA, 2014). Areas which lack green spaces or are hot spots should be located, clusters identified and neighborhoods lacking access and green spaces should be prioritized. Green spaces would take the form of streetscapes, green infrastructure, green roofs and facades, parks, lawns, and with appropriate planning, would create corridors of cooling air flow, habitat connections and networks of green infrastructure to reduce UHI and enhance ecosystem services. Reducing energy usage will also improve UHI. More shade, whether from trees, green roofs or green facades, reduces the need for air conditioning which generates large amounts of heat (Norton et al., 2015). Walking and cycling reduce vehicle usage, which reduces heat and greenhouse gases which trap heat and adding green corridors to these trails not only encourages higher use, but it can also create cooling corridors throughout the city. Implementation of Green Building strategies such as Energy Star, LEED and SITES AP ensures higher standards of planning, construction, implementation and maintenance.

While advanced planning to allocate larger areas of green space is ideal, changes to even small areas can make a large difference, especially to residents (Norton et al, 2015). Areas with high usage, such as bus and transit stops, public gathering spaces, schools and community centers and pedestrian and cycle paths should be prioritized. Wherever possible, trees and green infrastructure should be used, but building placement, screens, canopies, reflective colored surfaces and other forms of shade should be used when plantings are not feasible, sustainable or of a size for immediate relief. Addressing requirements for new development to use better planting techniques and practices, using % tree cover, not tree counts, as a guide, encouraging more tree save areas and mitigation, reducing construction waste and encouraging circular economy ideals are valuable steps for improving UHI.

A review of the literature in the reference section of this paper alone shows the importance of green infrastructure in regulating urban heat island effects, particularly urban trees. Given that there is "growing evidence on the positive impacts of urban ecosystem services on quality of life in cities" (Gomez-Baggethun and Barton, 2013), and a net gain in the value and benefits of urban street trees, the use of trees to mitigate UHI effects is a valuable resource. To achieve the desired reduction of temperatures caused by UHI effect, an increase from 10% to 40% canopy coverage is needed. This translates to 4 times the number of trees required per project. Grouping trees in clusters will increase the canopy coverage while reducing the land use requirements and may save additional costs to future projects.

Beyond reducing UHI, there are many ecosystem services that are improved with the addition of green spaces in cities. Urban forests provide shade but also provisioning services such as food sources, natural resources and habitat; regulating services like cleaning water and air and sequestering carbon; cultural services that include aesthetics, historic landscapes, recreation and sense of place; and supporting services that include nutrient cycles, soil formation and oxygen creation. The quality, type, and placement of green spaces has been shown to have impacts on human health and well-being (Jennings et al, 2017) and therefore offer many benefits to the inhabitants of cities. These include heat mitigation (UHI), aesthetics and connectedness with spirit of place, interaction with nature, storm water management, flood control, physical activity and recreation for human health and fitness, improved mental function and cognitive abilities. With that in mind, how these urban spaces are designed alongside their green spaces is an important link to human well-being and the success of cities. As urbanization continues, we will need to "strategically conserve and manage our natural resources" (Jennings et al, 2017).

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Chapter 3: Using Urban Heat Health Score to Compare the Heat Health of Different Locations in the United States

Article 2

ABSTRACT:

With increasing urbanization, determining the severity of Urban Heat Island (UHI) phenomena and its variations between regions and neighborhoods presents a difficult challenge. This research introduces a novel metric, urban heat health score (HHS) designed to facilitate the presence of and severity of UHI. As UHI is unique to each city, a strictly temperature-based approach will not be effective. A comparison or continuum between the "urban" or densest area and surrounding rural or "rural-like" area provides more insight to the heat health of these areas. Differences in daily average high temperature between these locations and land cover of tree and shrub areas, compare the Heat Health Score (HHS) allows municipalities and community groups to rate the heat health of locations. Results show that most urban locations remain hotter and with lower vegetative cover than their suburban or rural counter parts.

Keywords: heat health, heat health score, land use, land cover, urban heat island

3.1 Introduction:

In the past decade, Urban Heat Island (UHI) has become a topic of great concern. Rather than simplifying or even clarifying the causes and effects of UHI in cities, we have instead found that the process is more complicated. The effects of different weather, regions, rainfall, water bodies, latitude, wind patterns, elevation, and building canyons all influence UHI and create unique situations in each city that do not lend themselves to improvement by any one single method. This poses a greater challenge for small municipalities, non-government or design agencies and just regular people trying to understand the effect of programs and policies on the everyday wellbeing of their community.

Urban trees provide many benefits. Urban forests can sequester carbon (Godwin, Chen & Singh, 2014) and trees provide aesthetic and health values for humans (Williams, 2017). Trees provide economic benefits estimated $18.3 billion in the United States annually (Peterson et al. 2020). While urban zones are warming at twice the rate of rural zones, trees have been shown to reduce air temperature; a 40% increase in urban tree cover decreased air temperatures by an average of 1.8 to 3.6°F (Urban Heat Island Management Study, 2017). A study by Salmond et al (2016) of Phoenix, AZ showed a 20% increase in vegetation decreased average daily temperature by 7.18%. Additionally, street tree shading can reduce building wall temperatures by 9º Celsius thus reducing energy costs (Salmond et al, 2016).

With the continued increase in urbanization, the urban forest is facing more challenges than ever. More development creates more impervious area which limits the available space for urban trees (Yin et al, 2019). Disease, pests, storm damage, drought and age affect the canopy, which is an indicator for increasing heat in an area. Cooling is site specific and is non-transferrable between areas making off site mitigation or payment in lieu options essentially useless for improving the site conditions. In many locations, there is a lack of understanding about how trees grow, how to maintain them, what services and disservices they offer that prevent long lasting choices for tree canopy locations and species (Anderson et al, 2021). One of the largest challenges in replanting is following the "Right tree, right place" philosophy that sets urban spaces up for successful tree survival and benefits for the long term. Finally, monitoring trees for health and maintenance is limited, with confusion over public versus private lands and who is responsible for such work (Anderson et al, 2021).

3.2 Objective:

Trees provide essential ecosystem services including reducing heat, but how does one define an area as "having UHI?" When communities and their leaders want to understand how to define urban heat island and address the areas that need attention, how do they do this? Filho et al (2018) in their literature-based study, point out that different climates need different approaches. Using heat, or days over 32º C to assess vulnerability to UHI has limitations. For example, in temperate climates, an increase of 1-11 days over 32º is a significant increase, whereas in cities located in hotter climates, the increase in days over 32º is more in line with 19-56 more days (Filho et al, 2018). Although the range is quite different, the more temperate environment is often not seen as vulnerable as the sub-tropical or tropical environments. This can lead to a false sense of heat health. While it would seem to suggest that UHI is not as big an issue for those living in more temperate areas, the effects are felt and equally challenging to manage.

Urban areas must find a way to meet these challenges to the urban forest. Indeed, in my professional experience, many areas do not have the funding or staff to allocate to manage UHI issues. A simple method to compare areas that uses free, easily accessed tools is greatly needed. This type of tool could be used to influence leaders and community members to act, which includes implementing the policies and programs in place in other cities across the United States. Policies and programs that can be implemented to address UHI include:

- Tree protection ordinances (larger older trees provide more benefit)
- Landscape ordinances to add new trees and vegetation
- Climate Action Plans
- Public/Private groups to plant trees and educate
- Tree health monitoring
- Tree maintenance and management

With these policies and programs in mind, which have proved to be the most effective across the United States to reduce UHI in cities using trees?

- What differences do location, developed area and tree cover experience in temperature?
- How can we compare heat health between urban/suburban/rural areas around the city?
- Can urban Heat Health Score (HHS) explain the relationship between land cover and temperature? Does this support the policies and programs areas currently employ?

UHI phenomenon is unique to each city, and so a strictly temperature-based approach to define if an area has UHI will not be effective. While literature shows connections between UHI and land cover, it becomes a comparison or continuum between the "urban" or densest area and surrounding rural or "rural-like" area. By looking at the difference in daily average high temperature between these locations and comparing that to the land cover of tree and shrub areas, a score to rate the heat health can be created. This paper will fill the gap in methods to score or rank parts of cities based on a ratio or urban heat health score to compare areas through a continuum of values that reflect the presence of and severity of UHI. With this HHS, comparisons of temperature and land cover for different locations reveal the impact tree cover has on daily high temperatures in areas across the US, providing a system for evaluating heat impacts down to the neighborhood scale.

3.3 Methodology:

A review of literature shows that tree cover directly influences the land surface temperature of an area (Miner et al. 2017; Ziter et al., 2018). There is a gap in defining where UHI is present, comparing different locations in cities and across the US, and what, if any, policies for tree cover influences this. Having lived and practiced landscape architecture for the past 30 years in the metro area of Charlotte, NC, the author has seen the city transition from a secondary size (at best) location to one of the largest in the United States. One of the most amazing assets that Charlotte has is its majestic tree cover, once making the city almost invisible when flying overhead, and now facing serious canopy loss due to growth, age, pests, climate changes and changes in the value the population places on trees. As Charlotte continues to benefit from the growth in the area, protecting this valuable resource to maintain the title of "Tree City" has become a goal of many groups, and one that is held dear by many. This makes Charlotte an excellent case study for this research on the role of trees in mitigating urban heat island.

The American Council for Energy Efficient Economy (ACEEE) has created a list of cities in the United States that have policies and programs in place to address UHI. From this list (64 cities when last updated in 2020), 50 of the cities listed used trees and vegetation to manage UHI (ACEEE 2020). The variety of ideas, programs, policies, partnerships, processes and funding across these cities, showcases how complicated UHI can be and emphasizes the inability for a single approach to meet the needs of any given place, partially because of the difficulty in defining when an area is experiencing changes in heat health. However, certain similarities in climate, biome, and environments do have common approaches, and this paper seeks to clarify which policies and programs are effective for cities like Charlotte, NC, with temperate climates.

The following six cities were selected from the ACEEE list to provide examples of different strategies in place to address UHI, that are somewhat similar in climate and scale to Charlotte, NC, and offer a variety of UHI strategies. Table 3.1 summarizes the programs and policies in place for these cities.

1. Atlanta, GA, nearby large city to Charlotte, provides a good example for monitoring heat in the city to identify both corridors of use and hot spots. UrbanHeat ATL uses volunteers to carry portable sensors to take temperature along the path they walk or bike. The group Atlanta City Design: Nature identifies street corridors that can be used to increase street trees to reduce heat. Protection of the urban forest is a high priority (UrbanHeatATL.org, 2023).
2. Dallas, TX, enforces their tree protection policies with costly tree replacement values, based on classifications prescribed by their ordinance. Values are derived from the tree age, size, species. Historic trees are valued at a 3:1 ratio (replacement value= RV $579/inch at diameter breast height), significant trees valued at a 1.5:1 ratio (RV $290/inch dbh) and other classes of trees range from $193- $77 /inch dbh. In contrast, trees that are considered “trash” trees or invasive tree species do not have a replacement cost associated with their removal (Dallas City Hall Tree Mitigation Standards, 2018). Fees are placed into a special tree reforestation fund.

3. Hartford, CT has an Urban Forest Equity and Resilience Grant Program. This is used to fund projects that reduce tree cover inequity. It includes the planting, management and tree care to aid in the survival of the trees after they are planted (*DEEP Announces Urban Forest Equity and Resilience Grant Program*, 2021).
4. Louisville, KY completed the 2015 Urban Tree Canopy Assessment to create an interactive program that provides data on tree cover and heat at the neighborhood block level. Heat management scenarios and modelling of the status quo compared to cooling building materials and greening strategies allow users to compare the results and inform recommendations (Stone et al., 2019).
5. Raleigh, NC requires tree conservation on new developments, including tree protection on infill projects (less than 1 acre). Street protective yards along road right-of-way's are included as part of the Complete Street designs and a minimum of 1 shade tree per 2000 sf of parking area is required. Equity, resilience, sustainability and accessibility are part of their strategies (*Raleigh Strategic Plan*, 2020).
6. Washington D.C. utilizes two different programs to address UHI. Sustainable DC plan focuses on mitigating UHI through the reduction of greenhouse gases (*Sustainability DC,* 2011) while the Climate Ready DC plan expands the existing tree canopy with landscape codes and ordinances (Climate Ready DC, 2016). Priority is given to high risk and underserved areas of the city.

Table 3.1: Urban Heat Island strategies implemented by selected cities from ACEEE.org.

Location	UHI Strategies including Trees						
	Tree Protection Ordinance	Trees and Vegetation requirements	Canopy Cover requirements	Climate Action plan	Green Infrastructure	Sustainability Classifications (STAR, LEED, SITES, GBCI)	Monitoring and Management
Atlanta, GA	yes	yes	yes	yes	yes	yes	yes
Dallas, TX	yes	yes	yes	yes	yes	yes	yes
Hartford, CT	yes	yes	yes	yes	yes	yes	yes
Louisville, KY	yes	yes	planned (2018)	yes	yes	planned (2025)	yes
Raleigh, NC	yes	yes	yes	yes	yes	yes	yes
Washington D.C.	yes	yes	yes	yes	yes	yes	yes

How do these cities determine if and how much UHI is impacting their communities and the success of these programs? Comparing the temperatures across the city provides a limited picture of the situation but is a good first step. To create a means of understanding the heat health of a location, data on temperatures was collected using PV Watts website (www.pvwatts.com). This website compiles sun exposure, ambient temperatures with satellite views to locations around the US. Data on temperatures is averaged over multiple years then compiled into a Typical Meteorological Year (TMY) and allows the user to see the land cover as well as which National Renewable Energy Laboratory (NREL) designated grid for solar radiation and temperature the data came from. Using TMY has some drawbacks since many changes can occur in landcover over a multiple year period, but in the case of this paper, the use of TMY can provide many benefits that outweigh possible aging of the data. The website is free, designed to allow users to evaluate the suitability of specific sites for solar energy. This allows data to be collected in several important ways for this project:

- It is free.
- It is easy to use.
- Ambient temperatures at the site-specific level are available across the United States.
- NREL grids are highlighted so that areas with different data can be used without overlapping data.
- NREL provides temperatures based on TMY, at 5 m above ground. For this study, the year is 2020.
- Plan view and satellite views are both available. Satellite views are from Google Earth, which are updated every 1-3 years.
- Satellite views allow the user to see the approximate land cover of the site area.
- Hourly temperature data for each location is available and is consistent across test sites.

For comparison, a single day of the year is selected for the different cities. In the city itself, the Central Business District or main business core of the city is selected as the baseline for reference and labelled “urban”. This becomes the area other locations are compared to as it is a location that we can agree is developed, predominately impervious and built out. For the comparison of other locations, areas are selected from each city, based on how “suburban” or “rural” they are. There is a large amount of discussion and definitions of what is suburban or rural, however, in many cities these lines are blurred. Residential communities once seen as suburban are becoming denser and more built out, and rural areas in some cases are so far out as to be in different counties or further. Therefore, for the purpose of this study, a location that is somewhat suburban or somewhat rural will be selected and used to model locations for each city.

This is made through a visual assessment of impervious areas and green areas on the map image. Several sample cities are selected to make these comparisons, taken from the ACEEE website list and based on similarity to Charlotte, NC. An example of the website data is shown in Figure 3.1. First a developed area of the city, the central business district, is selected. This is our urban area. Next, an area outside of the central city business area with development, mostly residential type, and signs of green space or treescapes, is selected as a suburban type of area. And finally, a park, open space, natural area, forested area or other rural land use pattern is selected to represent a rural area more like what the cooler, undeveloped, non UHI affected area would reflect. This may be adjacent to the city, within the outskirts of the city or a nearby area, depending on how far the urban development of the city extends. For each of these, hourly temperatures are collected for the single day. These temperatures must all come from a different NREL grid. Temperatures are compared, looking at daily minimum, maximum and median, as well as the daily average. The difference between urban and suburban, and the urban and rural are calculated and evaluated.

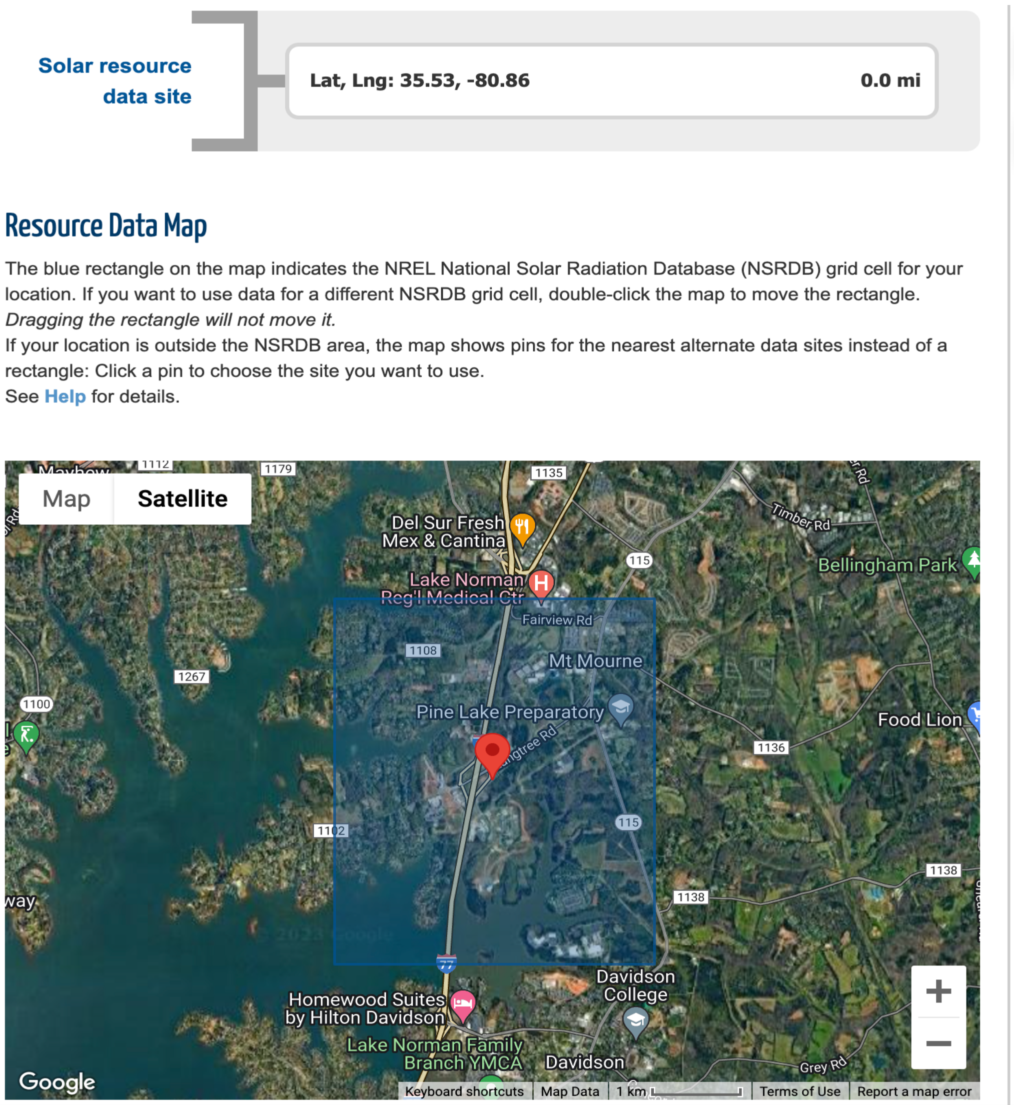


Figure 3.1 PVWatts website was used to identify selected areas for temperature data. The PVWatt's energy and temperature data estimate is based on an hourly performance simulation using a typical-year weather file that represents a multi-year historical period for Charlotte, NC for a fixed photovoltaic system, at 2 meters above ground.

