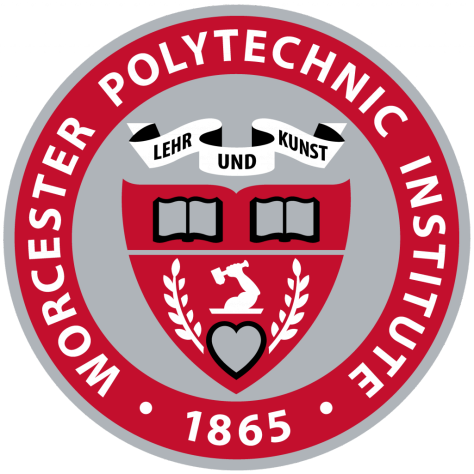

Interventions for Strengthening Resilience to Extreme Heat in Worcester, MA

A Major Qualifying Project Report Submitted to the Faculty of Worcester Polytechnic Institute in partial fulfillment of the requirements for the Degree of Bachelor of Arts

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Abstract

This project aimed to understand the ways in which extreme heat impacts Worcester residents in order to inform heat resilience interventions. Research instruments included 328 survey responses from Worcester residents and sixteen interviews with residents and community experts. This data was used to determine heat vulnerable populations, cooling adaptations residents rely on, and barriers that interfere with achieving heat resilience. Ultimately, this report determined eleven social, environmental, and infrastructural heat resilience interventions the city should pursue.

Executive Summary

Urban residents are at risk in the face of climate change due to characteristics of cities that foster pockets of high ambient temperatures, called heat islands. Meanwhile, temperate regions, which have historically prioritized resilience to cold weather rather than warm weather, are facing challenges in coping with increasingly extreme summers. Temperatures that are typical for an equatorial region have had devastating impacts in northern cities.

Experts regard heat resilience as an environmental justice issue, since marginalized groups disproportionately live within urban heat islands. Seniors, young children, individuals of low-income status, outdoor workers, and individuals with chronic medical conditions are also regarded as at-risk for heat-related illness and death due to societal or physiological factors.

Heat mitigation interventions include environmental, infrastructural, and policy changes that seek to reduce heat islands or provide opportunities for residents to seek refuge from extreme heat. Increasing the amount of vegetation or trees in an area will lead to decreased ambient heat. Cooler materials are used in roofing and pavement to reflect energy. Cities can also designate cooling centers where residents can access air conditioning and clean drinking water. Additionally, improving the energy-efficiency of homes leads to a more heat resilient housing stock.

Worcester, located in central Massachusetts, is beginning to face challenges in coping with increasingly extreme summer weather due to factors including the aging nature of the city's housing stock as well as a high concentration of vulnerable populations. Two previous studies have identified that the hottest neighborhoods in Worcester are home to the city's least affluent residents.

Heat mitigation interventions currently employed by the city of Worcester include re-greening projects, cooling centers, and energy retrofitting incentives. To target heat islands, the city planted two small-scale urban forests in 2024 and has plans to build two additional parks. Worcester also has cooling centers that residents can visit during periods of extreme heat. Further, Worcester residents are eligible for MassSave programs, which offer Massachusetts residents rebates on home modifications for improving efficiency.

While there are many ongoing efforts to understand and target heat vulnerabilities in Worcester, there has yet to be a large-scale study that incorporates input from residents in order to understand how extreme heat impacts populations within the city and how it could best be alleviated. The two pre-existing studies in Worcester both relied on heat vulnerability indices, a tool employed by researchers to estimate where vulnerable populations are located. Heat vulnerability indices use aggregate Census data to identify neighborhoods with higher proportions of heat vulnerable populations. However, this quantitative approach attempts to standardize the dynamics of heat vulnerability, which can obscure nuances that vary between cities. Thus, this study aimed to examine heat vulnerabilities in Worcester through an in-depth, field work based study, which would ultimately inform recommendations for heat resilience interventions to best meet residents' needs.

The data gathered includes 328 survey responses from Worcester residents as well as interviews with eight residents, three landlords, and five individuals with expert-level knowledge on various facets of heat vulnerability. The surveys and interviews collected data about residents' perceptions and experiences of extreme heat, which cooling resources residents utilize, as well as which barriers interfere with cooling. A mixed-methods analysis of quantitative and qualitative data identified patterns for how extreme heat impacts residents, including which social characteristics relate to higher levels of self-reported heat vulnerability.

The data suggests that Worcester residents have observed more intense summer weather in recent years, and a large proportion feel concerned for themselves or others during extreme heat events. Residents also worry about the future of extreme heat, leading them to desire further heat mitigation interventions in the city.

Based on survey data, extreme heat impacts Worcester residents' lives most greatly while they are walking through the city and while inside their homes, particularly while trying to sleep. The heat also makes productivity more difficult and forces many residents to avoid exercise and stay indoors more.

Populations who reported feeling the most vulnerable to extreme heat include low-income communities and seniors. Further analysis suggests that low-income communities in Worcester are more likely to live within a heat island, occupy a poorer condition rental unit, work outdoors, and face exposure to heat while using public transportation. Meanwhile, they are less likely to have air conditioning. Elderly residents in Worcester are vulnerable to extreme heat because they are more likely to have health conditions that impact the body's ability to regulate heat, either directly or through prescribed medications. However, increased neighborhood-cohesion appears to boost heat resilience for seniors.

This study also identified that Worcester residents are becoming increasingly reliant on air conditioning during the summer, however utility costs prevent many residents from achieving their desired level of cooling. Meanwhile, it is clear that much of Worcester's housing stock is in need of efficiency updates, but homeowners and landlords are limited by the cost and logistics of such modifications. Cost-effective cooling measures such as fans and window shades can counteract these barriers when used on their own or along with air conditioning.

Additionally, the report contains assertions regarding resources and barriers to cooling outside the home. Worcester's beaches, pools, and splash parks are frequently used as a low-cost cooling solution. Meanwhile, many Worcester residents believe that the city's heat islands are the result of the lower concentration of trees and other greenery in those areas. Additionally, non-senior residents do not frequently check in on friends, family, or neighbors during extreme heat. Lastly, residents identified a lack of free drinking water across the city as well as limited hours and advertisements for Worcester's cooling centers.

These findings directly informed recommendations to the city for further cooling interventions. The recommendations include employing a heatwave alert system with important information and resources, ensuring consistent access to cooling centers through expanding hours of operation, installing water fountains in priority locations, and keeping blue spaces open

for swimming. Furthermore, this study recommends shading priority bus stops, encouraging social connectivity among seniors, continuing to design greening initiatives within vulnerable neighborhoods, supporting low-income residents with summer utilities, incentivizing landlords to upgrade rental properties, and continuing to adopt building standards that promote efficient cooling. Lastly, the city is encouraged to research several additional sectors that could inform heat resilience.

Introduction

Due to human-induced climate change, the average global temperature has risen about 1.15ºC since prior to the industrial revolution (Forster, et al, 2023). Urban residents are likely experiencing these warming effects to a greater extent than their suburban and rural counterparts due to the urban heat island effect. This phenomena details how cities are an average of 4ºC warmer in the summer than rural areas primarily due to their use of dark and impermeable materials, lack of vegetation, energy usage, and concentration of pollution (Kolokotsa, et al, 2022; Forster, et al., 2023). Thus, cities are often central in conversations involving extreme heat and climate change.

With regards to global warming, cities in warmer climatic regions are often thought of as being the most at-risk; however, climate scientists are increasingly expressing concern for residents of temperate regions (Paterson & Godsmark, 2020). A report from the journal *Globalization and Health* describes how heat-related tragedies "are not isolated only to absolute extreme high temperatures but can also occur when temperature is relatively higher for a given place" (Paterson & Godsmark, 2020). For example, temperatures that are typical for a more equatorial region could have a devastating impact in a northern city. For this reason, if no preventative actions are taken, "it is likely that countries in temperate zones will see an increase in heat-related excess mortality" (Paterson & Godsmark, 2020). This research arises in response to deadly heat waves in cities including Chicago, Illinois, Portland, Oregon, and Paris, France, with heat-related deaths from each event totaling approximately 514, 15,000, and 111, respectively (Ashbaugh & Kittner 2024; Bouchama, 2004; Semenza, et al., 1996).

Worcester, Massachusetts is among one of the northern cities faced with difficulties in coping with summer weather. Referred to as the "Heart of the Commonwealth", Worcester is located in central Massachusetts. Worcester is the second most populous city in New England, with about 208,000 (United States Census Bureau, 2024). The city is already facing challenges in coping with climate change. Headlines on the Worcester Telegram & Gazette during the summer of 2024 read, "Worcester is feeling it: Water restrictions implemented as heat records are broken" and "Worcester battles high temperatures: First heat wave this year grips the region". In 2024, the school year was cut short for Worcester public school students due to predictions that temperatures would reach up to 100ºF (T&G Staff, 2024). Urban Climate Consulting LLC estimates that there were about 8 deaths and 300 hospital visits in Worcester that can be attributed to heat during the summer of 2020, which brought record-breaking highs (Urban Climate Consulting, 2022).

The city of Worcester faces challenges in securing heat resilience due to its population as well as its aging infrastructure. Many residents in Worcester face socio-economic disadvantages. About 20% of residents are below the federal poverty line (United States Census Bureau, 2024). Additionally, 23% are immigrants, most commonly from Ghana, the Dominican Republic, Vietnam, Albania, and Brazil (Data USA, 2023). It is important to consider these marginalized groups when addressing heat vulnerabilities in the city. Additionally, the age of Worcester's

housing stock impacts the heat resilience of the city's homes. About half of Worcester residences were constructed before 1967 and almost a third before 1940 (Jones, 2024). As a result, many homes in the city do not meet modern standards for energy-efficiency.

Extreme heat impacts individuals differently depending on where in a city someone lives as well as which socio-economic groups they belong to. It is important to identify heat vulnerable communities in order to most efficiently implement resilience interventions. To do this, researchers often create a heat vulnerability index. This tool utilizes scientifically agreed-upon variables such as age, income, and race–typically derived from the Census–to assign vulnerability ratings to neighborhoods. However, this approach assumes that the particular pathways through which extreme heat affects people's lives do not vary between cities, which can be a source of error. For instance, historically marginalized racial or ethnic identities are often disproportionately subject to living in hotter areas of cities; however, researchers have observed that in certain cities, the tight-knit community that can form in neighborhoods with ethnic minorities fosters resilience (Gronlund, 2015). Additionally, relying on only data-driven metrics rather than incorporating direct resident input can obscure the nuances of how heat affects individuals as well as which solutions would best support the population. Thus, it is not sufficient to only refer to a vulnerability index when developing heat mitigation interventions.

To bridge these gaps, this study utilizes direct resident involvement to inform recommendations for cooling adaptations the city should pursue. The goal of this project was to create recommendations for alleviating heat vulnerability for the residents of Worcester. To accomplish this, the following objectives were completed:

1. Understand Worcester residents' perceptions and experiences regarding climate change and extreme heat.
2. Identify populations in Worcester that feel vulnerable to extreme heat.
3. Understand how Worcester residents adapt during extreme heat events and what barriers impede their ability to adapt.
4. Propose feasible actions to most efficiently ease heat vulnerability in Worcester.

Background

This section will provide further context necessary for understanding the methods and findings of this report. It begins with the relevance of heat resilience for cities in temperate regions, provides a synopsis of heat vulnerability, and describes common interventions employed by cities to support heat resilience. Additionally, this section contains the important considerations for heat resilience in Worcester, including prior research as well as the city's current efforts to mitigate the impacts of extreme heat.

Urban Heat Island Effect

The urban heat island effect describes why cities are an average of 4ºC warmer than rural areas during the summer (Kolokotsa, et al., 2022). Cities are densely composed of materials like asphalt and concrete that absorb and store heat due to their dark color and impermeability (Forster, et al., 2023; Kolokotsa, et al., 2022). Vegetated areas act as heat sinks for their surrounding environment by absorbing heat and releasing it through evapotranspiration; however, urbanized settings often have a lack of green spaces (Kolokotsa, et al., 2022). Additionally, large buildings situated close together can mitigate air flow, resulting in warmer apparent temperatures (Kolokotsa, et al., 2022). The increased energy usage in cities also contributes to excess heat. The processes of transportation, industrial production, heating, and cooling all transfer heat into urban systems (Forster, et al., 2023; Kolokotsa, et al., 2022). Lastly, higher concentrations of air pollution can act as an insulator, preventing heat from escaping into the atmosphere (Kolokotsa, et al., 2022). The combination of these factors as described by the urban heat island effect explain why cities experience warmer temperatures than their surrounding suburbs. For this reason, cities are central in the discussions of climate resilience.

Climate Change in Temperate Cities

The emphasis on temperate cities as an area of concern in the face of global warming arose in response to growing accounts of deadly heat waves in cities within the middle latitudes, including Chicago, Illinois in 1995, Paris, France in 2003, and Portland, Oregon in 2021. The death counts during these three heat waves illustrate the threat extreme heat poses for cities in temperate regions. In Chicago, daily highs between 98ºF and 106ºF lasting only four consecutive days in July 1995 resulted in 514 confirmed heat-related deaths, although an analysis of excessive deaths–the difference between actual and predicted deaths during the timeframe of interest–suggests that this figure could be up to 700 (Whitman, et al., 1997). Across Western Europe, July 20th through August 20th of 2003 brought unprecedentedly hot weather, with eight consecutive days of temperatures reaching over 104ºF. In France, the death toll for this tragedy was about 15,000, with most losses concentrated in and around Paris (Dhainaut, et al., 2003). This event in particular acted as a warning signal for the rest of the world, as even France's world-renowned healthcare system was unequipped to handle the volume of patients seeking

medical help (Bouchama, 2004). Lastly, Portland experienced daily highs about 30ºF warmer than seasonally typical from June 26 to 28th, 2021, reaching a record-breaking high of 116ºF. There were 111 confirmed heat-related deaths in the city–again likely an underrepresentation, as analysis shows about 600 excess deaths in Oregon and Washington during that time (Ashbaugh & Kittner, 2024).

As climate change brings higher average temperatures as well as more extreme peaks, it becomes clear that many cities will need to revisit their capacity to withstand heat for the well-being of their residents (Forster, et al., 2023). This is because northern cities have a history of prioritizing heating solutions during winter months rather than cooling in the summer (Ritchie, 2024). In other words, many cities in temperate regions have not yet invested resources in cooling solutions like air conditioning, thus their infrastructure is not well-equipped to accommodate temperatures that would be considered manageable if they occurred further south (Paterson & Godsmark, 2020). For instance, as shown in **Figure 1**, the risk of heat-related deaths in Paris rises exponentially after only 20ºC–or 68ºF–due to factors such as a lack of air conditioning (Ritchie, 2024). Meanwhile, a history of planning for extreme heat in Austin, Texas results in lower risk levels at higher temperatures (Ritchie, 2024).

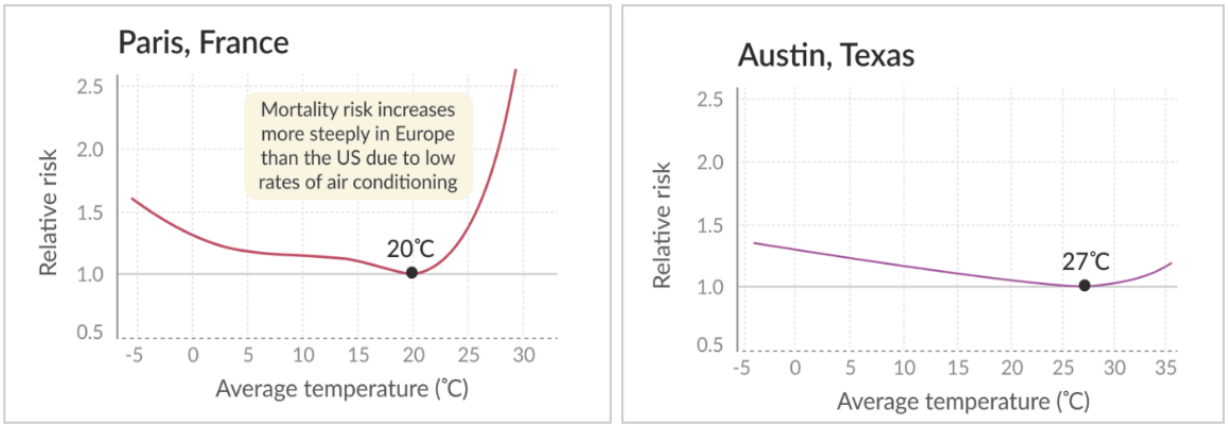


Figure 1. *Comparison between the risk of heat-related death by temperature for Paris versus Austin (Ritchie, 2024).*

Heat Vulnerability

In urban planning, *vulnerability* describes how susceptible to harm a person or community is as a result of a disturbance, such as a natural disaster. Its opposite, *resilience*, is the capacity to withstand a disturbance. Different types of populations experience varying levels of vulnerability due to economic, social, and health-related factors. Intersections of more vulnerable identities often compound to make certain communities particularly at risk to environmental calamities. In order to most effectively boost resilience within a community, it is essential for planners to identify and support those who are most at-risk.

In regard to extreme heat, there are several factors that predispose individuals to heat-induced illness, as revealed by analyses of morbidities and mortalities during heat waves. The CDC names adults over 65, infants and children, people with chronic medical conditions,

people without air conditioning (AC), and pregnant people as populations who should take additional precautions to ensure their safety during extreme heat events (CDC, n.d.). Additional relevant factors of heat vulnerability include housing condition and social connectivity.

The population perhaps most widely regarded as heat vulnerable is the elderly. Elderly individuals are more limited in their ability to adapt to rapid temperature changes, and they are more likely to have medical conditions that interfere with heat regulation, either directly or due to related medications (CDC, n.d.). Researchers of the Chicago 1995 and Paris 2003 heat waves identified that residents 65 and older were disproportionately represented in heat-related deaths (Bouchama, 2004; Semenza, et al., 1996). In Chicago, seniors accounted for 72% of heat deaths despite only composing about 16% of the population (Semenza, et al., 1996).

Due to physiological and behavioral factors, children are vulnerable to heat stroke and exhaustion. Their larger surface area to body mass ratio causes them to lose fluid faster, leading to dehydration (EPA, n.d.). Children are also more likely to be active outside, but they lack the foresight to stay hydrated and limit physical activity during extreme heat (EPA, n.d.).

In discussions of heat vulnerability, income status is a complex yet crucial factor, as it influences individuals' exposure to heat and access to cooling resources both inside and outside of their homes. Within residences, income status determines whether individuals can afford to purchase and run air conditioning units (Gronlund, 2015). Researchers of all three heat wave case studies identified the presence of air conditioning as a key determinant of heat-related deaths (Ashbaugh & Kittner, 2024; Bouchama, 2004; Semenza, et al., 1996). During the Portland heat wave, those without air conditioning in their homes accounted for a staggering 85% of deaths (Ashbaugh & Kittner, 2024).

Further analysis demonstrates a connection between air conditioning use and renter status, which is also related to income, as those with higher incomes are more likely to be homeowners. In 2021, renters in Portland were 2.4 times less likely than homeowners to have air conditioning (Ashbaugh & Kittner, 2024). They also tended to live in older homes that were less energy-efficient due to outdated infrastructure, including cooling systems and insulation (Ashbaugh & Kittner, 2024). During the heatwave in France, researchers saw a correlation between poor insulation quality and heat mortality (Gronlund, 2015).

Insufficient insulation can create a financial barrier to cooling ones' home, since more energy would be required to reach a suitable temperature than in a home with proper insulation (Gronlund, 2015). About 30% of renters across the United States are "energy burdened", meaning they spend over 6% of their income on energy (Ashbaugh & Kittner, 2024). When renters are financially confined to outdated apartments–particularly on the upper floors of buildings, as excess heat can seep in from housing units below–the results can be deadly. Over half of victims of the Chicago heat wave were living on the top floor of their residence building (Semenza, et al., 1996). At the extreme end of low-income, unhoused individuals are highly vulnerable to extreme heat due to inconsistent access to water, shade, and air-conditioned spaces (Heat Action Platform, n.d.).