3.4. Analysis

July 14 was selected as a day likely to experience summer heat and serves as a starting point for data collection and analysis. The most recent temperatures for PV Watts were collected between 2019-2021 using data from the National Solar Radiation Database (NSRDB) geostationary satellites with temporal resolution of 10, 30 and 60 minutes and a spatial resolution of 4 km. Temperatures are shown in Celsius.

For the urban area of Charlotte, NC on July 14 the daily minimum temperature was 22º C, high of 36º, median 27º, and average of 28º. Peak temperature occurred between 13:00 and 14:00 and the minimum temperatures were between 2:00 and 5:00. The location selected was partially impervious commercial area, and partially residential area with high tree cover and with high level of infrastructure. Similarly, a nearby suburban area, between Cornelius and Davidson, NC, experienced a minimum temperature of 19º between 1:00 and 4:00 am. The high temperature was 30º between 12:00-14:00, with a median temp of 23.5º and average of 23.9º. Land cover in this area is a mix of suburban residential with commercial areas, Interstate 77 and state highway 115. These two locations are somewhat similar however they vary by a range of 7º at 10:00 am (Charlotte was hotter).

In comparison, the more rural location of Mt. Mourne (Iredell County; Charlotte covers almost all the land in Mecklenburg County) recorded a high temperature of 30º between 14:00 and 15:00. The lowest temperature of 19º was between 4:00-6:00 and again at 23:00. Median was 22.5º and the average was 23.8º. The differences in temperature between Charlotte and Mt. Mourne range from 1-7º hotter in Charlotte, with no case of Mt. Mourne being warmer at any time that day. Figure 3.2 displays the hourly temperature changes for July 14, typical meteorological year 2020. Table 3.2 contains the data derived from PV Watts for the three locations comprising information on Charlotte, NC.

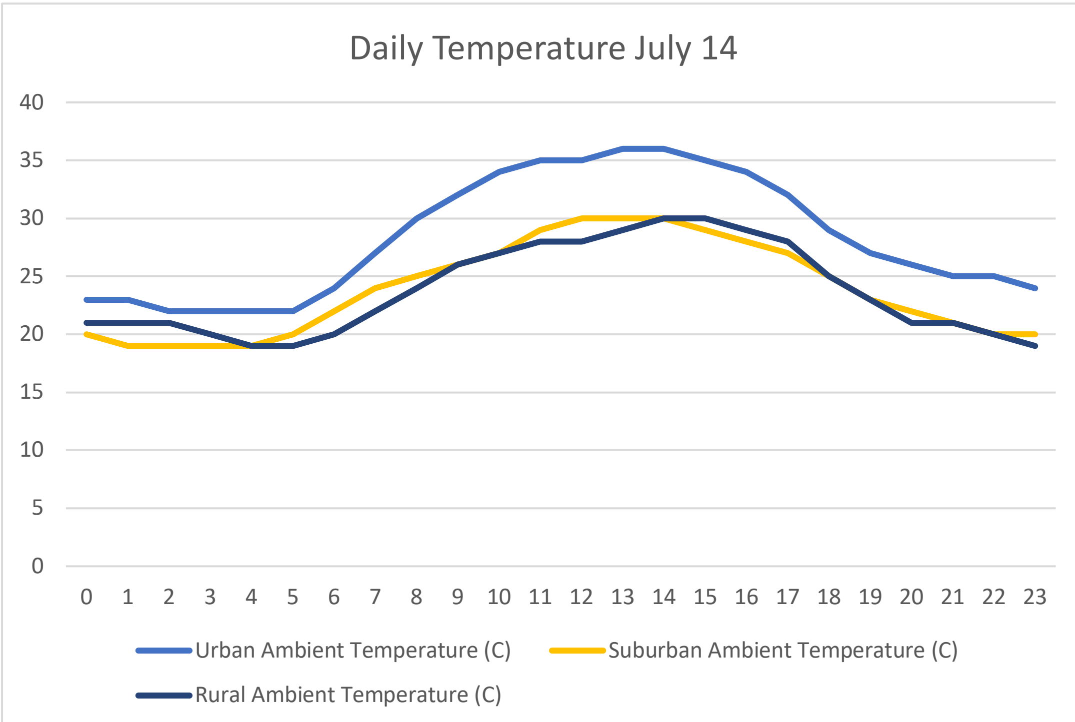


Figure 3.2 Comparing urban, suburban and rural temperatures for July 14, typical meteorological year (TMY) 2020.

Table 3.2 Daily temperatures for urban, suburban and rural type areas for Charlotte NC on July14, TMY 2020

Requested Location:	Charlotte, NC	Requested Location:	Davidson,NC	Requested Location:	Mt Mourne NC
Location:	Lat, Lng: 35.21, -80.82	Location:	Lat, Lng: 35.49, -80.86	Location:	Lat, Lng: 35.53, -80.86
Lat (deg N):	35.21	Lat (deg N):	35.49	Lat (deg N):	35.53
Lng (deg W):	80.82	Lng (deg W):	80.86	Lng (deg W):	80.86
Elev (m):	217.1600037	Elev (m):	241.559998	Elev (m):	247.0500031
Urban		Suburban		Rural	
Hour	Ambient Temperature (C)	Hour	Ambient Temperature (C)	Hour	Ambient Temperature (C)
0	23	0	20	0	21
1	23	1	19	1	21
2	22	2	19	2	21
3	22	3	19	3	20
4	22	4	19	4	19
5	22	5	20	5	19
6	24	6	22	6	20
7	27	7	24	7	22
8	30	8	25	8	24
9	32	9	26	9	26
10	34	10	27	10	27
11	35	11	29	11	28
12	35	12	30	12	28
13	36	13	30	13	29
14	36	14	30	14	30
15	35	15	29	15	30
16	34	16	28	16	29
17	32	17	27	17	28
18	29	18	25	18	25
19	27	19	23	19	23
20	26	20	22	20	21
21	25	21	21	21	21
22	25	22	20	22	20
23	24	23	20	23	19

This same process was applied to each of the example cities, and then each of the cities which responded to the survey sent to all the ACEE cities. Results for the example cities are discussed below:

1. Charlotte, NC: On July 14, temperatures in Charlotte, center city in the uptown commercial area, reached a high of 30º between 12:00 noon and 14:00. The low temperatures were 22º C in Charlotte, and 19º C in both Davidson and Mt. Mourne.

Comparing the difference in hourly temperatures of Charlotte- Davidson with Charlotte-Mt. Mourne shows a range of 1-7º of cooler temperature at all hours than in Charlotte. Suburban Davidson is an average of 4.42º lower and more rural Mt. Mourne has an average of 4.54º lower.

2. Atlanta, GA: Temperatures in Atlanta peaked at 33º between 13:00 and 14:00, while suburban Marietta reaching 32º during the same period. East Cobb, the rural designated location, reached a high of 31º for a more extended time between 12:00 noon and 15:00. Atlanta however, reached a low of 21º between 3:00 and 5:00 am as compared to Marietta, which never got below 22º, which was maintained from 0:00 midnight through 6:00 am and again at 23:00. East Cobb reached a low of 19º between 4:00-5:00 am and again at 22:00-23:00. The higher temperatures during the nighttime in Marietta may reflect the effects of urban sprawl outside of the urban core of the city, new development with young tree cover or even more tree cover in the urban part of Atlanta.
3. Dallas, TX: The suburban location chosen was Bear Creek Nature Park, specifically selected to see the contrast between the urban center city area and a highly treed and greened space. The difference is the highest of the locations selected. While the suburban area of Cockerel Hill shows a range of difference in temperature from -1 to 1º, the rural park area ranged from 7 to 12º cooler than the urban center. Planning departments and city governments are not able to create park conditions continuously throughout the city, but the rural park location does show that the temperature difference is worth noting and considering if "urban forest pockets" could bring similarly cooling effects within developed areas.

4. Hartford, CT: The urban area reaches a peak temperature of 27º earlier in the day (10-11:00 am) with a short period of the minimum temperature of 18º at 0:00 and 1:00 am. The suburban area of Central Manchester showed a slower increase in temperatures though out the day, peaking at 13:00 with 26º. Lowest temperatures were from 22:00-23:00 with 16º. The rural area of Glastonbury reached a peak temperature of 20º between 12:00 and 15:00 with lowest temperature of 15º between 1:00 and 6:00. While the peak high was held longer in the rural area, it was a significant 7º cooler than the peak temperature in the urban area. Rural area was 2-9º cooler than the urban area while the suburban area ranged from -2 through 5º difference.
5. Louisville, KY: In this example, suburban area of Floyds Knob was very similar top the temperature of the city center of Louisville differing by 0-.2º. The rural location of PeeWee Valley, a wooded natural area, ranged from 3.8-7.9º different. Temperature in PeeWee Valley reached a low of 14º between 2:00 and 4:00 am with a daily high of 26º. In comparison, for both urban and suburban areas, the daily minimum was 20º and high 32.5 and 32.2º respectively.
6. Raleigh, NC: Urban temperatures ranged from 21-31º, suburban Ridgewood from 20-28º and rural Forest Park from 20-27º. The suburban area here peaks at 28º at 13:00 hour time slot, but that is the only peak temperature hour. City center reached 31º at the 11:00 and 12:00 time slots. Rural area peaks at 27º from 9:00 through 15:00, the longest span but remains the lowest temperature of the three. However, the suburban area tracked with the rural site, remaining similar in temperatures. This may show a positive result from the ordinances already in place to preserve existing neighborhoods with older trees that are larger and denser.

7. Washington, DC: Washington DC urban area had temperatures n between 23 and 32º, with the rural area of Greenbelt Park ranging from 20-28º. In some cases, the difference was up to 5º lower in Greenbelt Park. Tacoma Park, a suburban neighborhood, had a range of 18.3-31.4º, reaching similar high temperatures between 10:00 am and 16:00, but cooled faster that the urban area and to lower temperatures than both the urban and rural areas.

This same method was utilized to track temperature changes for the 14 cities and 16 respondents which submitted the survey outlined later in Chapter 4. A comparison or urban-suburban-rural temperatures for the example cities discussed here as well as the surveyed cities can be seen in figure 3.3.

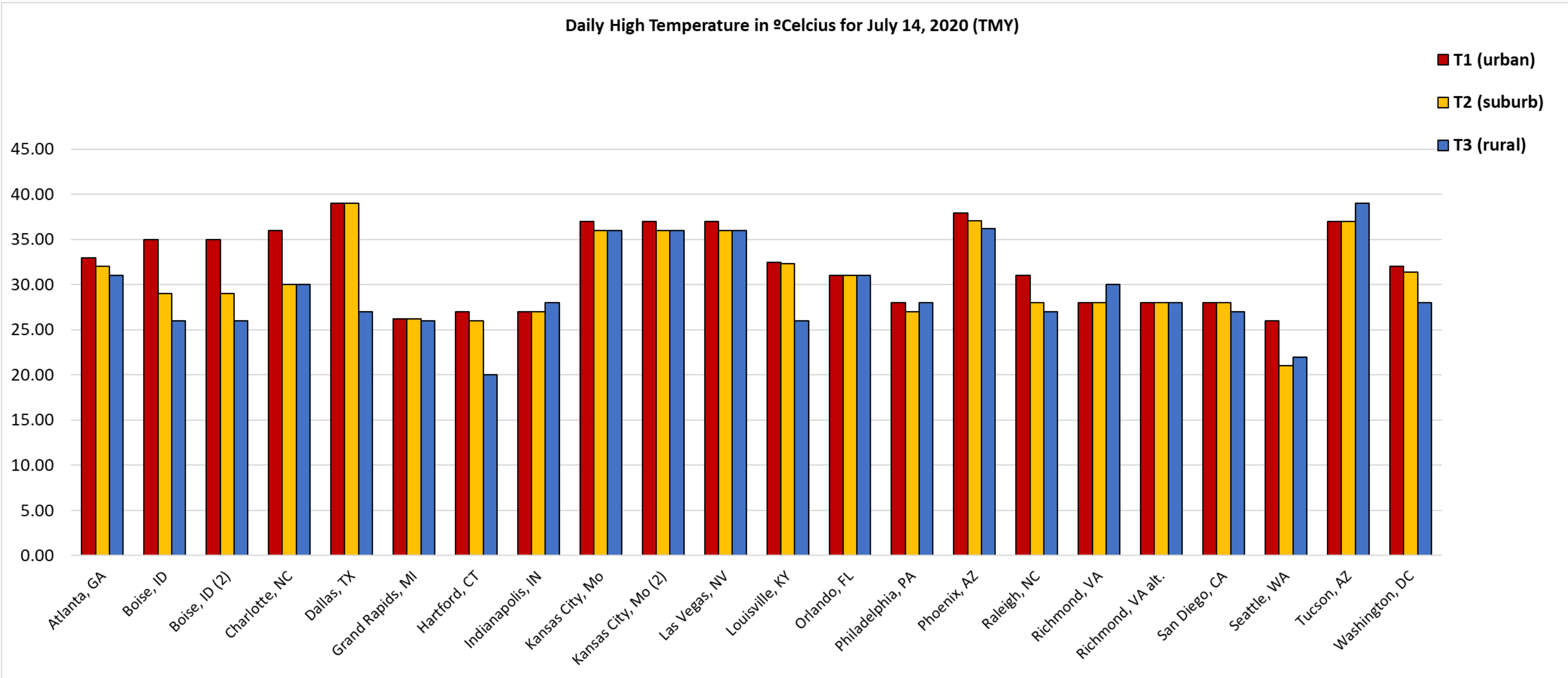


Figure 3.3 Temperature differences between urban, suburban and rural locations in metropolitan areas of all ACEEE cities which responded to survey.

Another way to determine the magnitude of UHI is to look at land use/land cover (LULC) as well as temperature. This can be accomplished using i-Tree Canopy, a free program developed by the USDA Forest Service (https://www.itreetools.org/). I-Tree is used by multiple municipalities in the creation of assessments, planning and data sets on tree canopy cover. Examples of cities from the ACEEE list which have used i-Tree in their assessments include Sacramento, CA; Tucson, AZ; Boise, ID and Pittsburg, PA. The methodology for determining percent land cover using i-Tree for all of the cities is:

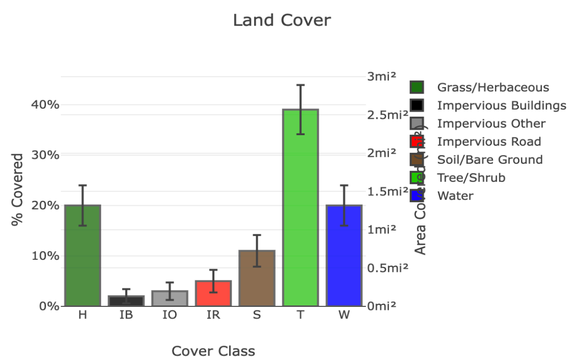
- Sites for this study were selected both assuring different National Renewable Energy Laboratory (NREL) grids and different land use/land covers, as determined in the selection of locations using PV Watts for temperature data.
- A screen shot of the aerial maps from PV Watts was taken to show location.
- i-Tree used the PV Watts boundary for land cover data.
- Minimum of 100 random locations selected within the area boundary.
- Land cover/land use determined at each random location.

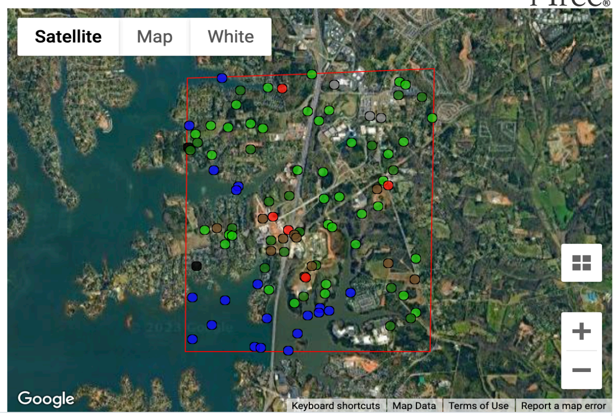
I-Tree is used to estimate the land cover for each area, and percent tree cover may serve as a proxy for UHI, with higher tree cover reflecting lower UHI effect. The boundary from the PV Watts website for each temperature station is copied into the i-TREE program, and a minimum of 100 points are selected at random from the site. These points are labeled into predetermined land cover categories, including tree/shrub, grass/herbaceous, impervious building, impervious road, impervious other, water and bare soil. Figure 3.4 is an example of the i-Tree calculations for Mt. Mourne, just north of Charlotte, NC. The results for the urban, suburban and rural locations are listed in Table 3.3.

i-Tree Canopy

Cover Assessment and Tree Benefits Report

Estimated using random sampling statistics on 1/19/2023





Abbr.	Cover Class	Description	Points	% Cover ± SE	Area (mi²) ± SE
H	Grass/Herbaceous		20	20.00 ± 4.00	1.32 ± 0.26
IB	Impervious Buildings		2	2.00 ± 1.41	0.13 ± 0.09
IO	Impervious Other		3	3.00 ± 1.73	0.20 ± 0.11
IR	Impervious Road		5	5.00 ± 2.24	0.33 ± 0.15
S	Soil/Bare Ground		11	11.00 ± 3.13	0.73 ± 0.21
T	Tree/Shrub		39	39.00 ± 4.88	2.57 ± 0.32
W	Water		20	20.00 ± 4.00	1.32 ± 0.26
Total			**100**	**100.00**	**6.59**

Figure 3.4: Example of i-Tree land cover results for Mt. Mourne

Table 3.3: Land cover results from i-tree for Charlotte area.

Cover class Charlotte	%	Cover class Davidson/Cornelius	%	Cover class Mt. Mourne	%
Urban		Suburban		Rural	
Grass/ Herbaceous	0.19	Grass/ Herbaceous	0.1778	Grass/ Herbaceous	0.2
Impervious Building	0.16	Impervious Building	0.0444	Impervious Building	0.02
Impervious Other	0.16	Impervious Other	0.067	Impervious Other	0.03
Impervious Road	0.16	Impervious Road	0.111	Impervious Road	0.05
Soil/bare ground	0.02	Soil/bare ground	0	Soil/bare ground	0.11
Tree/shrub	0.31	Tree/shrub	0.4667	Tree/shrub	0.39
Water	0	Water	0.133	Water	0.2

With information from both PV Watts and i-Tree, the percent of land cover between urban/suburban and urban/rural can be compared. With these two variables (Δtemp/Δtree cover) a value for urban heat health score is created that allows for comparison between the heat health of different areas of a city.

3.4.1 Analysis of Charlotte:

For Charlotte, an area in the downtown was selected, followed by a nearby town, Davidson, which is a suburban community north of Charlotte (suburb) and Mt. Mourne (rural) although these areas have their own municipal governance and ordinances as well as county ordinances. Areas were selected with varying visible green space coverages to allow for greater comparison between the locations. Charlotte downtown has impervious areas that total 48% of the land cover. Tree and shrub cover is 31%, and turf or herbaceous ground cover is 19%.

Davidson has 22% impervious land cover. Tree and shrub cover is 47% and turf and herbaceous cover decreases to 18%, showing more land area is dedicated to tree cover. Mount Mourne has only 10% impervious area with a high of 39% tree and shrub cover. In this situation, turf and herbaceous cover is also higher, at 20% due to large pasture and farmland. When land cover is compared with ambient temperature, we see Mount Mourne with its higher tree cover and lower built upon area shows lower temperatures across all hours of the day compared to Charlotte. The temperatures track in a similar pattern of highs and lows, with coolest temperatures occurring in the early morning hours. Davidson temperatures and land cover show higher tree cover than Mount Mourne and provide a middle range between urban and rural type settings.

While observing land cover types can often predict temperature differences, this approach does not always explain the whole picture. UHI is influenced by elevation, wind and rain patterns, proximity to water, building locations and urban canyons, among other factors (Eastin et al., 2017), making it cumbersome to use to compare areas in a quick and effective manner. Instead, a method that includes both ambient temperature and percentage of land cover would create a way to compare smaller areas, even ones near each other and could have a practical application for planning departments, committees and neighborhoods to locate areas of concern and priority in tree planting. This Heat Health Score (HHS) is a unique metric that represents a continuum of differences in temperatures and land cover that allows one to see the effects of different land cover types on temperature in an area- effectively the heat health of that location.

Temperature is affected by landcover type and a comparison of temperature to land cover can show a range or continuum of differences in urban heat impacts and through the heat health score of a location (T1:L1 compared to T2:L2).

The formula for Heat Health Score (HHS) = $(\Delta T/\Delta L)$

It creates a value that reflects the relationship between the daily high temperature and the percentage of land cover with tree and shrub cover.

ΔT represents the difference between the daily high temperature of the urban area (T1), less the daily high temperature of the suburban(T2) or rural (T3) area. (T1-T2) or (T1-T3)

ΔL represents the difference in percent of tree/shrub cover between the urban area and either the suburban or rural area. (L1-L2) or (L1-L3)

Variable combinations may be as follows:

ΔT is positive	urban area is hotter than the suburban/rural.
ΔT is negative	urban area is cooler than the suburban/rural.
ΔL is positive	urban area has more tree cover.
ΔL is negative	urban area has less tree cover.

These combinations result in positive or negative scores which represent different outcomes. Negative results show that either the urban area is hotter with less tree cover (the expected result), or that the urban area is cooler with more tree cover (a desired result). Positive results show the urban area is hotter with more tree cover or that the urban area is cooler with less tree cover. These results require a deeper look into the other possible causes for change in

UHI. This ratio creates a score spanning little or no difference between the ratio of daily high temperatures and tree/shrub cover, to increasingly divergent results. Results may be positive, showing that the urban area is cooler that the area used to compare it to, or negative, with the larger the negative number, the greater the difference in HHS between the areas. The smaller the value, the greater the effect of UHI between two locations, and the higher the need for policies that regulate green spaces in those areas. The urban area is used as the base line, allowing one to see how divergent the city spaces are from the rural. The results are often negative numbers, although that is not always the case. Table 3.4 shows the values for ΔT and ΔL for Charlotte compared to suburban Davidson and rural Mt. Mourne.

Table 3.4 Results of temperature and land cover for the Charlotte, NC area.

Charlotte to Davidson

Tree/shrub	
Difference in daily high temperature urban/suburban ºC	6
Difference in land cover %, urban and suburban	-.16
Difference in average temp ºC	4.42

Charlotte to Mt. Mourne

Tree/shrub	
Difference in daily high temperature urban/rural ºC	6
Difference in land cover %, urban and rural	-.08
Difference in average temp ºC	4.54

Heat Health Score (HHS)

HHS between the urban area of Charlotte and the suburban area of Davidson. (6/-.16) = -37.5

HHS between the urban area of Charlotte and the rural area of Mt. Mourne (6/-.08) = -75

There is a larger difference in the HHS between Charlotte and Mt. Mourne than the HHS between Charlotte and Davidson, showing that the effects of UHI are greater in Davidson than

Mt. Mourne, with Charlotte's urban location feeling a larger impact from UHI than either of the other two communities. Table 3.5 reflects the i-Tree percentages for land cover in these areas.

Table 3.5 Land cover percentages determined through the selection of 100 random points using i-Tree Canopy.

Charlotte to Davidson		Charlotte to Mt. Mourne	
Difference in land cover (%), urban and suburban		Difference in land cover (%), urban and rural	
Grass/ Herbaceous	12	Grass/ Herbaceous	-01
Impervious Building	11.5	Impervious Building	14
Impervious Other	9.3	Impervious Other	13
Impervious Road	4.9	Impervious Road	11
Soil/bare ground	02	Soil/bare ground	-09
Tree/shrub	-15	Tree/shrub	-08
Water	-13	Water	-20

3.4.2 Analysis of Multiple Cities

The comparison of urban/suburban/rural for Charlotte reflects expected results, but will this approach work in other areas? To explore that question, a survey regarding goals and policies addressing urban heat island was created and sent to the planning departments of each city on two occasions, July 17, 2022, and a follow up reminder on September 13, 2022. Appendix A contains the sample survey. Of those 50 cities surveyed, 16 responses from 14 cities were received. The temperature data from the cities that responded to the survey was used to learn about the perceived success of UHI policies implemented by each city. Using the same process for these cities as for Charlotte, PV Watts for neighborhood level ambient temperatures along with i-Tree software to determine the percentages of each land cover for the area, data from these next cities can be combined with the data from the 6 sample cities. Figure 3.5 shows both the ratio of change in temperature to change in tree and shrub land cover, the Heat Health Score, for urban to suburban and urban to rural.

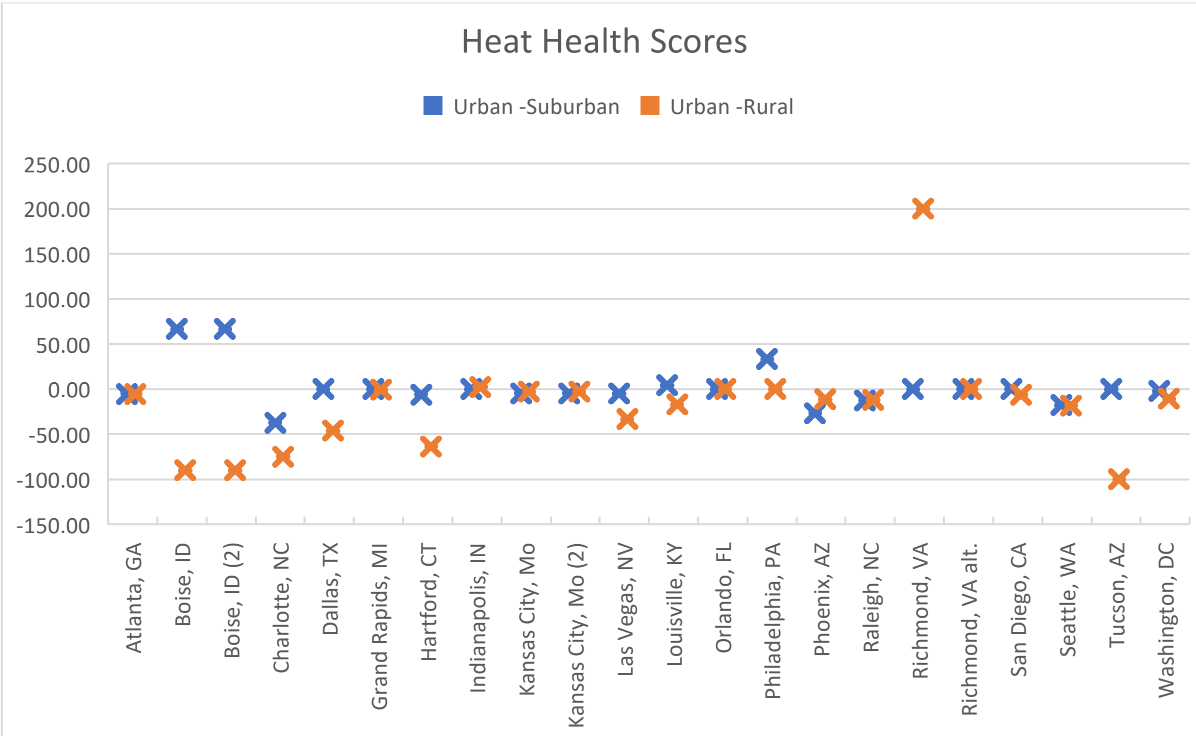


Figure 3.5 shows the comparison of urban to suburban and urban to rural Heat Health Score. Both Boise, ID and Kansas City, MO had two respondents to the survey. Richmond, VA alt was included later to compare to the outlier rural location.

In these results the heat health is not always greater outside the urban core of cities as seen by the HHS. Suburban and even rural areas can experience higher effects from heat than their urban counterparts. Tree cover appears to be a major variable, but in cases where the HHS is higher in suburban and rural areas, we must explore other variables for answers. Table 3.6 shows the data for both the surveyed cities and the locations selected for literature review.

In many cities, the data reflected the expectations; urban area had higher temperatures than the suburban area. Boise, Charlotte, Seattle and Raleigh had the greatest difference between urban and suburban temperatures with 6º C, 6º C, 5º C and 4º C differences in temperature respectively. Dallas, Grand Rapids, Indianapolis, Orlando, Richmond and Tucson experienced no change in temperature between urban and suburban areas.

The difference in temperature between urban and rural sections of the city mostly followed this expectation. In some cases, rural areas remained the same temperature as their urban counterparts, for example Orlando and Philadelphia show no temperature changes in both areas. The other rural areas ranged from 0.2º C lower to the highest of 12º C difference. Three cities showed the reverse, however. Indianapolis Scott Starling Nature Preserve was 1º C warmer that the urban area, Richmond Forest Ridge was 2º warmer and Tucson Gates Pass Trailhead was 2º warmer. For Richmond, this can be explained by the reduced tree cover in the area selected as rural (it was a cemetery) but a higher grass/herbaceous percentage of 21%. Forest Ridge Park tree/shrub land cover category was 24% in the cemetery as well as having 12% water and a combined impervious covers and bare soil of 40% but Richmond urban area was a close 23% in tree cover 52% impervious areas and 6% water in the urban area. Turf or lawn can rate like impervious surfaces in heat adsorption, and this combined with the high impervious infrastructure in the cemetery may have raised the temperature. A second Richmond site, Stony Point, was selected for comparison, with a much higher tree cover of 69% tree cover, 14% impervious areas and bare soil, 10% grass/herbaceous and 7% water. These different land covers change the HHS between Richmond urban and rural to a 0, which suggests that the policies and programs for tree cover in Richmond should be looked at for insight.

Tucson is a very interesting case since the rural area of Gates Pass Trailhead is a natural area that is composed predominately by rock and low vegetation, both of which do little to minimize heat. Tucson's urban area has greater 2% tree/shrub cover than the rural area. Indianapolis Scott Starling Nature Sanctuary has a tree/shrub land cover of 58% versus the urban area's 15%, therefore would be expected to be significantly cooler. Since that is not the case, other factors which might impact this result include elevation, cloud cover, wind patterns, urban canyons and albedo, and warrant closer inspection.

Land cover predominately followed the expected results. Urban areas had the highest percent of impervious surfaces, rural the lowest. Tree/shrub cover in the selected areas had more variation. Boise locations had the highest tree cover at 32% with Charlotte and Hartford close at 31%. Las Vegas had 5% and Phoenix had 8% tree/shrub cover in these built-up areas. In the suburban areas, Raleigh at 52% has the highest tree/shrub land cover of all the cities. Charlotte and Hartford have 47%, Seattle has 44%, and Washington, DC has 42%. Lowest tree/shrub cover in rural areas include Louisville at 10%, Phoenix at 11% and Tucson at 16%. The rural classification was meant to reflect the natural biomes of the areas, which in some cases it did. Raleigh "rural" tree cover was 61%, and Atlanta, 55%, which reflect the temperate forest of the mid-Atlantic while Tucson, 17% and Phoenix, 23% reflect the more arid landscapes (much of this % is low trees and shrubs). In Tucson this is particularly evident in the positive value of 2% more tree cover in the urban area than in the natural park setting due to ordinances and required plantings.

Location			Daily High Temperature ºC					Landcover (% of trees and shrubs)					Heat Health Score urban to suburban	Heat Health Score urban to rural
City	Suburan	Rural	T1 (urban)	T2 (suburb)	T3 (rural)	ΔT1-T2	ΔT1-T3	L1 (urban)	L2 (suburb)	L3 (rural)	ΔL1-L2	ΔL1-L3	HHS (U-S)	HHS (U-R)
Atlanta, GA	Marietta	East Cobb	33.00	32.00	31.00	1.00	2.00	0.19	0.38	0.55	-0.19	-0.36	-5.26	-5.56
Boise, ID	West Bench	Robie Creek	35.00	29.00	26.00	6.00	9.00	0.32	0.23	0.42	0.09	-0.10	66.67	-90.00
Boise, ID	2	2	35.00	29.00	26.00	6.00	9.00	0.32	0.23	0.42	0.09	-0.10	66.67	-90.00
Charlotte, NC	Davidson	Mt. Mourne	36.00	30.00	30.00	6.00	6.00	0.31	0.47	0.39	-0.16	-0.08	-37.50	-75.00
Dallas, TX	Cockerell Hill	Bear Creek Nature Park	39.00	39.00	27.00	0.00	12.00	0.25	0.26	0.45	-0.01	-0.26	0.00	-46.15
Grand Rapids, MI	East Grand Rapids	Aman Park	26.20	26.20	26.00	0.00	0.20	0.31	0.43	0.58	-0.12	-0.27	0.00	-0.74
Hartford, CT	Central Manchester	Glastonbury	27.00	26.00	20.00	1.00	7.00	0.31	0.47	0.42	-0.16	-0.11	-6.25	-63.64
Indianapolis, IN	Glenroy Village	Scott Starling Nature Sanctuary	27.00	27.00	28.00	0.00	-1.00	0.15	0.29	0.58	-0.14	-0.43	0.00	2.33
Kansas City, Mo	East Community	Coachlight	37.00	36.00	36.00	1.00	1.00	0.19	0.40	0.54	-0.21	-0.35	-4.76	-2.86
Kansas City, Mo	2	2	37.00	36.00	36.00	1.00	1.00	0.19	0.40	0.54	-0.21	-0.35	-4.76	-2.86
Las Vegas, NV	Sun City	Red Rock Canyon	37.00	36.00	36.00	1.00	1.00	0.05	0.25	0.08	-0.20	-0.03	-5.00	-33.33
Louisville, KY	Floyds Knob	PeeWee Valley	32.50	32.30	26.00	0.20	6.50	0.15	0.10	0.53	0.05	-0.38	4.00	-17.11
Orlando, FL	College Park	Maitland	31.00	31.00	31.00	0.00	0.00	0.25	0.40	0.26	-0.15	-0.01	0.00	0.00
Philadelphia, PA	Fairhill	Penn Wynne	28.00	27.00	28.00	1.00	0.00	0.23	0.20	0.34	0.03	-0.11	33.33	0.00
Phoenix, AZ	Scottsdale	Anthem	37.90	37.10	36.20	0.80	1.70	0.08	0.11	0.23	-0.03	-0.15	-26.67	-11.33
Raleigh, NC	Ridgewood	Forest Ridge	31.00	28.00	27.00	3.00	4.00	0.28	0.52	0.61	-0.24	-0.33	-12.50	-12.12
Richmond, VA	Montrose	Forest Hills Park (cemetary)	28.00	28.00	30.00	0.00	-2.00	0.23	0.38	0.24	-0.15	-0.01	0.00	200.00
Richmond, VA 2	Montrose	Stony Point	28.00	28.00	28.00	0.00	0.00	0.23	0.38	0.69	-0.15	-0.37	0.00	0.00
San Diego, CA	Mountain View	Clairmont Mesa West	28.00	28.00	27.00	0.00	1.00	0.15	0.21	0.31	-0.06	-0.16	0.00	-6.25
Seattle, WA	Ravenna	Hamlin Park	26.00	21.00	22.00	5.00	4.00	0.16	0.44	0.38	-0.28	-0.22	-17.86	-18.18
Tucson, AZ	Tahoe Park	Gates Pass Trailhead	37.00	37.00	39.00	0.00	-2.00	0.19	0.16	0.17	0.03	0.02	0.00	-100.00
Washington, DC	Takoma Park	Greenbelt	32.00	31.40	28.00	0.60	4.00	0.14	0.42	0.51	-0.28	-0.37	-2.14	-10.81

Table 3.6 shows the data collected for both the surveyed cities and the locations selected for literature review. This includes the multiple locations for Boise, Kansas City and Richmond.