Income also affects individuals' ability to utilize important resources outside their homes during extreme heat. Access to transportation is essential for allowing individuals to visit cooling centers and other air-conditioned spaces (Gronlund, 2015). In the Chicago heat wave, individuals with no access to transportation were overrepresented by heat mortalities (Semenza, et al., 1996). The ability to pay for medical care is also an influential factor, as it determines whether individuals can seek emergency services in the case of heat-related illness (Gronlund, 2015). Experts regard individuals with no healthcare as being highly at risk during extreme heat (Gronlund, 2015).

Low-income populations intersect with other communities that are at risk during extreme heat, illustrating the interconnected nature of heat vulnerability. Outdoor or other non-climate controlled workplaces–which typically employ low-income individuals–can become deadly during extreme heat. Analysis of the Paris heat wave demonstrated that manual workers were at elevated risk for heat mortality (Gronlund, 2015). In the United States, people of color can experience greater vulnerability to extreme heat. Environmental epidemiologist Dr. Carina Gronlund writes, "Evidence of racial differences in heat tolerance due to genetic differences is inconclusive at best," meaning that people of color are at risk not due to physiological factors, but rather the history of racial discrimination in the United States. Decades of redlining and disenfranchisement for marginalized ethnic groups–particularly Black Americans–means that people of color in the United States today are more likely than White Americans to be low-income, have worse health, not own air conditioning, work outdoors, and live in areas with less greenery and more impermeable surfaces (Gronlund, 2015). These factors establish heat vulnerability as an environmental justice issue.

Several medical conditions are also determinants for heat-related illness and death. Conditions that increase heat vulnerability include cardiovascular diseases, diabetes, respiratory diseases, physical disabilities, and psychiatric disorders, among others (CDC, n.d.; Gronlund, 2015). These chronic conditions can compromise the cardiovascular system or other body systems that participate in cooling mechanisms (Gronlund, 2015). Certain disabilities and mental illnesses can worsen one's ability to sense temperature changes in order to make behavioral adjustments, such as hydrating (CDC, n.d.; Gronlund, 2015). Additionally, individuals with health conditions might be prescribed medications that impede temperature regulation (CDC, n.d.). Being pregnant also results in greater risk of heat-related illness, as individuals become more prone to dehydration and require more energy to cool down (CDC, n.d.). The presence of medical conditions was recognized as a determinant of heat-deaths in the Chicago and Paris heat waves (Bouchama, 2004; Semenza, et al., 1996).

There is a growing understanding of the importance of social connectivity in the face of environmental disturbances, including extreme heat. In all three heat wave case studies, individuals' social network was a key factor of resilience (Ashbaugh & Kittner 2024; Bouchama, 2004; Semenza, et al., 1996). Chicagoans living in their housing unit alone were over twice as likely to experience heat mortality than those living with at least one person (Semenza, et al., 1996). Case subjects who died in the heat wave stayed inside their homes more, had less friends

in the city, owned less pets, and participated in less organized social groups (Semenza, et al., 1996). Even for residents with air conditioned homes, those who visited a public location with air conditioning during the heatwave died less frequently (Semenza, et al., 1996). Hispanic individuals were underrepresented in mortality rates compared to non-Hispanic White individuals during the Chicago and Portland heat waves despite being a marginalized identity in the United States (Ashbaugh & Kittner, 2024; Semenza, et al., 1996). Dr. Carina Gronlund writes that this is because Hispanic communities in the United States are more interconnected than other ethnicities, fostering care between individuals. Perceptions of crime can interfere with social connectivity and resilience during extreme heat. In Chicago, some of the victims had chosen not to leave their homes or even open their windows due to safety concerns related to crime (Gronlund, 2015).

In order to identify populations that are most at risk to extreme heat within a target region, researchers quantify relative vulnerability scores by neighborhood, often at the scale of Census block groups. The scores are composed of the proportion of residents within each division who belong to a vulnerable identity, such as the percent of residents over 65 or the percent without central air conditioning, as well as factors indicating an urban heat island, including apparent temperature or percent of the area composed of impermeable materials. These factors are standardized and averaged, usually by equal weights, producing values that represent estimates for relative levels of vulnerability. Then, city planners use these estimates to design heat resilience interventions targeting those most at-risk.

Interventions to Support Resilience to Extreme Heat

The benefits of a heat resilient city far exceed the prevention of heat-related deaths. As established previously, low-income communities and people of color are more likely to be exposed to urban heat islands. Thus, cooling solutions can reduce these inequities (Gronlund, 2015). Mitigation strategies have also been shown to improve energy usage, air quality, health, and aesthetics (Targhi & Van Dessel, 2015). When cities are thermally comfortable, residents are more likely to walk or bike rather than drive, leading to less energy consumption and heat outputs, in addition to the health benefits of improved air quality and exercise (Targhi & Van Dessel, 2015). Heat resilience interventions take the forms of cooling infrastructure and policies.

Common solutions that address heat islands include replacing existing infrastructure with cooler materials, constructing green and blue spaces, and designating indoor cooling centers. Materials with high thermal conductivity can be replaced by materials that absorb less heat. Permeable pavements stay cool by releasing energy during evaporation (Targhi & Van Dessel, 2015). Meanwhile, cool roofs are lightly colored surfaces with high albedos, meaning they reflect rather than absorb sunlight (Targhi & Van Dessel, 2015).

Urban planners can also maintain or construct natural areas to act as heat sinks within an urban setting. These come in the form of green spaces as well as bodies of water, pools, or splash parks, referred to as blue spaces. Inverse to the heat island effect, the park cool island effect describes how green and blue spaces reduce ambient temperatures due to their high albedos and

low specific heat capacities, as well as by providing shade or opportunities for swimming (Targhi & Van Dessel, 2015). Natural areas constructed or maintained for heat resilience include pocket parks, urban forests, street trees, lakes, and ponds. Pools and splash parks also provide residents with recreational locations for staying cool. Similar to cool roofs, green roofs are roofs overlaid with vegetation that increase a building's albedo (Targhi & Van Dessel, 2015). In addition to addressing extreme heat, these infrastructure changes provide spaces for relaxation, exercise, and community, as well as improving aesthetic appeal (Kumar, et al., 2024; Targhi & Van Dessel, 2015).

Cooling centers are public indoor spaces that allow residents to access air-conditioning during periods of heat. City planners typically select existing air conditioned public buildings such as libraries to use as cooling centers. By addressing utility inequities while fostering a sense of community, cooling centers "[provide] reliable refuge from disruptions and a central point for gathering, sharing information, and accessing resources" which in turn "reduce[s] morbidity and mortality" (Ashbaugh & Kittner, 2023). During the Portland heat wave, the majority of mortalities occurred in East Portland, which disproportionately houses low-income and Black residents (Ashbaugh & Kittner 2024). To address this clear inequity, the city invested further in the East Portland Resilience Center and began partnering with local resilience organizations to expand the center's impact (Ashbaugh & Kittner, 2024).

Municipalities can also improve the capacity of their housing stock to stay cool during extreme heat using policies and financial incentives. Retrofitting programs typically offer free energy audits in order to demonstrate homeowners' ability to save on utilities by upgrading the efficiency of their homes. Certain programs partially or fully finance these upgrades. As discussed previously, there is a disproportionate "energy burden" felt by renters, who often live in less energy efficient homes. Thus, some cities have programs to finance air-conditioning installation or utilities specifically for renters. Renter AC policies exist in Phoenix, Philadelphia, and Washington DC, and have recently been enacted in Portland in response to the 2021 heat wave (Ashbaugh & Kittner, 2024). The Portland Clean Energy Fund was implemented in 2022 to install free heat pump cooling devices to those most in need. To be eligible for the program, applicants must be low-income and either 60 years old or older, living with a chronic medical condition, or living alone (Ashbaugh & Kittner, 2023).

Building standards can help to ensure that future housing stock is more resilient by creating incentives for developers to build energy-efficient homes. Portland's HEART Building Standards, which are currently being developed, will create financial benefits for meeting efficiency and clean energy standards for rental apartments (Ashbaugh & Kittner, 2023). The goal of these standards is to alleviate landlords' need to raise rent in order to execute updates to their rental properties. It will also mandate that rental apartments have the capacity to remain below a set maximum temperature throughout the summer months (Ashbaugh & Kittner, 2023).

Climate Change in Worcester

With its intense winters and warm summers, Worcester is no exception to the pattern of cities in temperate regions that are finding their social, environmental, and built infrastructure unequipped to accommodate the increasingly hot summers that result from climate change.

Weather records in Worcester show that heat in the city is on the rise. A regression line of the annual average daily average temperatures during the months of June, July, and August, fit between 1950 and 2024, reveals that daily averages have increased by about 2.5ºF during this time (NOAA, 2024). Instances of extreme heat are on the rise as well, as shown by the change in daily highs in **Figure 3**. In just the past 24 years, the annual mean of daily maximum temperatures during summer months have also increased by about 2.5ºF (NOAA, 2024). With the lack of sufficient global efforts to mitigate climate change, these trends are predicted to continue (Forster, et al., 2023).

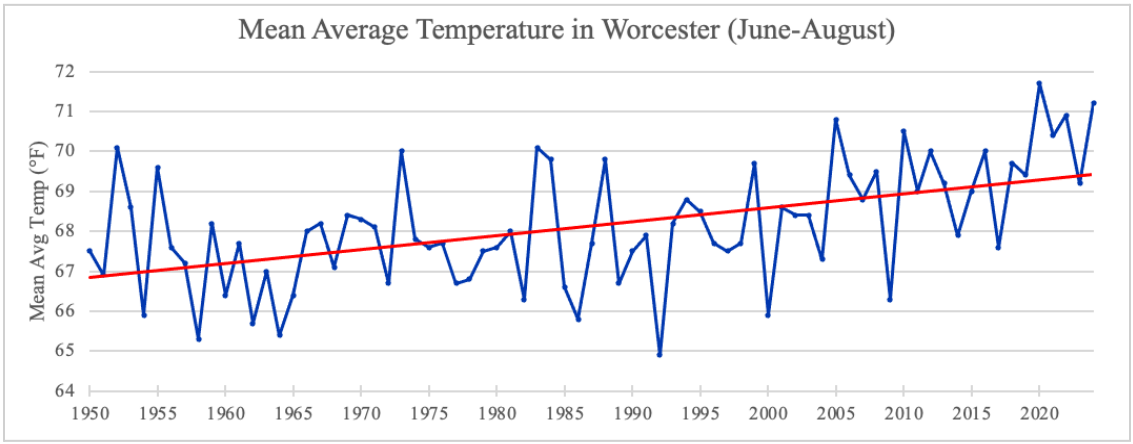


Figure 2. *Annual means of daily average temperatures recorded at the Worcester Regional Airport during the months of June through August (NOAA, 2024).*

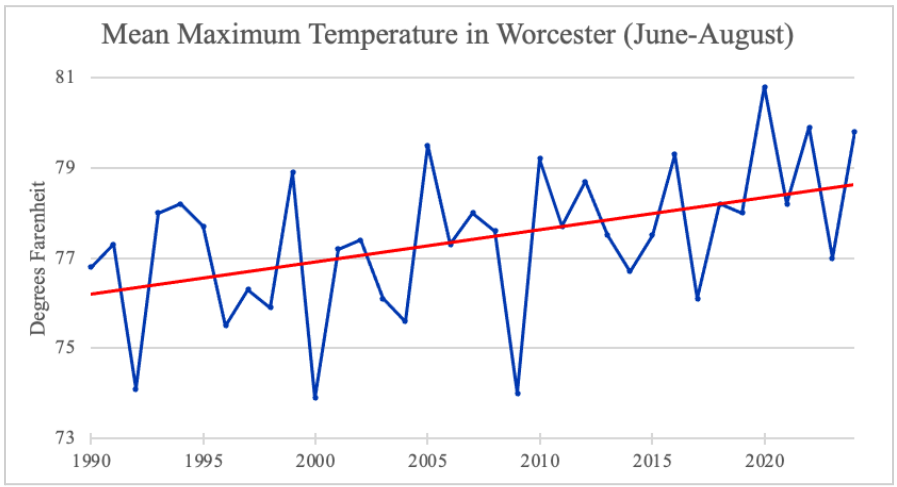


Figure 3. *Annual means of daily high temperatures recorded at the Worcester Regional Airport during the months of June through August (NOAA, 2024).*

Barriers to Heat Resilience in Worcester

Several aspects of the built and socioeconomic landscapes in Worcester help define the necessity to strengthen the city's resilience to heat. Spatial analysis shows that Worcester's heat islands exist in areas with less natural spaces and more impermeable materials. When looking at a heat map of Worcester compared to the city's tree canopy, it is clear that the hottest areas in the city have fewer trees, while the more forested neighborhoods remain relatively cooler (McCauley, et al., in preparation; Elmes, et al., 2017). Additionally, Worcester's Downtown region–the center of its heat island–is characterized by a lack of vegetation amongst a landscape of impermeable building materials, primarily asphalt, brick, and stone (Targhi & Van Dessel, 2015).

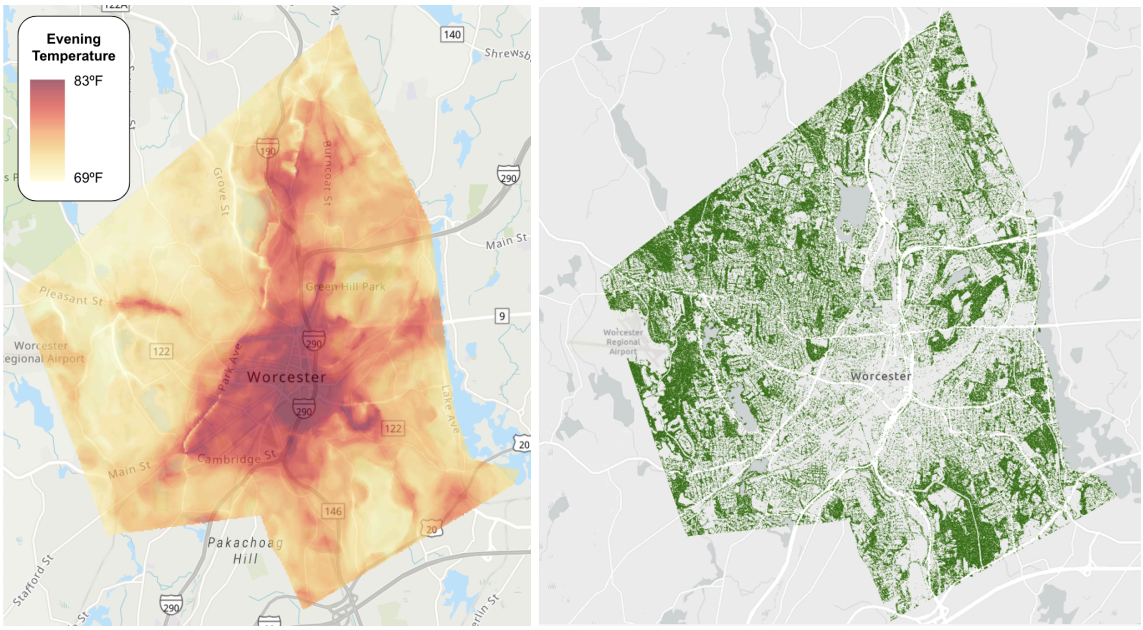


Figure 4. *Left: Worcester Heat Map (McCauley, et al., in preparation); Right: Worcester tree canopy shown in green (Elmes, et al., 2017).*

As informed by the history of trees in Worcester, the current amount of tree canopy across the city is likely less than it has been previously. Following a period of forest preservation and tree growth in the 19th century, Worcester's trees faced decades of disease and natural disasters, including a hurricane in 1938 and a tornado in 1952 (Middaugh, 2019) These events sparked major tree replanting efforts in order to reforest the city. Norway maples, known for their fast maturity, were highly prioritized in these replanting efforts, and in 2006 they accounted for 80% of the city's street trees (Middaugh, 2019; Palmer, et al., 2014). This monoculturing left Worcester's ecosystem highly vulnerable to the eventual infestation of the Asian Longhorned Beetle (Middaugh, 2019). After a Worcester resident discovered the insect known for its destruction of hardwood trees such as Maples, follow up research revealed that the beetles had already spread through the Burncoat and Greendale neighborhoods in northern Worcester (Middaugh, 2019). In collaboration with the Massachusetts Department of Conservation and the

United States Department of Agriculture, the city removed 30,000 affected trees both on public and private land, stropping the infestation from spreading beyond Worcester county (Middaugh, 2019; Palmer, et al., 2014).

After the species was eradicated, efforts began to restore the city's trees. The Worcester Tree Initiative (WTI), co-opted by Tower Hill Botanical Garden, intended to replant 30,000 trees within five years with the help of community volunteers (Middaugh, 2019). WTI announced that this goal was met in 2014, although the non-profit itself was responsible for planting less than a third of the new trees, as the State Department of Conservation planted about 22,000 (Palmer, et al., 2014; Worcester Tree Initiative, n.d.). The WTI appears to have been mostly inactive since its ten year anniversary in 2019.

In addition to factors that foster heat islands in Worcester, the city's housing stock is crucial to consider with regard to heat resilience. The research firm Construction Coverage found that half of Worcester residences were constructed before 1967 and almost a third before 1940 (Jones, 2024). This is problematic, as developers 60-85 years ago were not designing homes to accommodate the intensifying summer weather of recent decades. Thus, only about 12% of Worcester residents have central air conditioning today (McCauley, et al., in preparation). Worcester is also known for its "triple-decker" houses, which contain one living unit per floor. According to William Wallace, Executive Director of the Worcester Historical Museum, these three family homes were mostly constructed between 1880 and 1930 as high-density, affordable housing units that would offer a decent standard of living in order to attract potential factory workers and their families (Wallace, 2020). Due to their age, these residences pose concerns about the heat resilience of the city. Today, triple deckers account for approximately 14% of the 38,500 residence buildings in Worcester (McCauley, et al., in preparation).

Mirroring the pattern visible in other cities, residents of Worcester neighborhoods in more severe heat islands are also more vulnerable socially and economically, indicating an environmental justice problem. The Massachusetts Executive Office of Energy and Environmental Affairs designates those who are low-income, of a minority ethnicity, or non-English speaking as populations that are more likely to be impacted by environmental harms (Mass.gov, 2024). Environmental Justice (EJ) populations are census block groups in which there is a significant portion of individuals belonging to one or more of these three criteria (Mass.gov, 2024). Comparing this data with the heat distribution map produced by a WPI team illustrates that EJ populations are more likely to be exposed to extreme heat.

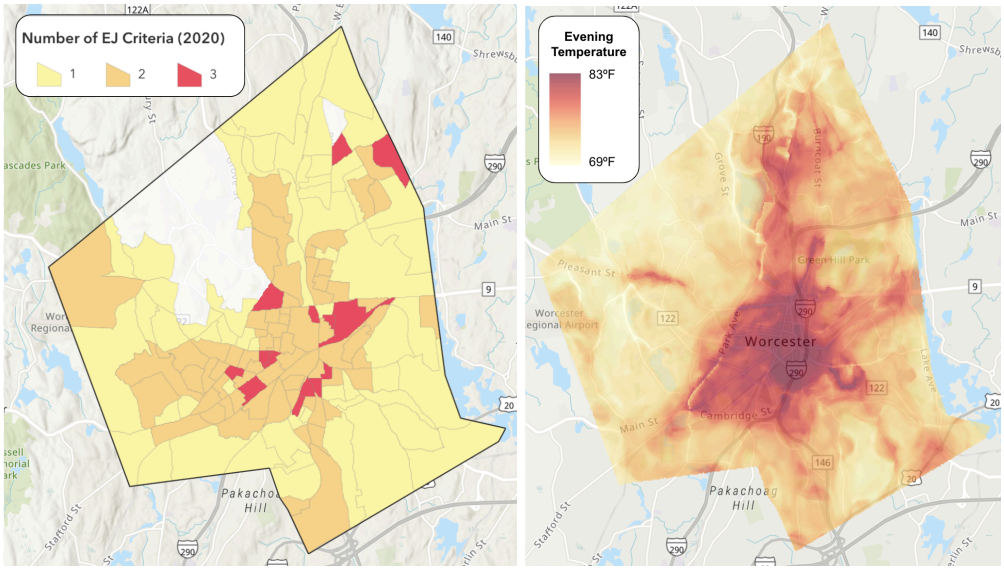


Figure 5. *Left: Environmental Justice populations in Worcester by number of criteria met (Mass.gov, 2024); Right: Evening heat distribution map of Worcester (McCauley, et al., in preparation).*

Existing Heat Vulnerability Research in Worcester

When implementing cooling solutions, it is imperative to prioritize the Worcester communities that are most at risk during extreme heat events. Two studies have aimed to identify these populations. The first was a project by Worcester Polytechnic Institute which created a heat vulnerability index of the city by census block group. The vulnerability index combined data pertaining to relevant demographics, health conditions, and social connectivity with the city's apparent heat distribution (McCauley, et al, in progress).