What does this mean for understanding urban heat island effects? Since the presence of UHI may be determined by impervious area versus tree cover, recognizing the land cover in each area is important. While this is not the only considerations (elevation, cloud cover, rainfall, wind, time of year, time of day) it is a clear one to use as a proxy. Different regions have different temperature ranges to begin with. For example, Tucson will be hotter and drier than Seattle. So how do we create a means of measuring the prevalence of UHI to an area in a way that can be used to recognize the continuum of heat a single city might experience in relation to its locales across the country? One way is to create a ratio of the difference of temperature versus the difference of tree/shrub cover, as shown above with a heat health score, HHS. Where there is no temperature difference between the areas, the nominator of the equation remains 0 and results in a HHS of 0. A score of zero may imply that the effects of urban sprawl are wider than the selection of suburban and rural locations. In the case of Richmond, where the temperature difference in the first scenario is reversed (urban temperatures are LOWER that the selected "rural" area, which was a cemetery) the HHS become significantly larger, a HHS of 200 between urban and rural Richmond, but the HHS between urban and suburban Richmond is 0 because there is no temperature difference between the two locations. With this high HHS for Richmond, and alternate rural location, Stony Point, was selected and tested. In this case, the change in daily high temperatures was 0 (both were 28º C) and the rural tree cover was 67%, creating a change in tree cover of 37% less in the urban part of Richmond. HHS for this location was 0.00 which was more in line with expected results.

Indianapolis experienced a similar result because the temperature in the "rural" area selected was higher than in the urban area, resulting in a positive HHS of 2.33. This reversed result is more common in the urban to suburban ranges, with Boise, Louisville, and Philadelphia experiencing positive values for HHS, indicating that urban locations may have higher tree cover than their suburban counterparts. In these cases, the suburban areas may be experiencing more development, have fewer established trees or may be experiencing the effects of urban sprawl, and heat is a larger factor in these suburban areas. Additionally, these differences may also reflect the impacts from policies and programs in urban areas having the effect of increasing tree cover or improving other heat related variables.

3.5 Conclusions and Implications

For smaller communities and community groups, using heat health score can provide a free and manageable method to evaluate locations, striving for a HHS of 0 or greater to reflect cooling effects of tree and shrub land cover, allowing them to advocate for funding, policies changes and programming. Over time, this method can also be used to monitor improvements to the heat health of a location, with limitations based on the updates to TMY temperature information and Google maps updates. While PVWatts and i-Tree were used as free programs to obtain weather and tree cover data, they can be used in conjunction with other available data that groups may have access to.

Tree cover remains a consistently import factor in controlling or reducing heat; the need to protect, increase and improve tree cover in cities is essential as increased temperatures and extreme heat events become more frequent. Expecting private landowners to provide the means to achieve these improvements is an unlikely scenario if we consider the economic costs of purchasing land, installing trees, caring for trees and providing long term maintenance including water for these. A more likely scenario is to look at policies and programs designed to acknowledge UHI and determine what impact they have on influencing UHI. A study by Pataki et al. (2021) shows trees provide many benefits to urban areas including increased property values, improved water and air quality, reduced energy use, supporting animal and plant habitat, improved mental and physical wellness for inhabitants as well as providing aesthetic benefits. The installation of more trees can mitigate the loss of certain ecosystem services and improve the harms caused by climate change, however, land availability in urban areas is limited. This poses challenges for tree growth and health. Urban areas are not necessarily able to plant the quantity of trees needed to mitigate the climate challenges that they are facing, so policies and programs are needed to maximize the allocation of trees within cities through required plantings, equitable programs and partnerships to increase tree canopy area.

Using the HHS, five locations had positive scores, showing that the urban area was either cooler in relation to the suburban or rural, or that the urban area had greater tree cover. What about these areas is creating this positive score? One consideration is that the policies and programs in place are doing their job, reducing UHI in these locations. A look at policies in the next chapter will further this research.

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CHAPTER 4

Determining the Effectiveness of Policies and Programs Aimed at Reducing Urban Heat Island
Article 3

ABSTRACT:

The challenges posed by climate change and urbanization continue to grow and urban heat island has emerged as a critical issue affecting the health of cities and their inhabitants. This article will investigate the effectiveness of policies and programs designed to mitigate UHI through the qualitative analysis provided by a survey of planning departments selected from the American Council for an Energy Efficient Economy (ACEEE) list of cities addressing UHI. Through an assessment of the responses, this research sheds light on the perceived successes and challenges of current policies and offers practical recommendations for policymakers.

Keywords: urban heat island, mitigation, tree canopy cover, green infrastructure, policies, programs, equity

4.1 Introduction:

Charlotte Planning department has spent years developing the Unified Development Ordinance with the input of many stakeholders from the public and the direction of the Planning Department. On August 22, 2022, the Charlotte City Council approved the draft of the Unified Development Ordinance (UDO) and it went into effect June 1, 2023. The UDO was developed to combine all the development standards and codes into one document to consolidate the information needed to successfully meet Charlotte's polices for development and to make the process of approval smoother. It was also an opportunity for the city to evaluate and update the current requirements. Although reducing heat and providing shade and cooling are discussed in the new UDO, UHI is not named as a specific problem to be addressed.

Awareness of the issue and developing a method for identifying UHI are important considerations for cities as development and growth of urban areas continues. UHI affects ecosystem services, human health, even the correct functioning of mechanical equipment (Miner et al., 2017). A review of cities with policies related to UHI from the American Council for an Energy Efficient Economy (ACEEE, Mitigation of Urban Heat Islands, 2020) list of cities with policies and programs that address the effects of UHI and collects information relevant to the reduction of UHI to benefit the environment, economy and energy expenditure in cities- all very vital components to sustainability and resilience. A comparison of the policies and programs compiled from the ACEEE website shows the prevalence and use of different methods to manage UHI.

There are different ways to address urban heat island. One way is to do so through built structures. One can use light or reflective colors, reduce the footprint of impervious areas, reduce energy usage which decreases the amount of heat released into the area around the buildings, limit transportation methods that use and release carbons and use buildings and structures to create shaded areas and block sunlight for example. A second way is to use vegetative methods to reduce heat including green infrastructure instead of grey infrastructure, green roofs, green walls, more street trees and tree planting in both public and private lands, and saving, protecting and maintaining existing trees, such as the ones selected for this study. Raising public awareness to encourage higher conservation, efficiency, and caring for existing trees while adding more trees to private lands can help reduce the impact of UHI although on the individual level, results can be hard to see. Lower energy bills, aesthetics and increased building and land values serve as incentives for these productive behaviors.

4.2 Objective:

There are many factors which effect urban heat island (UHI), including locations, biomes, elevation, wind, rain events, and street canyons, but vegetation appears to be one of the least expensive and more effective methods in use to reduce urban heat. The role of tree canopy cover in reducing heat is discussed in both chapter 2 and 3 and leads to the question of how to increase tree cover and save more trees. Even without the support of research, we instinctively prefer the shade of trees. Density of cover matters, and larger, healthier trees provide more density (depending on the species). The most desired trees are ones that have the space, maintenance, and natural ability to survive where they were planted. When they have these needs met, trees are more likely to live longer, be healthier and therefore have a denser tree canopy (Westendorff, 2023).

The database on UHI by ACEEE, serves as the starting point for this research, with the goal of exploring what existing policies or programs are implemented throughout the United

States aimed at mitigating UHI effects in urban areas through tree-based approaches, are these seen as effective, how are they measured and monitored, and what actionable recommendations can be proposed for enhancing the Urban Development Ordinance (UDO) of the City of Charlotte, with a focus on UHI mitigation strategies.

Using a survey of 50 cities developed by the American Council for an Energy Efficient Economy, (ACEEE.org, 2020), city planners who responded that their municipality uses plants to mitigate the effects of urban heat, were asked which of the policies and programs they implement, and which have the greatest success in their opinion. Of the 50 cities surveyed, 16 responses were returned (32%). In 2 cities, both Boise and Kansas City, there were 2 respondents. Both responses for each city were included since the opinions are unique to the responder. All the responders noted that they used vegetation to impact heat in some way, 94% through trees and vegetation programs, and 62% used programs that had green infrastructure programs, as listed in Chapter 3, Table 3.1. For many cities the cost of funding new plantings, and all that they need to be successful is difficult to commit funding for. Other sources such as public-private partnerships, sponsorships and community groups can assist in meeting these needs.

4.3 Methodology

ACEEE collected data on 100 (in 2020) cities regarding if and how they addressed urban heat island and made this information available on their website. Each city was explored for policies and programs that were currently in use to address UHI and these were noted in the research. Cities which used vegetation as a means of influencing UHI were selected for further research and provided a compilation of 50 different cities across the United States. Policies and programs that were the most frequently cited sources of establishing green spaces include tree preservation, tree ordinances, parking lot ordinances and green infrastructure.

As discussed in Chapter 3, a survey was created and sent to the planning departments of all 50 of the ACEEE cities referenced for UHI policies. The survey was intended to be short, completed easily by a member of the planning department or other referred staff member involved in managing the implementations of these. Questions were aimed to discover which policies and programs were used to address urban heat island within different cities of varying regions across the United States, and to illicit suggestions of which policies and programs provided the results cities were trying to achieve. To accomplish this, respondents were asked to give their own personal opinions based on their experience working at the city, and to offer insight into what methods worked, or might improve the results.

The survey was created using Survey Monkey and can be found in Appendix B as well as at https://www.surveymonkey.com/r/TY53ZC3 . It was created on July 10, 2022, and distributed via email to the planning department of all 50 cities which were on the ACEEE list on two occasions, July and September of 2022. Responses were received between July 18 and September 19, 2022. For cities with fewer or no policies, higher values for the heat health score were expected, with the pairing urban/rural values higher than the urban/suburban. For cities with stronger policies or in climates that lack tree cover in the natural biome, this may be reversed.

4.4 Analysis:

How does the perceived effectiveness of the different policies as shown in the survey of ACEEE cities compare with the UHI policies used in these areas? How did the respondent rate the success of different policies and programs implemented by their area? Does this align with the Heat Health Score from chapter 3? In this way, the survey reflects the responses of an individual working in the planning department of a given city. The respondents have first-hand experience with the ordinances and guidelines that are mandated by the municipal location, would be familiar with the climate, biome, and political climate of the city and would have the ability to assess the success or failure of such policies. Specific recommendations for the City of Charlotte as they implement the new UDO will be drawn from these examples.

While urban heat island (UHI) is not always named directly in these ordinances and policies, all the respondents to the survey stated that they either already had or were in the process of adding policies and programs that would help to mitigate UHI and other climate related problems. All the respondents also used policies that relied on natural systems to manage and regulate heat. Using natural systems as part of UHI involves increasing tree cover and greenspaces in the city, supporting biodiversity and ecosystem services, and implementing UHI mitigation strategies in new development and redevelopment plans. Atlanta at the time of survey responded with a “no” but added that a plan was in process. Both Kansas City and Indianapolis are using climate-based plans and assessments to address UHI. In Indianapolis, the Office of Sustainability developed a Climate Hazard and Social Vulnerability Assessment Index to partner with Keep Indianapolis Beautiful to plant 1500 trees per year in areas prioritized by the study. Kansas City created a Climate Protection & Resiliency Plan with various programs to manage UHI. Strategies and actions to reduce UHI include carbon mitigation goals, such as energy efficiency, improved building standards, renewables energy, reducing vehicle miles travelled (VMT), adding transit and walkable/bike-able transportation in development plans.

When asked which policies and programs were used, multiple selections were allowed since municipalities enact multiple policies to reach their goals. Of the respondents, 50% used pollution reduction methods to address UHI, 94% used plant materials such as trees and shrubs, and 62% used green infrastructure. By far, vegetation was seen the most important method for reducing UHI. Programs and policies that are used can be classified into one or more of the following groups: tree protection ordinances, ordinances that use vegetation such as trees and shrubs, climate action plans, green infrastructure, sustainability classifications, monitoring and management programs and many cities use a combination of these methods.

The survey provides qualitative data on the perceived effectiveness of different policies and programs used in the municipal departments that regulate such policies, as well as quantifiable data on which policies and programs used the most frequently. A comparison of frequency and perceived effectiveness shows that some polices are more effective. In the absence of a single comprehensive method for evaluating different methods of reducing UHI, this research is interested in which programs and policies individual members of planning staffs recommend using when addressing heat in their cities.

Question 1: What city do you work for?

This question was simply a way to recognize which city was responding.

Question 2: Does your city have policies or programs related to urban heat island (UHI)?

While many cities do have policies directed at reducing heat, not all of them refer to urban heat island as a unique problem. The goal was to see which cities address UHI as a specific issue needing efforts contained in policies or programs to confront the problems UHI causes. Results are shown in figure 4.1. Only one respondent's city did not have direct requirements for UHI, however, in comments, the council members of that city were in the process of creating plans to implement for UHI.

Question 2: Does your city have policies or programs related to urban heat island (UHI)?

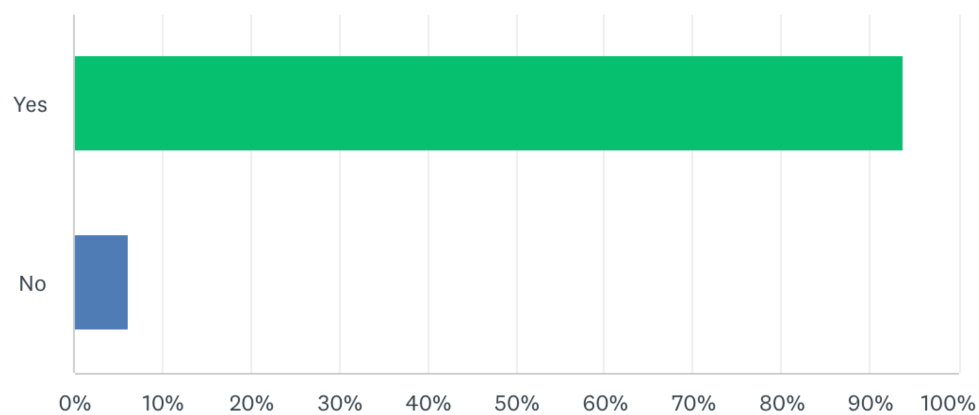

Figure 4.1 Survey question 2. Policies and Programs related to UHI.

Question 3: Are the policies or programs addressed with any of the following methods (multiple responses were allowed). This question reveals whether pollution reduction or vegetation were used to address UHI, see figure 4.2. Other responses included an Energy Benchmarking Ordinance, experiments in cool pavement treatments, roof color and building material selections. One respondent notes that while some of these types of policies are in place, UHI reduction may not have been the top initiative. Tree protection ordinances are also listed as being used to reduce heat island effect of new impervious surfaces. Further into the survey, all respondents referred to at least one program or policy that was based on plants or plant health to address urban heat island, and several selected multiple programs and policies.

Question 3: Are the UHI policies or programs addressed with any of the following methods (check all that apply)

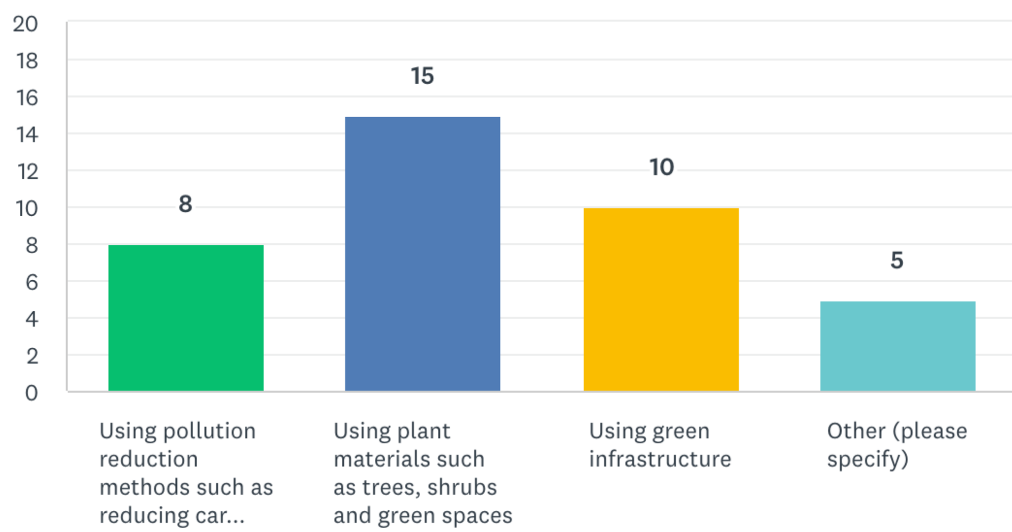

Figure 4.2 Survey question 3. Methods to address UHI.