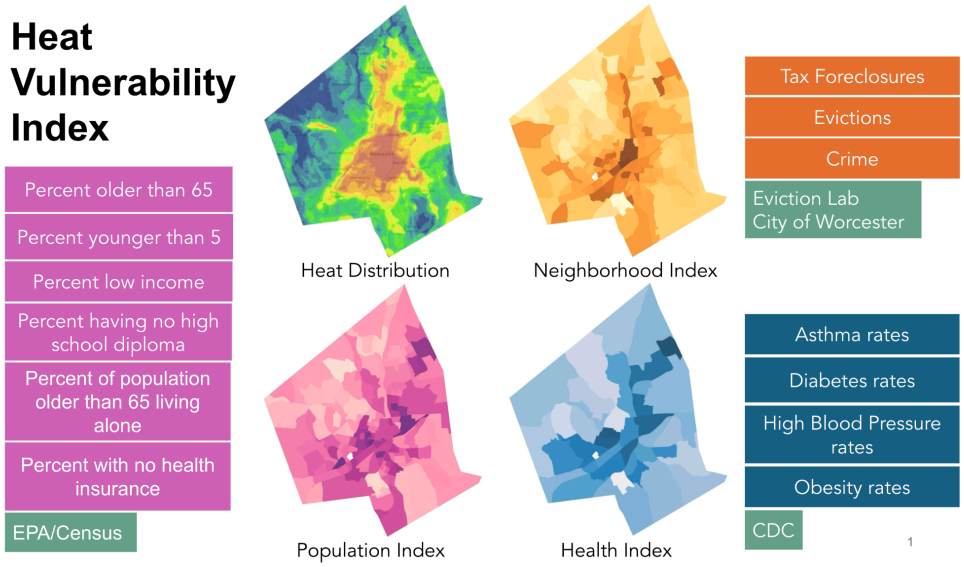


Figure 6. *Components of Worcester Polytechnic Institute's Heat Vulnerability Index for Worcester (McCauley, et al, in preparation).*

In 2021, the City of Worcester commissioned Urban Climate Consulting LLC to complete a heat risk assessment of Worcester. While their research mainly focused on predicting the impact of different heat management strategies, they also created a vulnerability index. The two visualizations yield comparable results, however Urban Climate Consulting's vulnerability index divides the city into less granular sections and describes vulnerability levels as low, medium, or high, rather than on a continuous scale. As shown in **Figure 7**, both suggest that heat vulnerable populations are concentrated throughout central Worcester and along Interstate 290. Meanwhile, the outskirts of the city, particularly in the West, exhibit less vulnerability, with less dense urban infrastructure, more vegetation, and higher housing values. Additionally, Urban Climate Consulting simulated ambient ground-level temperatures that would result from several heat adaptation strategies involving cool roofing materials and tree coverage. They ultimately recommended that the city increase tree canopy by 30,000 trees, particularly in neighborhoods with more vulnerable communities, however they suggested completing further research before investing in cool materials due to trade-offs revealed in their simulation (Urban Climate Consulting, 2022).

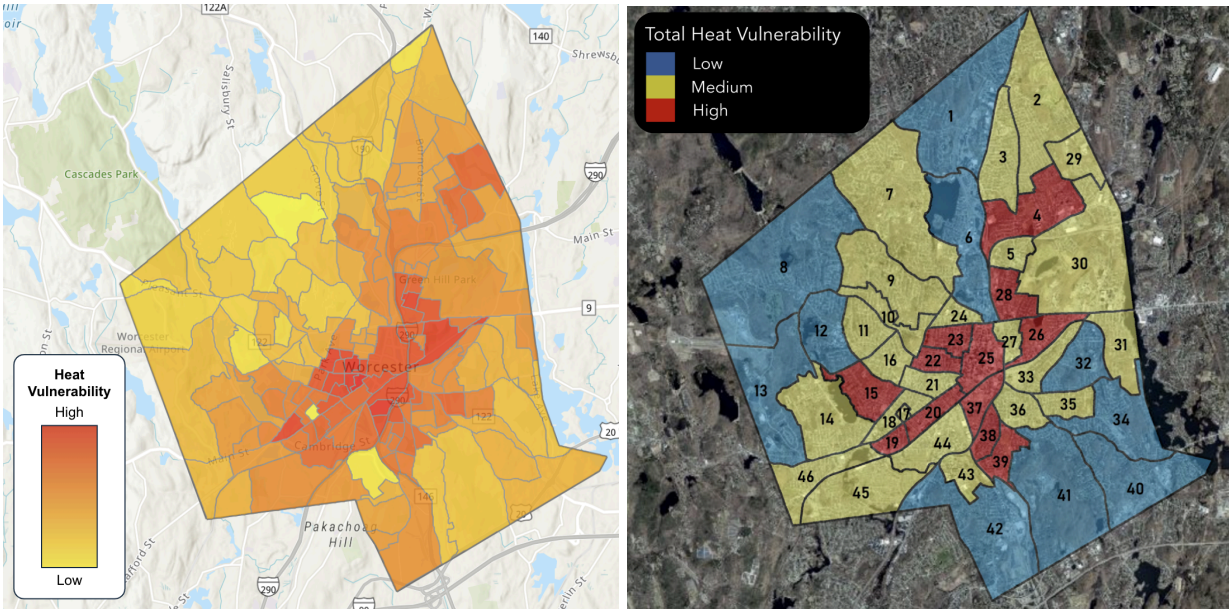


Figure 7. *Heat vulnerability indices created by Worcester Polytechnic Institute (left) and Urban Climate Consulting (right).*

While these findings act as an effective starting point for improving heat resilience, they are both dependent on aggregate Census data, lacking any direct input from residents. Namely, neither study collected information about Worcester residents' experiences with extreme heat nor their opinions on cooling measures the city should pursue. This is essential in order to best formulate strategies for improving resilience. Residents also may need to opt-in to certain management strategies, such as home energy retrofits, so it is helpful to understand the demand for such initiatives before investing in them.

Existing Heat Mitigation Measures in Worcester

Heat mitigation interventions currently employed by the city of Worcester include re-greening projects, cooling centers, and energy retrofitting incentives. Following the Worcester Tree Initiative of 2009-2014, the city has designed two urban forests and two pocket parks with the goal of natural cooling in mind. The forests were planted in 2024 with assistance from community volunteers utilizing the Miyawaki method, in which species are planted closely together and must compete for sunlight, which results in faster growth and more biodiversity per area (Worcester DSR, n.d.). Both of these forests were selected from densely populated environmental justice communities that face more heat exposure. “We want to reduce emissions and… prepare for future climate change all at the same time,” said John Odell, Chief of Sustainability & Resilience in Worcester, explaining how the forests will absorb carbon outputs and heat from adjacent buildings and parking lots (Worcester DSR, n.d.).

Additionally, two “CoolPocket” parks will be installed in highly heat vulnerable communities (Worcester DSR, n.d.). The goal of a “CoolPocket” is to create cool areas for recreation and community building, while also targeting other environmental issues such as air quality and flooding. Informed by input from local community members–including students of an adjacent elementary school–the plans are to replace large paved areas with mulch and grass fields for recreation. Additionally, shaded areas will be expanded using trees and play structures, creating a multi-use oasis for heat resilience (Worcester DSR, n.d.)

As established, cooling centers are an important resource for residents during periods of extreme heat. Worcester has about five cooling centers, including the Worcester Public Library and the Worcester Senior Center, each of which are accessible via the fare-free Worcester Regional Transit Authority (City of Worcester, 2024). When a heat wave is forecasted, the city announces which cooling centers will be “activated” on which days and times. These announcements also include a brief summary of preventative measures residents should take: “limit strenuous physical activity, stay hydrated, and check on neighbors” (City of Worcester, 2024).

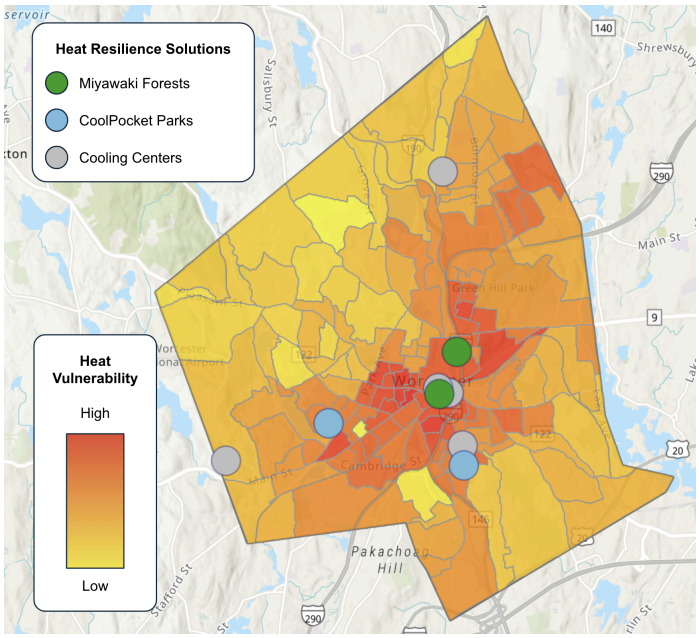


Figure 8. *Heat resilience solutions implemented by the City of Worcester compared to relative heat vulnerability levels across the city. (City of Worcester, 2024; Worcester DSR, n.d; WPI, 2024).*

Worcester residents are also eligible for programs of Mass Save, a statewide initiative in collaboration with local energy providers. Mass Save offers free energy assessments and incentives for installing energy efficient cooling and insulation for homeowners, renters, landlords, and businesses (Mass Save, n.d.). Through Mass Save, low-income residents can qualify for no-cost home upgrades. Since its establishment in 2008, Mass Save reports that they have reduced carbon dioxide outputs by 3.7 million metric tons and electricity usage by 12.2 million MWh (Mass Save, n.d.).

Methodology

Goal and Objectives

This project aimed to create recommendations for alleviating heat vulnerability for the residents of Worcester, MA. To accomplish this, the following objectives were completed:

1. Understand Worcester residents' perceptions and experiences regarding climate change and extreme heat.
2. Identify populations in Worcester that feel vulnerable to extreme heat.
3. Understand how Worcester residents adapt during extreme heat events and what barriers impede their ability to adapt.
4. Propose feasible actions that would most efficiently ease heat vulnerability in Worcester.

Research Instruments

Surveys and interviews were conducted in order to gather resident input to inform the project objectives.

Survey

Information about Worcester residents' feelings, behaviors, and adaptive capacities during extreme heat was gathered using the Worcester Heat Survey, which aimed to answer these key questions:

- How do Worcester residents perceive extreme heat and climate change?
- How does extreme heat impact the well-being of Worcester residents?
- Which populations in Worcester identify as being vulnerable to extreme heat?
- What measures do Worcester residents take in order to cope with extreme heat?
- What barriers impede Worcester residents from coping with extreme heat?

The survey, available in English, Spanish, Portuguese, and Vietnamese, was anonymous and confidential. Participants could skip any questions they did not want to answer. Thus, the total responses for each question vary. Response counts for individual questions are reported in the Results & Discussion section as necessary.

The researchers distributed the survey during July and August of 2024, both in-person and online. To incentivise survey participation, respondents had the option to enter a gift card raffle. The researchers created flyers that described the goals of the survey, advertised the gift card raffle, and linked to the survey via QR code (See **Appendix A**). Both the flyers and handouts were duplicated in the three additional languages and distributed in person in various high-trafficked areas of Worcester, shown in **Table 1**. Printed surveys were offered to those who preferred a paper option. To reach more potentially interested parties, the researchers contacted several local activist groups, churches, and other organizations to inquire if they could share the

survey with their volunteers or mailing lists. Two organizations–shown in **Table 1**–agreed to share the survey. Additionally, the researchers posted information about the survey on local social media pages, also listed in **Table 1**.

Date	Time	Location	Event	Method
7/11/2024	1-4 PM	Downtown	-	Posted flyers, handouts
7/16/2024	1-4 PM	Park Avenue	-	Posted flyers, handouts
7/23/2024	3-4 PM	Colony Retirement Homes	-	Paper surveys
7/25/2024	5-7 PM	Union Train Station	-	Handouts
7/25/2024	6-8 AM	Union Train Station	-	Handouts
7/30/2024	2-5 PM	Colony Retirement Homes	Multicultural Event	Table-sitting, paper surveys
7/31/2024	2-5 PM	Main South	-	Handouts
8/1/2024	11 AM-2 PM	Worcester Common	Out to Lunch Festival & Farmers Market	Handouts
8/3/2024	12-4 PM	Worcester Common	African Festival	Handouts
8/8/2024	11 AM-2 PM	Worcester Common	Out to Lunch Festival & Farmers Market	Handouts

Local Organization	Response
Regional Environmental Council Worcester	Shared with email list
Worcester Regional Chamber of Commerce	Shared on social media

Social Media	Page
Facebook	What's Happening Worcester
Facebook	Brasileiros em Worcester
Facebook	Mexicanos en Worcester
Reddit	r/WorcesterMA
Nextdoor	Neighborhoods in Worcester
Discord	WorcesterMA

Table 1. *Summary of survey distribution methods via in-person outreach, local organizations, and social media.*

The data analyzed in this report encompasses 328 responses that were nearly or fully completed. English responses accounted for 322, and the remaining six were completed in Spanish. With regards to distribution methods, approaching residents in public spaces resulted in the largest proportion of responses, followed by the researchers' post on the Worcester Reddit page.

Means of distribution	Survey responses	Proportion
Approached in person	115	38%
Reddit	89	30%
Facebook	30	10%
Heard about it from friends/family/etc.	23	8%
Saw a flyer at a local business	21	7%
Other social media	21	7%

Table 2. *Survey responses by distribution method (n=299).*

Interview

To gain further insight on Worcester residents' experiences with extreme heat as well as how landlords and the city's actions play a role in heat resilience, semi-structured, anonymous and confidential interviews were conducted. The researchers spoke with Worcester residents and landlords, as well as experts on various facets of heat vulnerability in the city. The interviews took place concurrently with the survey from July to August 2024, during which 16 were completed. The researchers transcribed recorded audio using Otter AI. Potential interviewees were identified through the Worcester Heat Survey as well as by contacting local experts.

Interviewees were designated as primarily a resident, landlord, or expert, however, several of them had knowledge or experiences ranging across multiple of these categories. Thus, the researchers focused each interview on questions pertaining to the interviewees' most relevant identities. The resident-targeted questions aimed to investigate experiences, behaviors, and sources of vulnerability with regards to extreme heat, as well as barriers to increasing resilience. The researchers sought to understand which barriers landlords face in providing heat resilient homes, as well as how the city could work to alleviate these barriers. The expert interviews varied with each interviewee's specific area of knowledge, generally focusing on actions the city is taking to improve heat resilience and which barriers impede progress. Interview questions varied based on the experiences and knowledge of each participant, but the question guide utilized by the researchers for the resident-targeted interviews is included in **Appendix C**, along with the consent statement read to every interviewee.

Interviewee	Relevant Experience/Identity
Expert A	Worcester Dept of Sustainability & Resilience (DSR)
Expert B	Energy retrofitting
Expert C	Energy retrofitting
Expert D	Main South Community Development Center
Expert E	Massachusetts Association of School Committees
Landlord A	Advisory committee for DSR

Landlord B	Rents out a triple-decker, grew up in Worcester County
Landlord C	Worcester Property Owners Association
Resident A	Senior, Worcester resident since 1983
Resident B	Senior, volunteers to assist blind community
Resident C	Senior, living in triple-decker
Resident D	Senior, disabled, living in high-rise apartment
Resident E	Living in high-rise apartment
Resident F	Invasive plant management, Worcester resident since 1985
Resident G	Disabled, living in triple-decker, tenant rights activist
Resident H	Senior, lives in retirement community, Worcester resident since 1971

Table 3. *List of interviewees with relevant stakeholder information.*

Mixed Methods Data Analysis

The survey and interviews yielded a combination of quantitative and qualitative data. A variety of analysis methods were utilized to create assertions that inform each objective. Open-ended survey responses were coded into categories. For instance, for a question asking participants who they would contact if they needed help during extreme heat, responses were coded into three categories: "Named a person or public service they would contact", "Could not name a person or public they would contact", and "Perceived the question as N/A to them". Once all the variables were coded as necessary, graphs were created to visualize overall patterns as well as to explore relationships with other variables. Relevant quotes from interview transcripts were sorted into codes within each objective to support the assertions. Many interview codes contained secondary codes within them. For example, the code "Barriers to maintaining a thermally comfortable home" contains secondary codes including "Cost of utilities" and "Limitations of window AC", among others. Further methodology is provided below for each objective.

1. Understand Worcester residents' perceptions and experiences regarding climate change and extreme heat.

This objective utilized the following survey and interview responses:

- *Survey question 28 (Changes in Summer Weather*): Since living in Worcester, have you noticed any changes in the summer weather? (Open-ended)
- *Survey question 4 (Feelings during Extreme Heat):* During extreme heat events, what best describes your experience? (Multiple choice)
    - I do not feel any discomfort or concerns
    - I feel discomfort but no major concerns
    - I am concerned for my well-being

- *Survey question 11 (Heat Resilience in Residence):* How resilient to extreme heat do you feel in your residence?
    - From 1 (very vulnerable) to 10 (very resilient)
- Responses coded as "concerned about the future of extreme heat"
    - *Survey question 29 (Other Comments):* Do you have anything else to say about your experience with extreme heat in Worcester? (Open-ended)
    - Resident interview question: Do you perceive extreme heat as a health risk to yourself or your family?
- Responses coded under "Whether there should be further cooling adaptation initiatives in Worcester"
    - *Survey question 29 (Other Comments)*
    - As mentioned by interviewees (unprompted)
- *Survey question 6 (Heat Stress Moments):* Describe up to three moments (including activity, location, and time) when you have felt the most heat stress in Worcester. Example: Waiting for the bus, Union Station, in the morning
    - Moment 1: _____
    - Moment 2: _____
    - Moment 3: _____
- How does extreme heat disrupt participants' daily lives?
    - *Survey question 29 (Other Comments)*
    - Resident interview question: What is your life like during a heat wave? How does extreme heat disrupt your daily life?

Note that the recurring themes pulled from *Survey question 29 (Other Comments*) are particularly revealing, as these responses contain residents' most pressing thoughts about extreme heat in Worcester.

2. Identify populations in Worcester that are most vulnerable to extreme heat.

To understand which subgroups in the city self-identify as vulnerable with regards to extreme heat, *Survey question 4 (Feelings during Extreme Heat)* and *Survey question 11 (Heat Resilience in Residence)*–listed above–were treated as dependent variables. Responses to *Question 11* of five or less out of ten were generalized as "more vulnerable than resilient", while responses of over six are described as "more resilient than vulnerable". Survey responses from other questions were used as potential independent variables and were cross-tabulated with the dependent variables to explore relationships between the variables. For example, cross-tabulating responses to average household income before taxes with resilience to extreme heat in home suggests that lower-income Worcester residents identify as less heat resilient.