Question 4: Of the policies which the city has implemented, which do you feel are most effective? Shown in figure 4.3, this question was designed for a general response between the use of built and/or pollution reduction ways to reduce UHI compared to vegetative means of managing UHI. When asked if pollution reduction methods or methods implementing trees or vegetation was more effective, 60% (9) of the respondents believed that using trees was the most effective of the policies, with green infrastructure receiving 13% (2) of the responses and 47%

(7) felt that a combination of policies was most effective. One respondent added several other policies or programs which they felt were effective. These included bonuses for green roof construction, LEED green building and solar panel programs.

Question 4: Of the policies which the city has implemented, which do you feel are most effective?

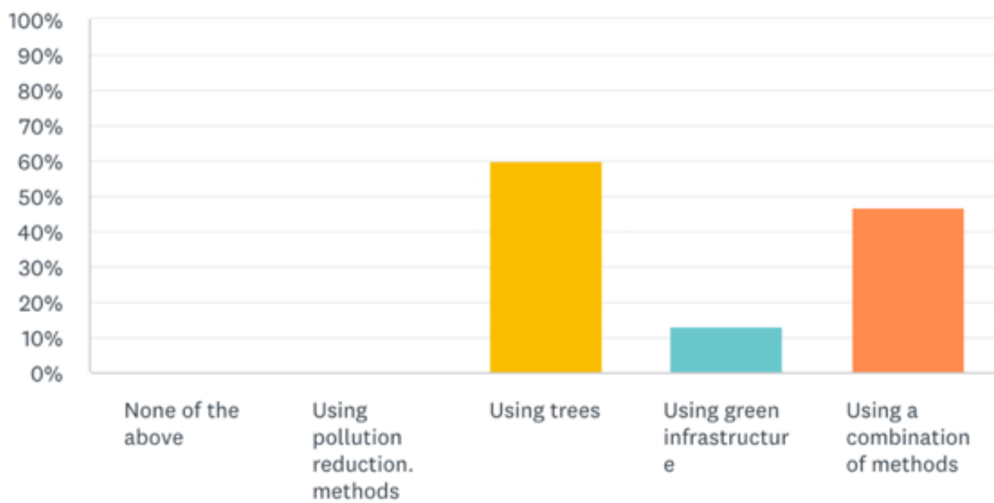

Figure 4.3. Survey question 4. Responses regarding the effectiveness of UHI reduction policies. One respondent added: green roof construction bonus, LEED Green Building, Solar panel program.

Question 5, shown in figure 4.4, asks which types of programs are used to address UHI and provides options that were used in the matrix of 50 cities. These allow respondents to select multiple options and include the following selections: none of the above (0%); Tree protection ordinance (62.5%); trees and vegetation requirements (68.75%); tree canopy cover requirements (37.5%); Climate Action Plan (68.75%); Green infrastructure (62.5%); Sustainability classifications (37.5%); monitoring and management programs (31.25%). All the respondent's cities used at least one of these, but there also was no consensus on a single platform for reducing UHI. Climate action plans along with tree and vegetation requirements were the most frequently cited, with 11 locations implementing these. Next highest with 10 respondents selecting these, were tree protection ordinances and green infrastructure. Tree canopy cover requirements and requiring sustainability classifications such as LEED, SITES, and other GBC programs both received 37.5% cities requiring and last was monitoring and management programs at 32.5%. In addition, comments included other programs such as Get a Street Tree Program, Green Roof Construction Bonus, and Green Street Infrastructure programs which include bioswales and porous pavements to reduce street runoff.

These results are interesting since research to date shows that increasing tree canopy cover to 40% provides a decrease in urban temperatures by a range of 1.1 – 5.7 ºC (Ziter & Turner, 2018) and an increase in vegetative cover by 10% can resulting in a lowering of urban daytime temperatures by 1º C (Norton et al, 2014). This makes canopy cover as a metric a likely candidate for effective management of UHI. Yet few of the respondents (37.5%) have implemented canopy coverage as a program target for reducing urban heat.

In addition, survival rates and healthy growth are essential to the effectiveness of any vegetative program, yet monitoring and management programs are quite low with 5 respondents that are in cities that collect metrics or manage their tree canopy for greater success. In a later response asking for methods to improve UHI reduction, methods for monitoring and management of trees and vegetation are mentioned frequently.

Question 5: Which types of programs are used in your city to address urban heat island?

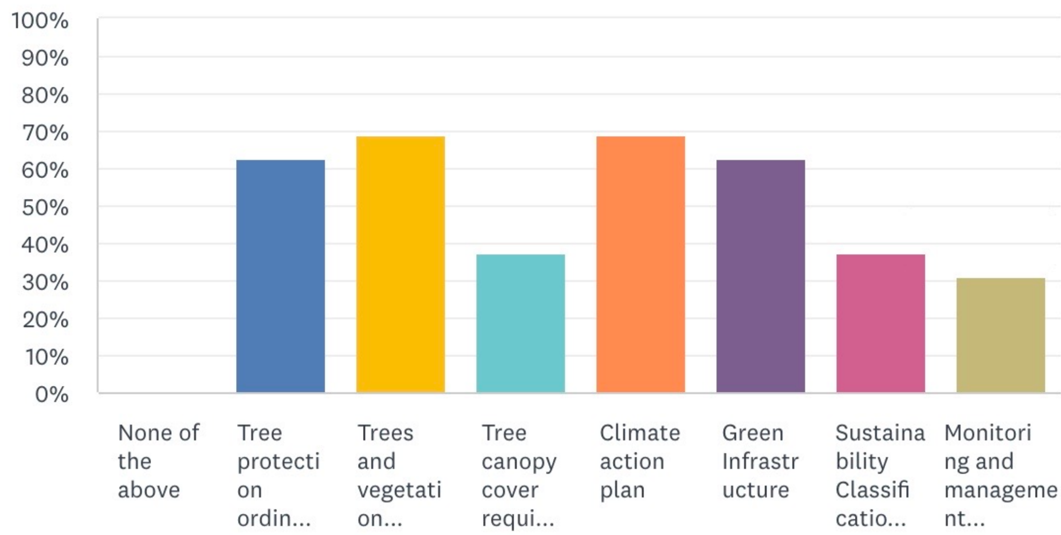

Figure 4.4 Survey question 5. Additional choices added by respondents include other programs such as Get a Street Tree Program, Green Roof Construction Bonus, Green Street Infrastructure programs through the Water Department (bioswales, porous pavements, efforts to reduce street runoff).

Question 6: The policies and programs using trees to manage urban heat island are actively implemented and enforced in your city (figure 4.5). While having the policies and programs in place at the municipal level is important, application and enforcement of these are imperative for success. Question 6 looked to understand the satisfaction respondents held for the way their city implements and enforces the policies and programs related to UHI. Most of the respondents agree or strongly agree that their location was active in implementing and enforcing the programs and policies that used urban trees. This step is essential in meeting UHI goals.

Question 6: The policies and programs using trees to manage urban heat island are actively implemented and enforced in your city.

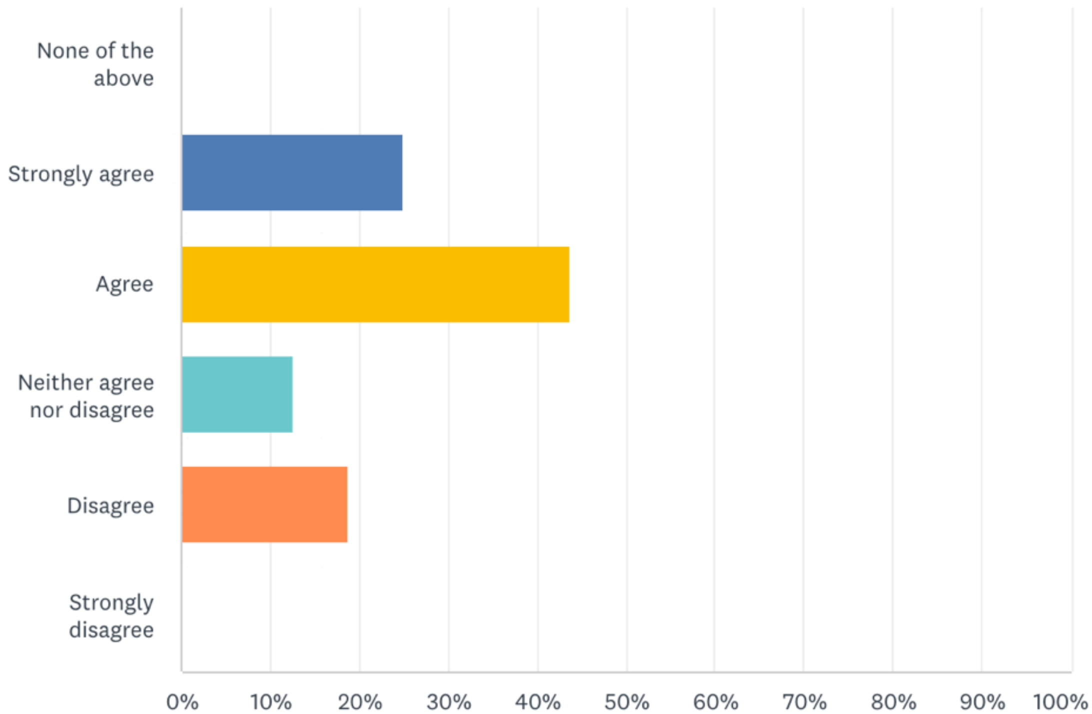

Figure 4.5 Survey question 6. Enforcement of the policies and programs using trees to manage UHI.

Question 7: Results from the implementation of policies and programs using trees to reduce urban heat island are measured and monitored. As mentioned earlier, the survival of the plant materials is essential to the success of any programs and policies that use vegetation to achieve the desired results. This requires that plants be monitored for health and growth. Replacement numbers on projects hover near 10 % in the first two years. However, while policies may say that monitoring and replacement of plant materials is required, few municipalities have the staff available to perform and enforce this. In a webinar entitled *City of Trees* from the national ASLA conference in San Diego (Klemic, van Doorn & Short, 2022), replacement funds, plans and implementation are seldom accounted for. The results for this question were encouraging.

While the data for tree monitoring suggests that it is done in many cases, this is less apparent in monitoring UHI itself. Question 7 (Figure 4.6) addresses the measuring and monitoring of urban heat island within each city. Of the 16 respondents, 3 strongly disagreed and 3 disagreed that UHI was measured and monitored in their city, while 2 neither agreed nor disagreed. Another 3 somewhat agreed while 4 agreed. The responses to this question suggest that the requirement to track the results of implementing policies and programs for using vegetation to reduce UHI is not included in the text, the desire to collect and maintain this information is not expressed or that an awareness of the need for the information might not be understood.

Question 7: Results from the implementation of policies and programs using trees to reduce urban heat island are measured and monitored.

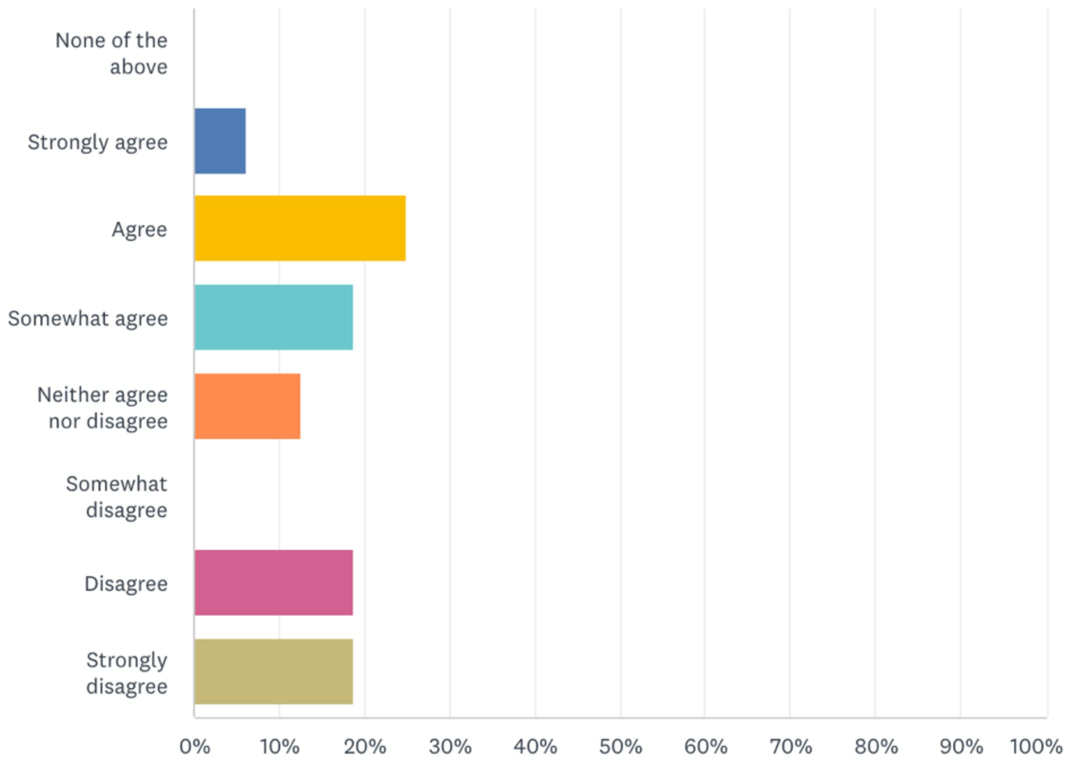

Figure 4.6 Survey question 7. Measuring and monitoring UHI.

Question 8: My city believes monitoring tree canopy cover is vital to the city's long-term health. Continuing along the lines of monitoring vegetation, this question refers specifically to tree canopy cover (figure 4.7). Canopy cover reflects the health and age of trees within the city. Young and stressed trees have thin, smaller canopies while older and healthier trees have denser and fuller canopies. One caveat to this is that different tree species do have different densities of foliage which could impact the canopy cover of an area. For example, a Honey Locust tree has a light and airy, deciduous leaf canopy, while a Live Oak has a much denser and in most of its range, evergreen canopy. Most respondents strongly agreed (5) or agreed (9) with this statement. One neither agreed nor disagreed and only one strongly disagreed. This question is seeking to find what the prevailing mood toward monitoring of trees is and could reflect either disagreement that monitoring itself is important or that it is not a priority to the city given other demands.

Question 8: My city believes monitoring tree canopy cover is vital to the city's long-term health.

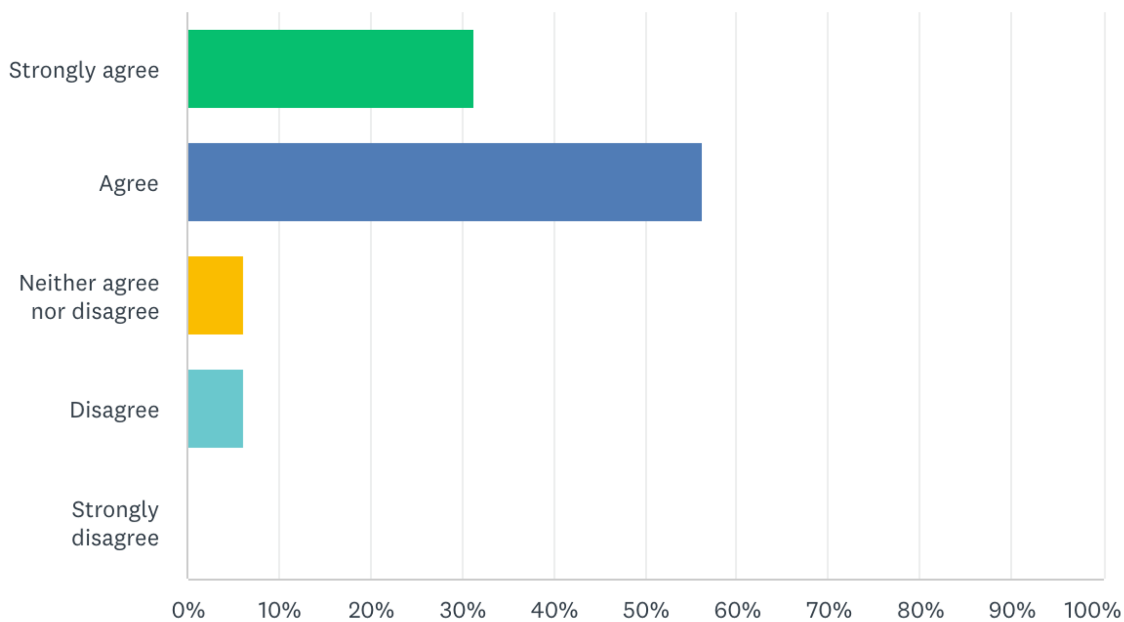

Figure 4.7 Survey question 8. Monitoring tree canopy cover.

From this question, it appears that most cities do believe that it is important to monitor the health and size of the tree canopy cover. Further questions are needed to determine if these cities allocate resources toward maintaining existing and new tree canopy cover.

Question 9: Long-term tree care is part of the city's policies and programs to use trees to reduce urban heat island. After learning in question 8 that most respondents believe their city considers the monitoring of tree canopy cover is vital, here the question seeks to discover if these cities include tree care in their requirements or through various programs. The responses here are varied (figure 4.8). None of the above, neither agreed nor disagree and strongly disagree each had one respondent. Strongly agree and disagree each had 2 respondents and the remaining 9 responses agreed. While monitoring tree health is important to these cities, results show that most cities do have policies or programs that address tree care (11 agree or strongly agree).

Question 9: Long-term tree care is part of the city's policies and programs to use trees to reduce urban heat island.