3. Understand how Worcester residents adapt during extreme heat events and which barriers impede their ability to adapt.

This objective relies on frequencies and summaries of the following:

- *Survey question 8 (AC):* Do you have air conditioning at your residence? What is its functional state? Select all that apply.

	Fully functional	Intermittently functional	Not functional	I don't have this
Central cooling system	☐	☐	☐	☐
Window AC units	☐	☐	☐	☐
Individual/other AC units	☐	☐	☐	☐
Fans	☐	☐	☐	☐

- *Survey question 7 (Cooling measures*): When you experience extreme heat in Worcester, what measures do you take? Select all that apply.
    - Open the windows
    - Turn on the fan
    - Turn on the air conditioning
    - Etc. (full list in **Appendix A**)
- Interview quotes and responses to *Survey question 29 (Other comments*) coded under the following themes:
    - Barriers to maintaining a thermally comfortable home
    - Barriers to staying thermally comfortable outside the home
    - Behavioral adaptations for staying cool
    - Social interactions during extreme heat

4. Propose feasible actions that would most efficiently ease heat vulnerability in Worcester.

The recommendations for improving heat resilience as detailed in this report pose solutions to the ways in which the largest populations as well as the most vulnerable populations are impacted by extreme heat, as revealed by objectives one through three. The action items address a wide spectrum of the impacts of extreme heat, from inside residents' homes to public spaces. Recommendations were ordered roughly from the least resources required per the amount of positive impact to the most resource-intensive. The Worcester Department of Sustainability and Resilience provided feedback on a draft of the recommendations, and revisions were made in accordance.

Results & Discussion

The following details the findings of this report by objective.

1. Worcester residents' perceptions and experiences regarding climate change and extreme heat

While largely unsurprising, these findings suggest the necessity of further heat mitigation solutions throughout the city. The findings suggest that climate change is affecting Worcester residents' lives already, and they fear for the future if no additional measures are taken to improve heat resilience.

1.1 Worcester residents perceive that they have observed the effects of climate change in recent summers.

Research participants perceive that summer weather is becoming more intense over time. In response to *Question 28 (Changes in Summer Weather)*–which asks open-endedly whether participants have noticed changes in summer weather since their time living in Worcester–81% responded affirmatively (n=232). Meanwhile, only 12% reported that they have not noticed changes, and 6% were unsure or said that they have not lived in Worcester long enough to have noticed changes. Using the number of years survey respondents reported having lived at their current address as a proxy for relative time living in Worcester reveals that longer-time residents were more likely to report that they have noticed the effects of climate change in Worcester. About three-quarters of the responses coded as "not sure" and "no" were reported by individuals who have lived at their current address for under two years. Overall, 90% of respondents who have lived in Worcester for at least five years reported that they have noticed changes in summer weather during that time (n=107).

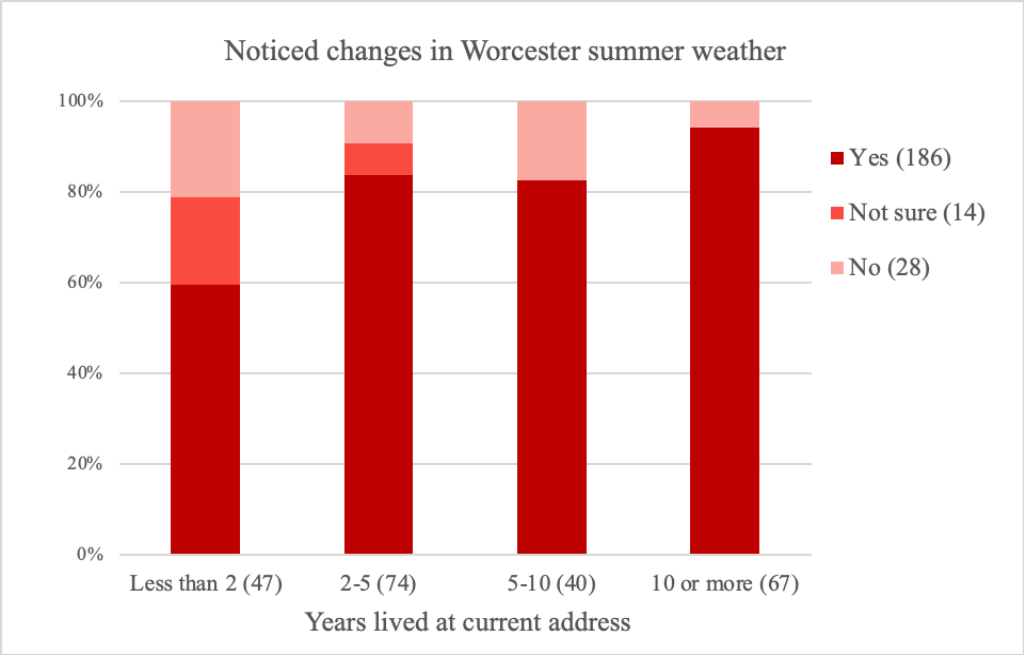


Figure 9. *Frequency of respondents who have noticed changes in summer weather by the number of years they have lived at their current Worcester address.*

While survey participants were not asked to report the specific changes they have observed, most of the participants who responded affirmatively to *Question 28 (Changes in Summer Weather)* noted at least one specific observation in their response. The most frequent changes described were higher temperatures, longer periods of high heat, and increased humidity, as shown in **Figure 10**. Overall, residents perceive that summer temperatures and humidity levels are staying consistently high throughout the summer rather than spiking occasionally, which they believe to be the case for previous summers. A participant who has lived in Worcester for eight years described how "there used to be an occasional really hot day but now there are weeks of unbreakable heat" during the summer. Another resident wrote, "It's gotten so much hotter over the last several years. We used to only have a couple of days of extreme heat in the summer and now it feels like it's constant", describing the concerningly short period of time they believe these changes have occurred over. "We just finished the longest heat wave I've ever experienced in 20 years," another comment reads, again capturing residents' perception of the rapidly intensifying conditions. Furthermore, one respondent described how the past summer brought "extreme humidity to the point of not enjoying being outdoors or out of air conditioned spaces" in the way that they could in previous years. The interviewees shared the same sentiment. Expert E said, "Having 90º[F] days isn't unusual in Central Massachusetts, but the [total] number and the number [of continuous 90º days each summer summer] has definitely gotten more over the past number of years". Expert E summarized their perception of changes in Worcester summers by saying, "I think the extremes are more extreme", referring to heat, humidity, and storms. These comments depict the widespread perception that Worcester summers are becoming less manageable.

Perceived change	Responses (n=232)
Hotter days	81
Longer heat waves	29
More humidity	26
More frequent heat waves	17
More rain/stronger storms	15
Spring/summer starting earlier	5
Other	24

Figure 10. *Summary of impacts of climate change Worcester residents report noticing. Note that the question was open-response, and some participants noted multiple changes.*

Interestingly, several residents expressed how Worcester's summer weather in recent years is reminiscent of regions known for their warmer climates. One respondent wrote, "I moved here because Virginia was too hot and [the heat] followed me". Others commented how the temperature, humidity levels, and thunderstorms of recent summers remind them of southern states they have lived in or visited. Additionally, one survey participant who lived in Colorado before moving to Worcester wrote, "There are days where the high desert summer weather in Colorado felt more bearable than our current heat wave due to the high humidity levels," referring to a heat wave in mid-July of 2024. These comparisons to subtropical and arid climates capture residents' perceptions of the severity of climate change in Worcester.

1.2 Worcester residents are concerned for themselves and others during extreme heat events.

Noticing the effects of climate change in Worcester causes residents to feel worried for themselves or others in the city. Nearly a quarter of survey respondents reported that they feel concerned for their well-being during extreme heat events. This means that roughly one in four Worcester residents might feel unsafe due to summer heat, representing a substantial population of the community. Additionally, in seven of the ten resident-perspective interviews conducted, participants stated that they believe extreme heat in Worcester poses a health risk to themselves or their loved ones. Resident D responded, "It's a health risk to everything, the environment, all living things, as well as myself and my family", demonstrating their perception of how extreme heat impacts the Worcester community and beyond. An elderly interviewee responded, "I think being old is risky. I'm 85, so I'm… aware of those risks", referring to the diminishing ability to regulate internal temperature as one ages (Resident C). The interviewee went on to describe the adaptive measures they must take in order to externally manage their body temperature during high heat, such as staying indoors and avoiding physical activity.

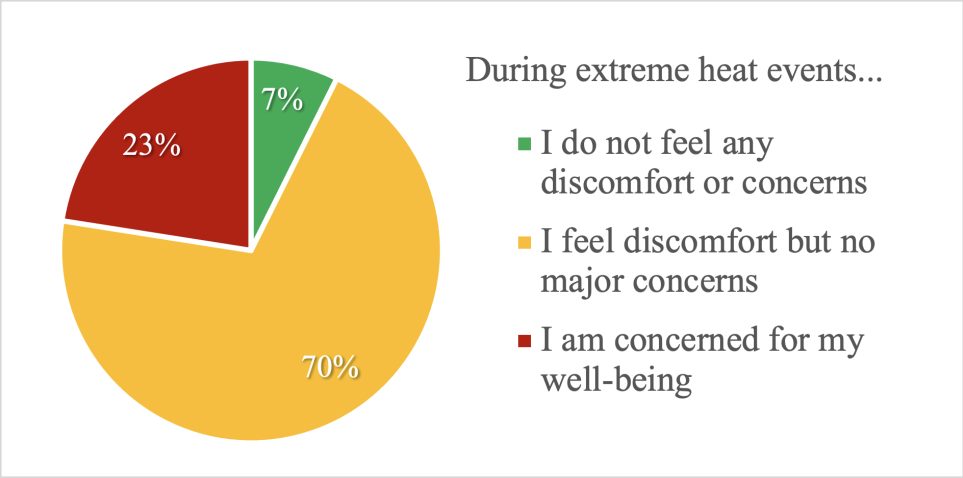


Figure 11. *Responses to the Worcester Heat Survey question, "During extreme heat events, which best describes your experience?" (n=324).*

The concern Worcester residents feel for themselves and their loved ones is reflected through the intentional action of checking-in on each other during high heat events. Six of ten resident-perspective interviewees indicated that during heat waves, they either check in on others or others check in on them. For example, Resident F described how they and their spouse habitually call their elderly neighbor on hot days to make sure he is okay. Interviewees who are more vulnerable themselves described how other community members care for them during extreme heat events. Resident C spoke about how his live-in landlord checks in on him regularly due to his age, especially during extreme heat. Meanwhile, Resident G, who lives in an un-airconditioned third floor apartment of a triple-decker, said that although their downstairs neighbors do not directly talk to them about the heat, they noticed that someone has been opening a third floor window in a shared porch when it is too hot, as they often do in order to air out excess heat rising from the lower apartments. Thus, although this resident does not usually speak to their neighbors about the heat, they suspect that someone is trying to alleviate their discomfort. The way that residents care for people in their lives who are most vulnerable to extreme heat demonstrates that the risks posed by extreme heat are understood.