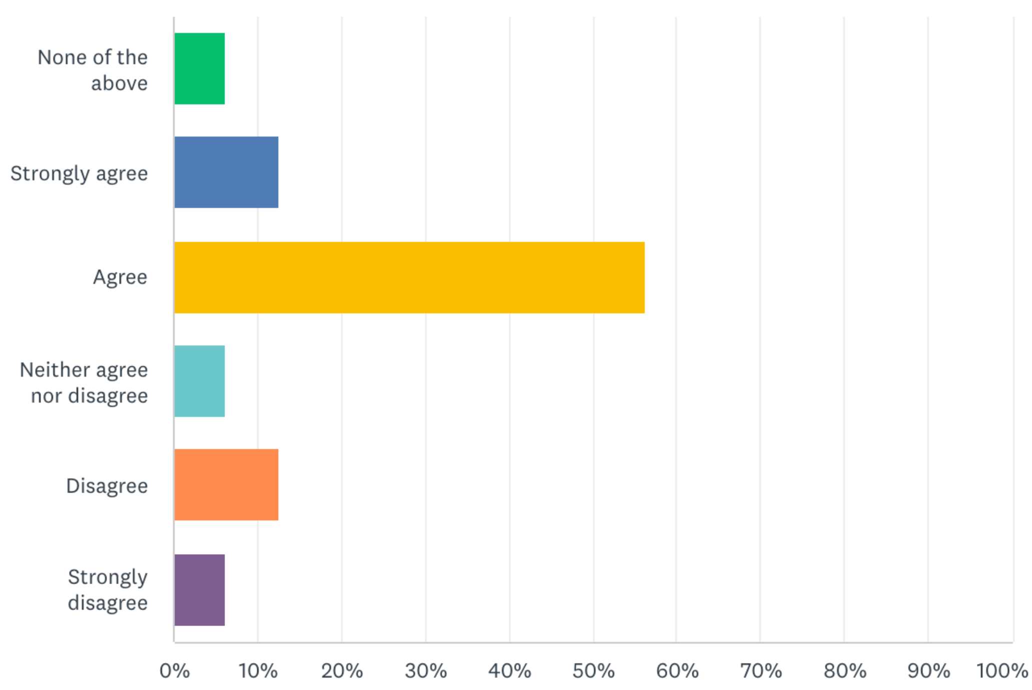

Figure 4.8 Survey question 9. Long-term tree care

Question 10: My city believes Public-Private partnerships are essential to the success of tree planting initiatives. This question addresses the role of partnerships in the effort to plant and care for more trees (figure 4.9). Of the respondents, 8 agree, 4 strongly agree that public-private partnerships are essential, while 2 neither agree nor disagree and 2 disagree. The 8 agreeable responses show that city governments rely on partnerships to assist with tree planting initiatives. Further research would reveal how these partnerships assist, but financial and personnel considerations as well as expertise and leadership are all possibilities.

Question 10: My city believes Public-Private partnerships are essential to the success of tree planting initiatives.

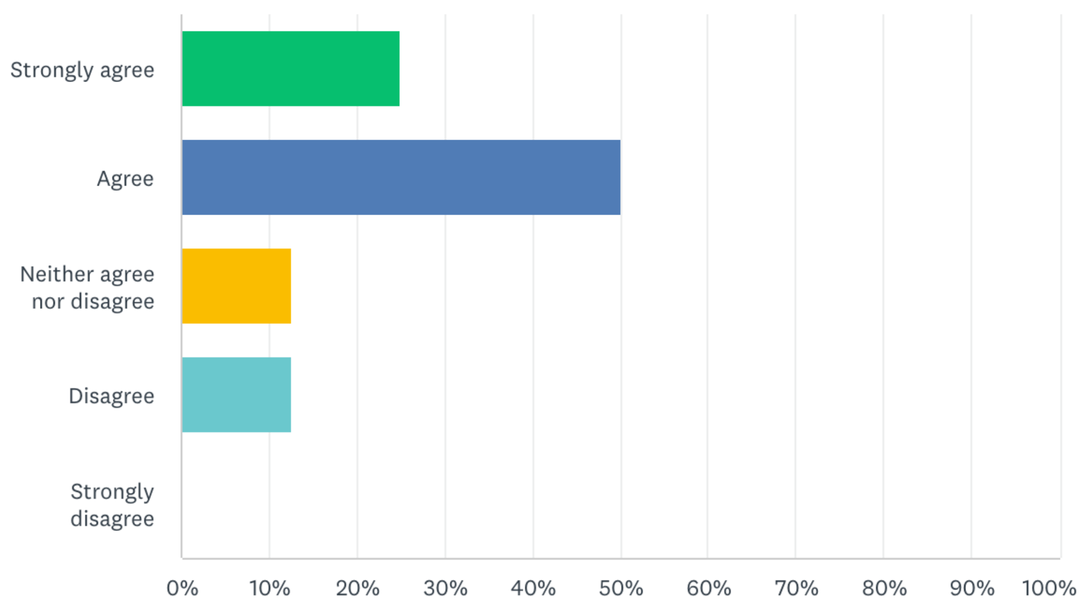

Figure 4.9 Survey question 10. Use of private-public partnerships.

Question 11: Within my city, funding for new tree planting, care, and replacement is adequate. Funding policies and programs can be a challenge for many cities, and budgets reflect what the city leaders value and see as most important. None of the respondents selected strongly agree, however 6 did agree. Of the remaining, 3 neither agreed nor disagreed, 5 disagreed and 2 strongly disagreed. These responses are heavier on the disagree side which suggests that not enough funding is directed toward tree planting initiatives. It shows that these initiatives are valuable to the respondents who felt more money could be allocated toward tree planting than currently is available. This may also offer insight as to why public-private partnerships in question 10 were considered essential to tree planting initiatives.

Question 11: Within my city, funding for new tree planting, care, and replacement is adequate.

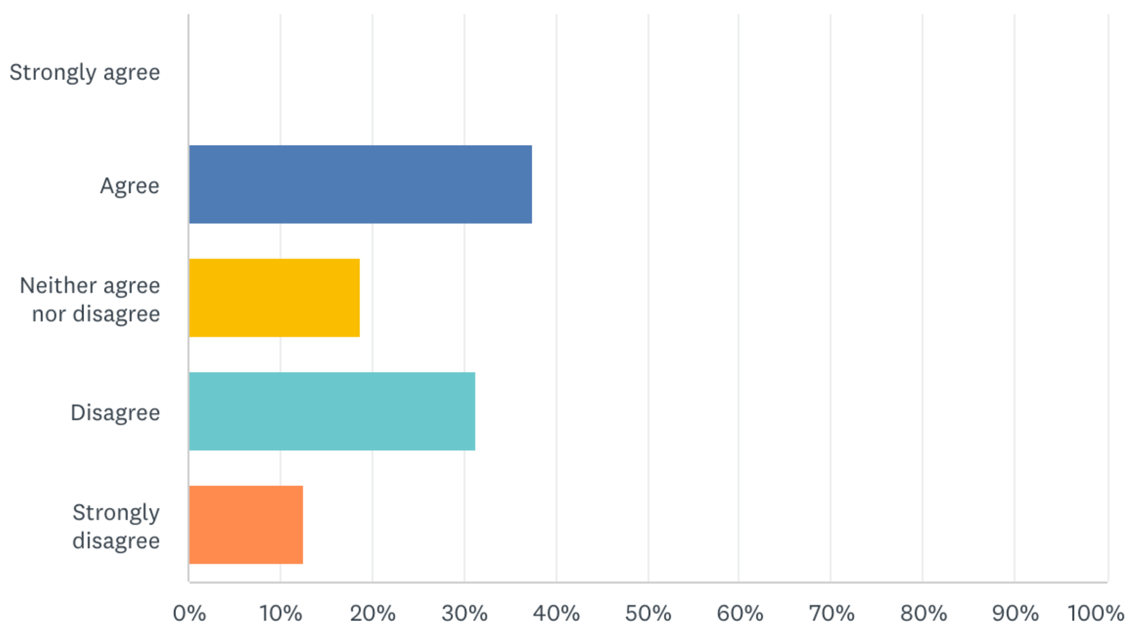

Figure 4.10 Survey question 11. Adequate funding for tree initiatives.

Question 12: Within my city, tree canopy cover is equal across all neighborhoods. Urban heat island does not hit all areas of a city equally. In areas with high density of impervious areas, the heat is greater (Li et al., 2018)). These areas may be commercial or industrial areas, high density housing, mixed use, new development, or simply neglected areas within the city. Often the less advantaged neighborhoods feel the effects of UHI phenomenon the greatest. Question 12 seeks to understand if the city leadership feels that there is equity of tree cover in all areas of the city (figure 4.11). Based on the responses, only 1 city felt that tree canopy cover was equally dispersed across the city. The remaining respondents disagreed (9) or strongly disagreed (5) with this statement. Future research would be able to follow up on this question, determining what efforts are in place and how they might be improved, but for this paper, the implication is that any policies or programs selected should address the equality of tree canopy cover across all neighborhoods.

Question 12: Within my city, tree canopy cover is equal across all neighborhoods. Urban heat island does not hit all areas of a city equally.

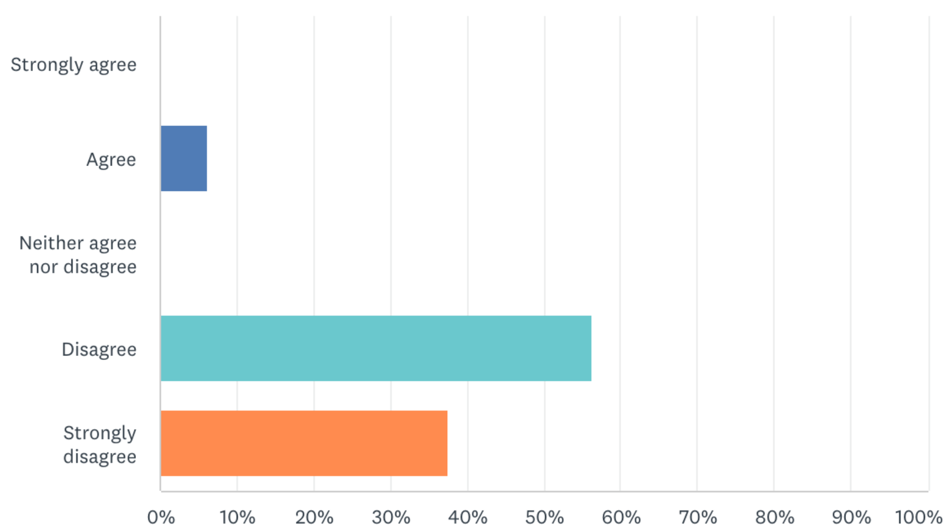

Figure 4.11 Survey question 12. Equality of tree canopy cover.

Question 13: My city considers tree planting in underplanted areas to be a priority. This expands question 12 to ask if priority is given to areas within the city that are underplanted. This could involve the allocation of more funding, more requirements of future development, stricter enforcement, addressing age and decline in canopy cover. Responses (figure 4.12) show 3 strongly agree, 7 agree, 4 neither agree nor disagree, and 2 disagree. Overall, most of the respondents agree with this statement, and show that the cities are placing priority on areas that need more tree cover. Those in disagreement may already have programs in place or may have other areas of priority that need attention. This is another area for future research.

Question 13: My city considers tree planting in underplanted areas to be a priority.

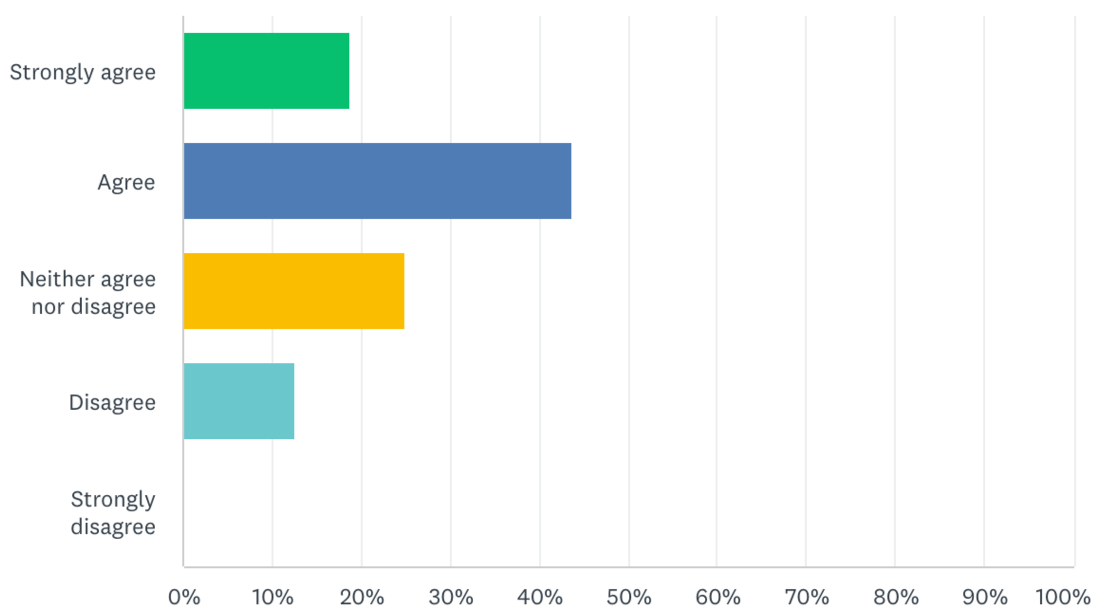

Figure 4.12 Survey question 13. Priority tree planting in underplanted areas.

Question 14: Tree regulation and care are part of the planning department's responsibility. Every city has their own unique way of governing and where tree care falls is one of those areas that can be covered under many different departments. Since the planning depart is where the policies and programs for planting requirements are often housed, it would be interesting to see if planning departments were equally responsible for the overseeing of care and maintenance of trees. Figure 4.13 shows 2 strongly agree, 2 agree, 6 disagree, 1 strongly disagrees and 5 responded with other. Responses to "other" reply that the department of Parks and Recreation, combined Parks and Recreation with Planning department or the Office of Sustainability under Public Works. Urban Forestry is included in one comment as being "heavily involved", and another response mentions that tree regulation and changes are handled with other departments and experts.

Question 14: Tree regulation and care are part of the planning department's responsibility.

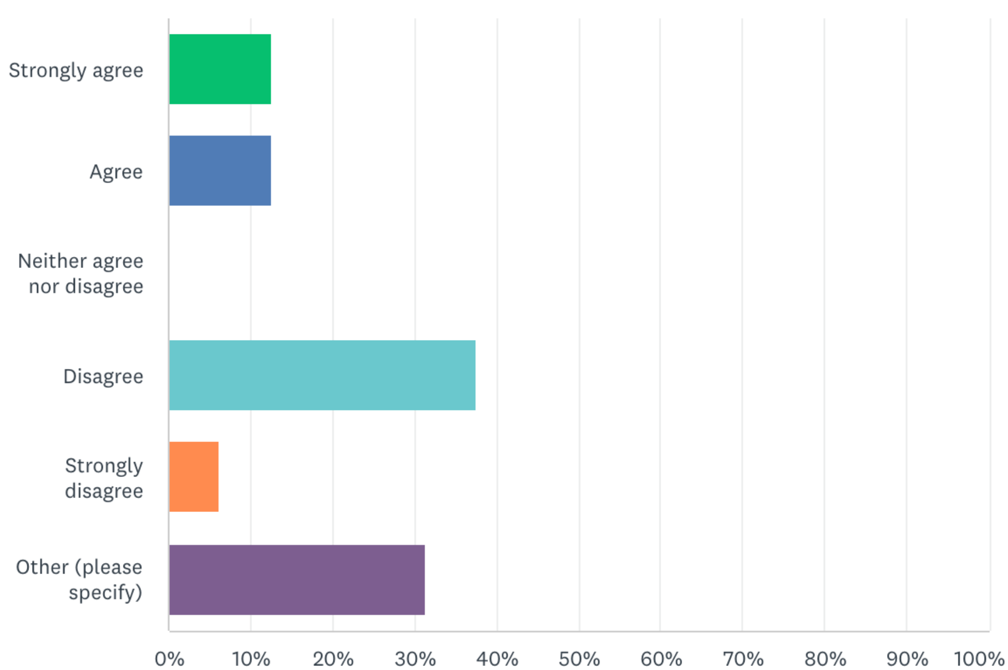

Figure 4.13 Survey question 14. Responsibility for tree regulation and care.

Question 15: In which region of the United States are you located? This question is placed here to end the multiple-choice questions and move to individual input questions and to see which regions are best represented by this survey. Survey results were constrained by the small number of respondents (16) despite reaching a 32% response rate. The respondents represented six out of the nine regions of the United States. Since UHI is influenced by the hours of sunlight, wind, rain, elevation and type of vegetation, it is useful to see where the respondents were located. Each of the different regions may benefit from different approaches to managing UHI. The majority of responses came from the Mountain area (5), with South Atlantic (4) a close second. Pacific, West North Central, and East North Central had 2 respondents each and only one respondent was from the Middle Atlantic area. North Carolina falls into the South Atlantic region along with 25% of respondents. This shows that the region of the country Charlotte, NC is located in is represented in this survey.

Question 15: In which region of the United States are you located?

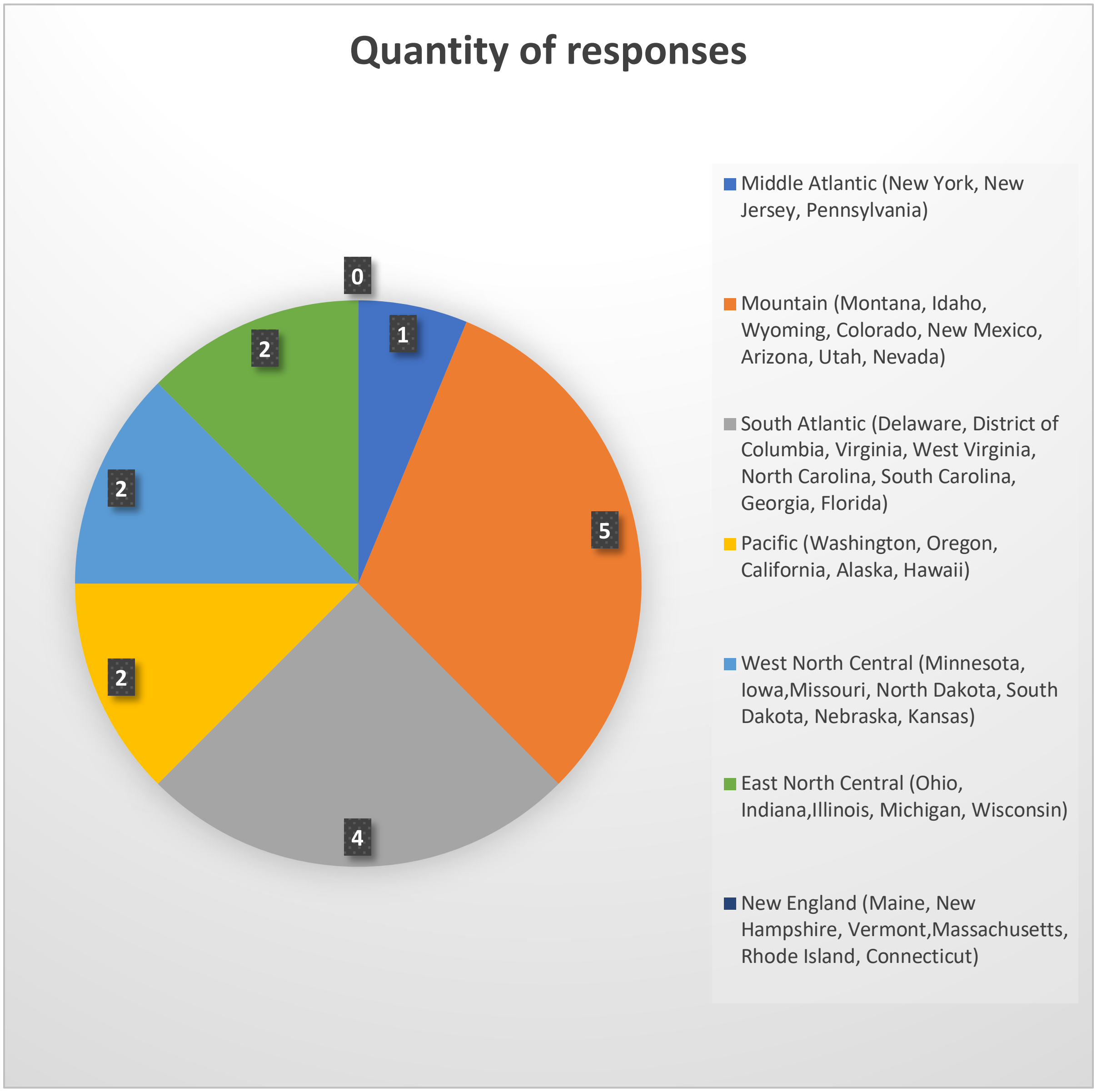

Figure 4.14 Survey question 15. Regions represented by respondents.

Survey questions transitioned to direct responses from individuals to ascertain their opinions and experiences related to UHI. The responses from questions 16-18 follow.

Question 16: What changes would most improve your city's policies on urban heat island? (Showing 15 responses received):

1. Need to stop worrying about having adequate space to plant trees and just plant them. Everywhere.
2. Additional funding add staff available to support tree maintenance.
3. Adequately funding programs aimed at increasing tree canopy and maintaining and protecting existing canopy.
4. The implementation of monitoring and measuring our tree planting. An introduction of a more strategic tree planting guide with funding. Development of green infrastructure programs and policies.
5. Continued funding for the programs that are already in place. More work redeveloping and maintaining smaller parks in disadvantaged neighborhoods.
6. Wider medians and ROW strips, suitable for tree planting. Requirement for in ground infrastructure, such as Silva Cells for tree plantings in areas where wide strips cannot be accommodated.
7. Enacting policies (and monitoring progress) specifically to address heat islands and not just adding heat islands to the climate plan and urban forest master plan.
8. Increasing the trees per lot policy, stronger tree mitigation policies,
9. Prohibiting removal of, or fatal damage to, high value trees for providing long term, effective canopy cover.
10. Actually funding and implementing those plans that address UHI.

11. Codifying tree requirements, including those that have penalties for non-compliance. An enforcement mechanism would also be useful to have.
12. Follow up after installation.
13. Stronger enforcement of private landowners letting trees die or removing shade structures after the permitting process closes.
14. Additional awareness of target areas and potential mitigation solutions specific to each Department's area of expertise.
15. Update the current tree protection ordinance to increase protection of existing tree canopy, planting trees, increase the average tree canopy to 50%, and removing invasive exotic species.

The main thrust of these responses to question 16 is that we need more tree planting, anywhere we can do it. Wider medians and right of ways for tree planting, more trees required for new approvals, improving parks and addressing lack of equity in tree planting. Along with this is the need to protect existing trees, to follow up, and to enforce the planting and protection requirements. This leads directly the next largest concern, funding and staff to plant trees, maintain trees, monitor and enforce requirements. Adding specific policies to address UHI rather than including it in Climate actions plans or as an additional benefit of other programs and including in-ground infrastructure to support tree health and trees as a greater part of green infrastructure requirements.

Question 17: In your experience, what types of programs and policies work best to address urban heat island? (Showing 14 responses as received):

1. Policies that encourage and streamline the process of tree planting and maintenance, and that involve both City staff and partnerships with outside organizations.
2. A combination of reducing pollution and increasing tree canopy.
3. All of the above.
4. Green Roof program, Solar Panel program, LEED Green Building bonus is new but has a lot of potential as more projects take advantage of the construction bonus.
5. Public private partnerships to promote the planting of trees on private property. In most cities public tree plantings are not enough to meaningfully combat urban heat islands. The most successful programs I have seen involve partnerships between cities, non-profits, and local retailers to promote private tree plantings. This, coupled with robust protections and support for public trees is the gold standard in my opinion.
6. Tree planting and other methods of shade cover (green roofs on bus stops and solar shade structures over parking areas) seem to be the easiest to implement and have the most research behind them.
7. Tree coverage policies related directly to the impervious area.
8. An approach to tree coverage that allows for a more comprehensive review of treed landscapes.
9. Urban Forest Master plan...with tree preservation ordinance.
10. Trees/vegetation - provided they are drought/heat tolerant or otherwise compatible with the location/region they are planted. Cool pavements Monitoring and management program C-PACE funding for resilience (includes financing for UHI projects)
11. We only have one, the ordinance for trees required in parking areas.

12. Solution driven programs that the city spearheads. Tree planting, built shade requirements, construction requirements, ground material programs.
13. Long term solutions built on collaboration with City stakeholders and especially residents within areas of concern.
14. Tree Protection Ordinance. Implementing recommendations from the City Design and Urban Ecology Framework

Tree protection and preservation is key here along with more city led or city/private partnership relationships to plant and maintain trees. Many of the comments also include selection of the right tree for the right location, looking at tree canopy cover over all and including programs to encourage planting on private property as well as public lands. Partnerships with non-profits as well as businesses can address both private and public locations to increase canopy cover.

Question 18: In your experience, how are the successes of these programs and policies measured? (Showing 12 responses as received):

1. Our urban foresters have a system in place to measure and monitor the status of the City's tree canopy.
2. They are not here.
3. Quantitatively and qualitatively in reports...Such as the Greenworks report released by the Philadelphia Office of Sustainability
4. Measuring the success of these programs can be difficult because canopy cover usually grows and shrinks slowly over time. I think it is essential to continually update Tree

Canopy Assessments in no greater than 10-year increments. Other metrics can help indicate success such as tree replacement proportions for new developments, public tree removal and replacement rates, and urban forest composition statistics (especially proportions of class and age of trees).

5. Kansas City is supposed to be measuring and monitoring tree canopy improvements. This program is housed under the Forestry Division of our Parks and Rec Department, which is underfunded and understaffed. The main way success is measured is by our non-profit partner, Heartland Tree Alliance, and research conducted by various universities in the area. The city needs to increase its involvement in the process.
6. Spreadsheets due at the time of building permit submittal and then inspected against during inspection.
7. We keep track of overall tree canopy lost or gained on a lot-by-lot development basis. Our city goal is to attain 40% of tree canopy coverage.
8. Monitoring of the UHI over time in correlation to percent tree canopy.
9. Implementation strategies, including those identified in our Master Plan (https://files.lasvegasnevada.gov/planning/CLV-2050-Master-Plan.pdf)
10. Not very successful
11. The city is working to measure tree canopy better, through LIDAR survey. The measurement of successes of other programs is minimal.
12. Three tree canopy studies have been done, 2009, 2014, and 2018. Measuring the tree canopy overall and analyzing where the loss is occurring, where it's gaining. The study gets down to neighborhoods and watersheds level, as well as council districts.

These responses show hopefulness as well as discouragement. Respondents recognize the importance of monitoring both tree canopy and urban temperatures, but also recognize that tree growth is a slow process and must be conducted over long periods of time. Using tree canopy assessments, LiDAR, tracking tree survival on a lot by lot or project by project level and relying on permit approvals as well as partnerships to help with identification and enforcement.

4.5 Conclusions and Implications:

This research reveals that trees are seen by cities to manage and reduce urban heat island. Cities believe trees can provide many benefits and believe that tree protection ordinances with enforcement and fines are an essential way to preserve and protect tree canopy cover. Increasing tree planting requirements and locations, specifying appropriate plant materials that ensure the right plant in the right place, monitoring, maintenance and replacement of lost trees, and community awareness, support and partnerships are viewed as the most effect means of improving tree canopy and managing urban heat island. Funding of staff and programs to add trees to public and private properties are challenges and can be helped through public-private partnerships that increase eyes on the health of the trees, aid in planting, expenses in obtaining the trees and selecting appropriate species. Many cities found that having the tree maintenance and care under city direction improved outcomes. To this end, adding language specific to managing urban heat island with tree cover and policies directed at reducing urban heat island will be helpful.

Several comments in the survey deserve additional attention. Using sustainability and energy saving programs such as GBCI Energy Star, LEED certifications and SITES AP certification would increase better land and vegetation management, reduce pollution and reduce energy and heat creation within cities. These certifications also aid cities by completing some of the documentation and monitoring that is needed but requires more staff. Tree Canopy Assessments are also mentioned as a useful tool for monitoring tree health and growth. Frequent assessments (every 5-10 years) would provide more data on tree health, growth and equity across the city property, and should be included in master planning. Finally, city construction details for streetscapes and plazas were only mentioned in comments from Boise, ID, although cities should consider the in-ground infrastructure that supports healthy tree growth. Sub-surface planting cells, room for irrigation and utility lines, proper drainage, and guides for tree root growth are upfront design considerations that could significantly improve the health, growth rate and longevity of trees, reduce water usage for irrigations and connect to green infrastructure systems that improve surface water runoff, pollution, biodiversity and habitat.

Looking at the results of HHS in chapter 2, five locations had positive scores, showing that the urban area was either cooler in relation to the suburban or rural, or that the urban area had greater tree cover. These were Richmond, VA in the first location of Forest Park Cemetery and Indianapolis, IN, both in the rural locations HHS. In the suburban locations, Boise, ID, Philadelphia, PA, and Louisville, KY also positive HHS.

Boise, ID had the highest HHS in the suburban areas, a score of 66.67. Comments from the survey show a strong understanding of tree physiology, requiring larger medians, using structural cells to support root growth, measures to monitor tree plantings and maintain the new plantings are clearly important. Their Tree Protection Ordinance addresses heat island effect by requiring trees to be planted near hard surfaces to shade roads, driveways, roofs. Public-private partnerships like the City of Trees Challenge and the “It’s getting hot” initiative are used to support the funding of tree plantings, including private citizens, business and the city. "The most successful programs I have seen involve partnerships between cities, non-profits, and local retailers to promote private tree plantings. This, coupled with robust protections and support for public trees is the gold standard in my opinion," (Boise, ID 1 Survey response, 2022).

Philadelphia, PA had a heat health score of 33.33 in the suburban area. Responses to the survey from the Philadelphia planning department reference green infrastructure, multiple tree programs like Get a Street Tree Program and community involvement through the Greenworks program. Green roofs, LEED Green Building bonus for developers and focus on smaller green spaces in disadvantaged neighborhoods are also mentioned. Philadelphia's Office of Sustainability publishes quantitative and qualitative reports on the state of the trees, and efforts are underway to create greater equality in access to green spaces. Philadelphia has a goal of providing all residents access to a park within ½ mile of home by 2025.

Louisville, KY scored a 4 for heat health in the suburban area. They use pollution reduction methods as well as trees and shrub requirements and green infrastructure. No comments were left in questions 16-18. Research through their website and ACEEE show private lands remain the greatest source of improvement and growth in urban tree canopy. 12% of Louisville study area is considered heat stressed- these areas are predominantly impervious areas or bare soil. Hot spots are identified through impervious area to canopy ratio and through surface temperature measurements. Urban Tree Canopy Assessment has set a goal to reach 45% urban tree cover through land development codes. Currently, Louisville has 37% tree canopy cover, mostly in protected parks. A loss of 54000 tree per year is estimated due to Emerald Ash Borer (EAB), one of the pests that is decimating specific species of trees. Maintenance and protection of trees essential as Louisville is in the top 10 cities of growing UHI in country (Louisville Tree Canopy Assessment, 2015).

In the urban to rural HHS, Indianapolis scored a 2.33. Their planning department stated the use of tree protection, tree and vegetative requirements, green infrastructure, sustainability classifications and monitoring and management of the tree canopy. They also did not respond to questions 16-18. Additional research shows Thrive Indianapolis program to focus on climate resilience and community sustainability. Indianapolis has experienced 2.2º F increase in temperature with 2-4 days over 95º F in 2018, but they are predicting summer temperature increases of 3-9º F and 10-15 days over 95ºF in 2050. Action goals under Natural Resources include using native plants, maintaining parks and open spaces, planting 30,000 additional native tree species by 2025 to increase canopy, reduce runoff and mitigate UHI. Current tree canopy ranges from 3-78% coverage by neighborhoods (ThriveIndianapolis, 2019).

Richmond, VA experienced the highest HHS in the rural location, with a score of 200 that reflected lower temperatures and almost equal tree cover in the urban site. The rural location had high grass/herbaceous cover, almost equally low tree cover and high impervious cover, these attributes explaining the higher HHS for the urban location. In chapter 3, a second rural location was selected, and this area, Stony Point, had very high tree/shrub cover, which reduced the HHS to 0. This score still reflects a healthy urban location. Richmond responded that tree and vegetation requirements, tree canopy cover requirements and climate action plans were used to manage UHI. Through Climate Action and Climate Resilience plans, Richmond addresses ways to reduce impacts from UHI, by planting trees, green roof, creating and maintaining green space, using permeable surfaces to reduce heat. COVID-19 increased awareness of which communities are most vulnerable, and priority has been placed on these areas. The Urban Forestry Division, Capital Trees, Richmond 300 planning process all recognize and address UHI. Greenways and parks are key pieces to reduce UHI. Urban Forestry Division prunes and maintains existing trees, removes dead trees, manages permits, canopy analysis, tree inventory mapping.

What makes these locations different? Many of the cities in the ACEEE database as well as the survey used in this paper use the same types of programs and policies. What sets these cities apart are strong public-private partnerships that build community support and supplement city budgets, seek greater dispersal of green spaces and with that equity in access to green space. Monitoring tree health and tree care as well as an approach that recognizes plant physiology also give these locations a stronger heat health score. They include wider medians, structural root supports, awareness of diseases and the importance of species selection, and most of all, heavy focus on just planting more trees.

Charlotte did not complete this survey, however a review of their website and personal experience over the last 20+ years as a landscape architect in the Charlotte-Mecklenburg County metro area reveals much information about Charlotte. Charlotte has a tree protection ordinance, vegetation requirements for buffers, parking lots and street right of ways as well as a tree ordinance for street tree planting requirements.

This is very much in line with what the ACEEE cities have. Like the results of the survey, Charlotte uses these multiple ordinances to support the use of vegetation for the beautification of the city, to reduce runoff and erosion, to shade and cool and to buffer uses. When this research began in 2017, Charlotte was in the early stages of creating a Unified Development Ordinance (UDO), designed to update other ordinances for development and locate all information into a single document that would allow for easier access to the codes that influence development in this area. Since that time, extensive community input has been received, drafts and revisions were created, and the City Council voted and approved the UDO which went into effect June 1, 2023. In the UDO, Charlotte includes tree protection, does mention green infrastructure, LEED and GBCI programs to obtain credits for density or other development bonuses. UHI is not mentioned although heat, shading, and cooling are. Charlotte also has public-private partnership with TreesCharlotte, Sustain Charlotte and Envision Charlotte that are addressing climate impacts through tree plantings, community involvement, energy efficiency and work with community leaders.

As with each city, there are specific challenges for Charlotte as urban heat island becomes a greater issue. There is high pressure from massive growth, with new developments using green fields and sprawling into rural lands. While once a goal of 50% tree cover seemed feasible, the current situation of growth has caused TreesCharlotte and Charlotte-Mecklenburg County to step away from that goal. Additionally, while urban infill is strongly encouraged to increase density and reduce sprawl, many of these projects fall under the 1 acre in size cut off for plans that must be submitted to the City of Charlotte for erosion control, tree save areas, park and open space requirements and buffer and landscape requirements. This is adding an additional layer of threats to the urban environment because of unmonitored tree canopy loss.

Right now, tree monitoring and maintenance of street trees by the city departments may help to preserve and protect the current canopy of 43% tree cover. Many private citizens cannot afford the cost of maintaining large maturing trees and so choose not to plant more or replace lost ones (Shoemaker, 2021). Policies that address the physiological needs of trees for root growth, drainage, reduced compaction of soil, removal of dead and diseased limbs and planning corridors for tree planting and growth are tools that the planning department can use. Active attention to the aging trees and pest issues are vital, as well as increasing equitable access to green spaces across the city. A shift from current language that uses tree spacing by language that introduces tree canopy cover area to new developments has worked for Boise, ID and should be considered as a metric for Charlotte. Community awareness on the value of trees, the role they can play in revitalizing the canopy of Charlotte, and the dangers of UHI will also strengthen the support for more trees. Existing residential lots are at risk of losing more trees through age, pests, aesthetics for homeowners and subdividing lots for urban infill. For this reason, community outreach and education on the importance of maintaining and replacing trees will be key.

There are additional opportunities to bring more trees into the urban spaces that have potential to make a difference in the resilience of urban spaces like Charlotte's. Smart growth principles include mixed use, walkable distances to parks, amenities and for transportation that can be an opportunity for green corridors to shade and cool. Greening public right of ways means that the city is responsible for the installation and upkeep which might increase the publics willingness to have street trees along their properties. Cool corridors would also create visually appealing spaces that attract more people to walk, scooter and bike rather than drive, reducing emissions that add to UHI. Using smart growth means cities like Charlotte can use creative urban site planning to make the city more sustainable and address UHI.

In other areas of the world, urban forestry principles are used to establish micro forests in small areas. Known as the Miyawaki Method, public lands, corridors, streetscape edges abandoned lots and micro parks are planted heavily with native species of plants and allowed to grow "naturally" (https://urban-forests.com/miyawaki-method/). Using a diversity of species, native to the area, these plants can thrive in the soil and climate conditions they are adapted for, and in addition, they provide increased biodiversity which increases the ecosystem services so often lacking in urban spaces.

Vacant lots and public lands can also be used for urban agriculture. Raised beds for planting small scale agriculture can provide more UES as well as address food scarcity, but also provide the city an opportunity to plant fruit and nut trees along edges of these areas. This is an opportunity for greater public-private connections, community groups and involvement to improve UES for all.

In highly developed areas with large areas of impervious surfaces that do not have room for more trees, large planters, green walls, green roofs and GI principles can be used. Large containers with trees can even be brought in to provide "instant" shade at bus stops, crossings, plazas and spaces that would not be able to support new tree plantings otherwise.

Monitoring and maintaining these trees remain essential, and can be helped through public interaction via apps, community scientists, schools- from primary to university levels and community programs. Signage on trees to show their value to communities as UES but also their replacement values, their impact on improving the climate and reducing heat would help educate the public and bring awareness to the services these trees provide. The planning department is a natural place to house tree oversight since the planning department reviews and approves plans for growth and development, especially in smaller cities that do not have many resources in their departments. In larger cities, this work can be shared with other departments such as park and recreation, sustainability, climate action or urban forestry. This means following up to make sure trees were planted, planted correctly, survive their early years when they are most at risk, maintained for proper growth and to reduce hazards and safety issues, and finally checked for long term survival and replacement when needed.

For any city, this is a major undertaking but is also why naming UHI as a serious issue needs to become part of the mission of cities everywhere. There is a monetary cost to this that remains an issue. It can be passed on the developers, but this will raise the costs passed on to the community, can be part of the annual budget but would require other programs losing funding or higher taxes, or could enlist community partners to help with the work, and economic incentives for homeowners and businesses might help encourage this assistance. Funding and economic implications to these programs and changes should be researched in future work.

Take Aways for Charlotte:

- First and foremost, protect the existing tree canopy. Whether it is new development or aging streetscapes, trees provide important functions through urban ecosystem services.
- Tree canopy loss is a non-transferrable resource.
- Once the large trees are lost, it will take decades to replace them and the UES they perform. This makes tree preservation vital to preserve heritage and large canopy trees.
- Urban infill of projects under the 1-acre size must be required to preserve Heritage and large canopy trees. Replacement values should be posted at the site and fines enforced.
- Tree protection areas and carefully considered new tree planting can create an ecologically significant impact to the regional and even national climate challenges.

- UHI is increased when older trees are replaced with younger trees. This requires years before the trees can manage UHI. Awareness of the benefits of trees extends to developers and homeowners alike, and preservation is the best method of maintaining lower temperatures on a site.
- Tree replacement numbers are highest in the under 3" caliper at breast height category (Roman, 2014), so providing premium growing conditions, selecting the correct species, monitoring tree health and maintaining trees over time is essential.
- Require diversity of plant species and work with local plant nurseries to source and grow native species for availability.
- Use Smart Growth and creative urban planning principles.
- Create green corridors for walking, biking and alternative transportation to form connectivity between uses. Build this into the requirements.
- Establish micro-forests on any land available.
- Use trees that provide food sources for people and animals. This means fruit and nut trees, especially in areas where community urban farming can be encouraged.
- Green impervious areas with large planters housing trees for "instant forests" and add green walls, green roofs and non turf plantings where possible.
- Add signage, QR codes, tags to trees along public areas to educate the public on the value of trees, both in terms of cost to plant and maintain as well as for the UES they provide.
- Involve the community in planting, maintaining and monitoring trees.

- Use the planning department as the leader for monitoring and enforcement of tree regulations, but allow other departments like sustainability, climate action, urban forestry and parks and recreation to take on some of the burden in terms of staff, programming and funding to support this effort.

Urban heat island is a growing concern with serious consequences to the health and resilience of cities and the people within them. There are different methods that policy makers and leaders in the communities implement to help reduce and mitigate the raising heat in cities that can include both green and grey solutions. Increasing tree cover is one of the most effective methods, but also requires time and planning. Municipalities should consider first increasing tree preservation and protection. This initial method maintains and increases tree coverage through preserving and maintain what is already in place. The best way to reduce the effects of UHI is protecting old, large trees, and this includes maintaining and monitoring these trees in keep them healthy and thriving. Policies aimed at protecting trees save larger trees, heritage trees and tree-save areas which allow heat to be managed on site, rather than through mitigation of urban heat island through new planting, which takes years of growth to accomplish. For example, a single large maturing tree, with a canopy radius of 20 feet can create a shaded area of over 2500 sf while a newly planted 2-3" caliper tree creates a less significant shade through a 5-foot radius and 157 sf of canopy area. Protection of one large tree is worth more in terms of reducing heat than planting 10 new trees for several years. Additionally, many newly planted trees have lower survival rates, delaying the benefit of cooling shade even more.

Tree protection and preservation are powerful tools in the reduction of UHI caused by the growth and development that many cities are currently experiencing, specifically on the temperatures and heat health of that site. There are common policies which all cities can implement to reduce UHI, but it takes multiple documents to adequately address UHI. Ordinances must be adaptable to the specific location, climate, weather criteria that make each city unique.

With the implementation of the Unified Development Ordinance in Charlotte, there will be some adjustments as practitioners adapt to the new format and changes. Revisions to the initial draft (UDO Second Draft, 2022) have stepped back from some of the initial changes regarding heritage tree removal, allowing payment in lieu for open space requirements that could be used for green spaces and trees to provide ecosystem services including UHI reduction. CharlotteUDO.org (2022) describes some of the changes to the second draft of Charlotte's UDO. For example, the Heritage tree preservation requirements have reduced from the initial requirements (figure 4.15).

Land Development Heritage Tree Protection

Current Regulations	UDO 1ST Draft	Proposed 2nd Draft
Preservation of "Champion Trees" in subdivision permitting	Preservation of Heritage Tree required unless there is no other reasonable location	Removal allowed where there is a demonstrated conflict
No mitigation required	Mitigation required: $1000/ tree removed + 1 tree planted	Mitigation required: $1500/tree removed + 1 tree planted. Each additional tree planted reduces fee by $250 Specimen trees may be preserved in-lieu of submitting mitigation payment
Counts toward tree save. Canopy area counts 1.5x	No incentives for preservation	Green Area (Tree Save) incentive credit. Canopy area of heritage trees counts 2x
	Diseased, dead, dying, or hazardous trees do not require mitigation	Diseased, dead, dying, or hazardous trees do not require mitigation

Land Development: Includes construction of a new principal structure, addition or expansion of built-upon area or building coverage to an existing structure by 5% or 1,000 sq ft., and approval of a new subdivision.

Figure 4.15 Example of revisions to Charlotte UDO. https://charlotteudo.org/wp-content/uploads/2022/06/UDO-2nd-Draft-Key-Changes-Document-V3.pdf

Charlotte and other cities may miss an opportunity to give tree preservation, landscape ordinances and UHI protections more strength when adopting revisions to the initial UDO wording. A great deal of time and effort have been allocated to getting public input on these documents and that does include builders, developers and landowners who have land rights and monetary incentives. Compromise and building the UDO with public input is essential to the process. Future research on the impacts of these changes, especially on if they are enough to move Charlotte forward in climate preparedness and resiliency, is needed.

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Chapter 5 Recommendations and dissertation conclusions:

While each of the previous three chapters achieves their purpose in adding to the arsenal of tools to manage UHI, by combing these works, they can help increase the sustainability and resilience of cities, particularly Charlotte.

First, understanding the value of urban ecosystem services, cities must increase the availability of these services. Chapter 2 demonstrates the role that trees play in the sustainability and resilience of Charlotte, NC. Trees provide needed ecosystem services in each of the categories of these services: provisioning, regulation, supporting and cultural (figure 5.1). One of the vital benefits trees bring is under the category of regulation, is shading and cooling, providing a means of mitigating and preventing urban heat island phenomena. Protecting and increasing tree canopy cover in Charlotte improves the ecosystem services in this urban area.

Chapter 3 builds on the benefits of trees regarding UHI management by using Heat Health Scores to compare the temperature and tree/shrub land cover differences between locations. It is a metric that is easily accessible to the public that evaluates the heat resilience using the urban center as a benchmark and comparing its score to suburban, rural or even different locations within the urban center to determine which areas are in need of more tree canopy cover. Future research should apply HHS to evaluate how changes in tree cover caused by new development or tree damage from pests, age, storms or fire will impact the temperature changes in areas over time.

Land Cover type	Provisioning					Regulation									Supporting			Cultural					
	food production	water supply	Raw materials	medicinal resources	genetic resources	air quality	climate regulation	carbon sequestration	energy effects	waste treatment	Pollination and seed dispersa	water regulation	disturbance regulation	shade/cooling	habitat	biodiversity	nutrient cycling	Aesthetic	Recreational	Human health benefits	Cognitive development	Sense of place	Social cohesion
urban forest	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
public street trees					x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
private trees	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
turf						x		x		x		x	x		x		x	x	x	x		x	x
Bare soil			x														x						
impervious area (roads, walks)									x	x		x	x						x	x			
impervious areas (buildings)									x	x		x	x	x				x	x				
water	x	x			x		x		x	x		x			x	x	x	x	x	x	x	x	x

Figure 5.1 Ecosystem Services (Derkzen 2015; Costanza et al 2014).

Combined, chapters 3 and 4 reinforce the need for appropriate policies and programs within local as well as regional areas to address climate issues such as UHI. A comprehensive review of cities within the United States for effective policies and programs aimed at mitigating and designing for resilience against UHI provides guidelines for other cities such as Charlotte that are in the process of revising their Codes of Ordinances. These are reinforced through the input from on the ground practitioners.

Policies that enforce tree protection and tree save areas offer the best opportunity for saving large canopy trees that keep urban heat down. Tree and shrub replacement in new developments and in areas experiencing tree loss due to age, disease, pests, weather conditions need to reflect more diversity of native species along with the appropriate planting conditions for the region. This includes large tree planting areas with the ability to allow roots to spread away from buildings and walkways, with enough width and depth for the health of the tree species used. The soil should be amended to accommodate the tree planting, with irrigation and/or soil cells to allow moisture and drainage as well as protection from compaction. Instead of turf, ground covers and ecosystem friendly plantings provide habitat and food for pollinators while reducing the use of mowing equipment and fertilizers. Certifications such as SITES and LEED offer guidance on best practices and require monitoring and maintenance. The principles of Right plant, right place will reduce costly errors in plant selection and ensure longevity. Mitigation in situ protects new and vulnerable communities from UHI and the health costs associated with that. In addition, many of the principles of planting to reduce UHI while enhancing resiliency also align with water quality, erosion control, storm water management and air quality best practices. Examples of how a streetscape could be redesigned to improve UES are included in figure 5.2. This keeps the street tree planting and spacing, removing turf and adding ground cover in resilient or native plant materials. Landscapes and ecosystems are living things, and as such they change over time. Monitoring and maintaining these trees and shrubs are essential, and along the public right of ways and lands, should be under the prevue of the city. These employees must also be trained in appropriate techniques, methods and plant care. Where resources are limited, private-public partnerships and connections with community groups and business may help bridge the gap.

Many of the cities listed in ACEEE's directory employ these methods, based on their regional locations. Comments from the city planners support these ideas. However, these methods may not be enough to impact the increasing challenges of UHI. Expanding the tools available to communities and cities will require new methods. Combined they can create strong, more resilient, sustainable and livable cities.

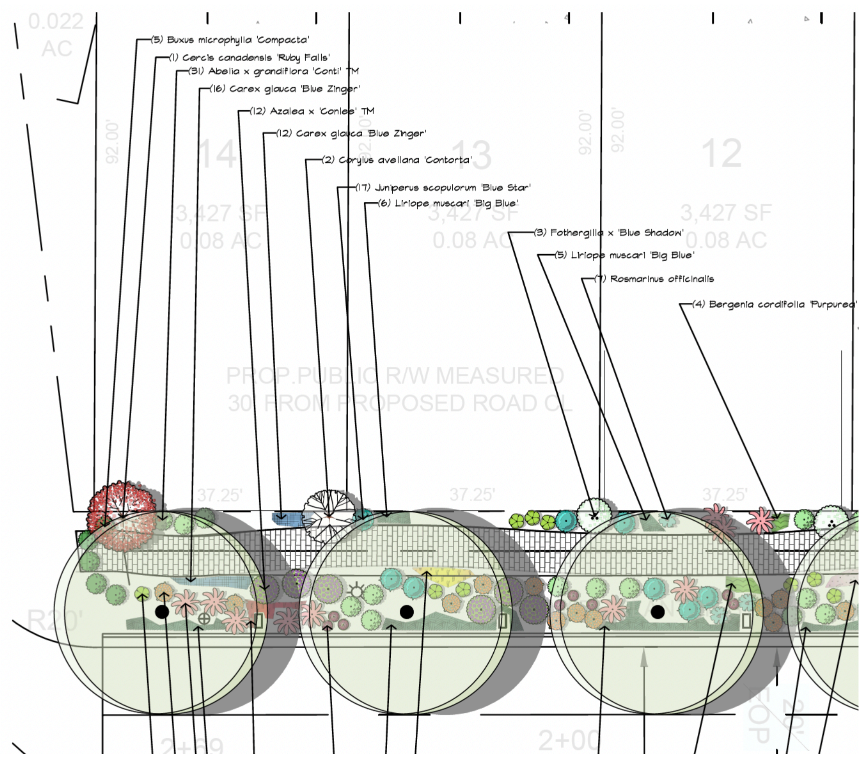

Figure 5.2 Streetscape plan enlarged area for John Marshal Homes neighborhood Davidson Springs. Landscape plan by V. Westendorff utilizing a variety of native and low maintenance plant materials.

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APPENDIX A

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Appendix B

Survey sample

UNIVERSITY OF NORTH CAROLINA CHARLOTTE | THE WILLIAM STATES LEE COLLEGE OF ENGINEERING

Policies and Program to manage urban heat island

Understanding UHI policy and program success rates.

This quick survey is designed to gather data on the implementation, monitoring, and success of different programs and policies that use trees to manage urban heat island effect in cities across the United States of America. It is part of the research for a dissertation by V. Westendorff.

1. What city do you work for?

2. Does your city have policies or programs related to urban heat island (UHI)?

Yes
No
Other (please specify)

1. Are the UHI policies or programs addressed with any of the following methods (check all that apply)

Using pollution reduction methods such as reducing car miles driven, energy efficiency, improved emissions or renewable energy
Using plant materials such as trees, shrubs and green spaces
Using green infrastructure
None of the above

3. Of the policies which the city has implemented, which do you feel are most effective?

Using pollution reduction methods
Using trees
Using green infrastructure
Using a combination of methods
None of the above

4. Which types of programs are used in your city to address urban heat island?

Tree protection ordinance
Trees and vegetation requirements
Tree canopy cover requirements
Climate action plan
Green infrastructure
Sustainability classification (STAR, LEED, SITES, GBCI etc.)
Monitoring and management programs
None of the above

5. The policies and programs using trees to manage urban heat island are actively implemented and enforced in your city.

Strongly agree
Agree
Neither agree nor disagree
Disagree
Strongly disagree

6. Results from the implementation of policies and programs using trees to reduce urban heat island are measured and monitored.

Strongly agree
Agree
Neither agree nor disagree
Disagree
Strongly disagree

7. Results from the implementation of policies and programs using trees to reduce urban heat island are measured and monitored.

Strongly agree
Agree
Neither agree nor disagree
Disagree
Strongly disagree

8. My city believes monitoring tree canopy cover is vital to the city's long-term health.

9. Long-term tree care is part of the city's policies and programs to use trees to reduce urban heat island.

10. My city believes Public-Private partnerships are essential to the success of tree planting initiatives.

11. Within my city, funding for new tree planting, care, and replacement is adequate.

12. Within my city, tree canopy cover is equal across all neighborhoods.

13. My city considers tree planting in underplanted areas to be a priority.

14. Tree regulation and care are part of the planning department's responsibility.

15. In which region of the United States are you located?

1. New England (Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut)
2. Middle Atlantic (New York, New Jersey, Pennsylvania)
3. East North Central (Ohio, Indiana, Illinois, Michigan, Wisconsin)
4. West North Central (Minnesota, Iowa, Missouri, North Dakota, South Dakota, Nebraska, Kansas)
5. South Atlantic (Delaware, Maryland, District of Columbia, Virginia, West Virginia, North Carolina, South Carolina, Georgia, Florida)
6. East South Central (Kentucky, Tennessee, Alabama, Mississippi)
7. West South Central (Arkansas, Louisiana, Oklahoma, Texas)
8. Mountain (Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada)

9. Pacific (Washington, Oregon, California, Alaska, Hawaii)

16. What changes would most improve your city's policies on urban heat island?

17. In your experience, what types of programs and policies work best to address urban heat island?

18. In your experience, how are the successes of these programs and policies measured?