While many residents are worried about themselves, friends, family, or neighbors, others feel that their immediate circle is not currently at risk, instead directing their concern towards underprivileged populations in Worcester. While the survey and interview did not directly inquire about respondents' perceptions of heat vulnerable communities in Worcester, several research participants indicated their concern for such populations. Expressing their awareness of privilege compared to more vulnerable communities in Worcester, one survey participant wrote,

> "I'm fortunate enough to be young, healthy, and live in a nice home, and there are still times where the heat can drastically impact my mood and level of activity. I'm sure this experience is greatly amplified for those who do not have access to the same benefits."

Additional responses suggest that residents are most concerned for low-income, unhoused, and disabled communities. One survey participant wrote, "I see many people who are unhoused

nearby, are there any resources for them?", while another commented, "I worry about [my] unhoused neighbors and folks working in the elements or waiting at an uncovered bus stop dying from this extreme heat". These responses reflect feelings of uncertainty and helplessness in regards to the well-being of Worcester's vulnerable communities. Resident H reported that they believe they would not be able to survive staying outdoors in the heat if they were unhoused, expressing the intense concern they feel for those in that situation. Another said that the heat poses "an absolute high risk for people who live in poverty, and particularly to the growing number of homeless," going on to describe their understanding of how gentrification increases rent, leading to the eviction of low-income residents who become unhoused if they cannot find another affordable unit. Additionally, residents feel concerned for the disabled community during extreme heat events. Resident D told the researchers that they worry for disabled residents who can face barriers in accessing cooling centers and other important resources. Another resident said that during heat waves, they make calls to the vision-impaired people they know through volunteer work. If they learned that anyone needed medical attention, Resident B said, "I'd be the one to jump in a car and [bring them to] the emergency room", demonstrating their dedication to assisting this community in the context of extreme heat. These comments about low-income, unhoused, and disabled people indicate that residents feel empathy towards heat-vulnerable communities, who they believe are not to blame for their underprivileged status, and are therefore deserving of more assistance. Whether for themselves, loved ones, or the Worcester population at large, residents demonstrate concern during extreme heat events through intentional communication and actions.

1.3 Climate change makes Worcester residents <u>worried about the future</u> for themselves and others in the city.

As residents perceive that summer weather in the city is becoming increasingly severe, concerns arise about how the community will be affected in the coming years. In response to *Survey Question 29 (Other Comments)*, several respondents expressed a strong sense of concern about future impacts of climate change. One resident wrote, "I am afraid for the future… I think heat could kill me someday", while another simply commented, "It's scary". Interviewees conveyed a similar trepidation for the future. Resident A bluntly explained their pessimism with regards to heat, saying, "Noticing the heat rising, particularly last year… and looking… [at] what is going on [globally]... I think we're f***ed," referring to their perception of a lack of widespread efforts to mitigate climate change.

Residents are worried not only about the effects of higher temperatures, but also about the complications they foresee in conjunction, as they or their loved ones continue to age, and as medical conditions or disabilities worsen. Resident H told us that they worry for their sister and brother inlaw who are entering their senior years. "Extreme heat is already an issue" for them, Resident H noted, "and it's going to become worse". Meanwhile, Resident D described how their

mobility-related disability that worsens with age makes them nervous about their ability to access cooling centers and other resources in the future.

Additionally, residents reported concerns about how the indirect impacts of climate change will affect the community. Two interviewees brought up the issue of mold, which they said could be caused by humid outdoor conditions as well as old air conditioning units. Resident E said, “Mold and mildew [are] much bigger concerns of mine than the heat itself,” while Resident G noted, “You don't really consider that window unit air conditioners need a proper… clean after a… decade or two of use”. Another symptom of climate change that residents spoke about was an increase of power outages. “Extreme heat can come with extreme thunderstorms [and] winds [that] can knock out power”, said Resident D, going on to explain how they worry about more frequent power outages interrupting air conditioning systems during periods of extreme heat. Such comments reflect the fear many Worcester residents have about what risks the future of summer weather will pose.

1.7 Worcester residents perceive a need for <u>further heat resilience interventions</u>.

Since extreme heat already disrupts elements of residents’ lives, they worry about the long-term well-being of the city if no further actions are taken to mitigate heat islands. Comments indicated this sentiment included residents’ perceptions of the most pressing issues related to heat resilience. For example, one survey participant wrote, “People who walk or use public transit, are homeless, or who live in substandard housing are in serious danger without drastic changes in local policy,” adding that they want to see efforts to decrease Worcester’s dependency on cars, which they believe contributes to heat islands. Another respondent addressed a desire for financial support with electric bills, writing,

“There needs to be as much emphasis on keeping cool as there is on keeping warm in winter. The electric company shouldn't be permitted to disconnect people on days when the temperature exceeds 90.”

This individual brought up an interesting point about differences between policies related to cooling versus heating. Since there has historically been an emphasis on staying warm during the winter, Massachusetts law requires that residential buildings are able to stay above a certain temperature throughout the winter, however no parallel law exists for the winter (Mass.gov, 2023). Finally, another participant summarized the sentiment by writing, “We need to do something immediately or people will suffer”. Such accounts reflect the common sentiment of the need for further heat mitigation actions, as residents perceive summer weather will increasingly exert an impact on the city.

1.4 Worcester residents experience heat stress while walking outside on impermeable and unshaded surfaces.

About half of survey respondents who participated in the open-ended *Survey question 6 (Heat Stress Moments)*–see **Appendix A**–reported "walking" at least once (n=259). Since the question was open ended, some responses included the destination or purpose of the walk, while others did not. The most commonly reported reasons were for pleasure, commuting to or from work or school, walking their dog, and completing errands.

Purpose/Location	Responses (n=100)	Proportion
For pleasure	33	33%
Work/school	18	18%
Errands	14	14%
Walking the dog	11	11%
Bus/train	9	9%
Car	8	8%
A business/event	7	7%

Table 4. *Responses for moments residents have felt heat stress that include walking as the activity and describe the reason for walking during high heat. Note that the Purpose/Location field could be the destination or starting point (ex. Responses like "Walking home after work" are included under "Work/school"). Additionally, the n-value corresponds to the number of responses coded to "walking" which disclose a purpose or destination.*

About half of the accounts of walking-induced heat stress were for necessary reasons, such as commuting to and from work or school. For these scenarios, residents cannot avoid walking even during extreme heat events unless they seek an alternative means of transportation. Although, for those without cars, waiting at one of the city's many unshaded bus stops poses issues as well (See **Assertion 2.1**). When walking to work or school, residents might be forced to walk through warmer areas in the city because they do not have the same freedom of choice of where to walk as if they were walking for pleasure. Similarly, they might need to arrive or leave at a predetermined time, limiting their ability to choose cooler times to walk.

Conversely, many residents still chose to walk during high heat for reasons deemed unnecessary. A third of accounts detailed that going on a walk for exercise or pleasure caused heat stress, while others described walking to the gym, a restaurant, church, or a social event. These responses suggest that although walking outdoors during extreme heat causes discomfort, many residents still try to maintain their regular habits for exercising and socializing. In other words, some residents perceive the benefits of engaging in their regular walking behaviors as outweighing their discomfort due to extreme heat.

The location types reported during walking-induced heat stress demonstrate a correlation between heat stress and walking through unshaded or impermeable surfaces. Of responses that

provided enough description, 89% described walking on paved surfaces such as sidewalks or parking lots, while the remaining 11% reported feeling heat stress while walking through a park or on a nature trail (n=140). This is likely because residents walk through parks and trails less frequently, but also because these areas are cooler. While only 11 participants reported walking through parking lots or driveways, these responses illustrate a compelling pattern; several responses described feeling heat stress during the short walk through a parking lot to enter or exit their workplace. In other words, the heat radiating from paved surfaces in a parking lot is strong enough to cause great discomfort in less than minutes.

Investigating the geographic locations where heat stress was reported while walking further demonstrates the impact of shade and impermeable surfaces on pedestrian discomfort. In short, instances of walking-induced heat stress were reported more frequently in the densely urbanized areas of Worcester with less trees providing shade and more dark-colored pavement and concrete emitting absorbed heat.

Worcester neighborhood	**Responses** (n=64)	**Proportion**
Downtown	32	50%
Elm Park, Piedmont, Beaver Brook	13	20%
Webster Square, Main South	10	16%
Biotech Park, Bell Hill, Shrewsbury Street	4	6%
Grafton Hill, Broadmeadow Brook	3	5%
Vernon Hill, Quinsigamond Village	2	3%

Table 5. *Reports of walking as a source of heat stress, categorized by which Worcester neighborhood the respondents were walking in. Note that the n-value corresponds only to responses coded as "walking" that disclosed a geographic location.*

Overall, the high frequency of responses for walking-induced heat stress suggest factors about the urban landscape of Worcester that contribute to stress and discomfort for those traveling on foot. It is important to ensure a thermally comfortable pedestrian experience. Increasing urban walkability has been shown to decrease energy consumption and improve public health through promoting exercise and limiting pollution (Targhi & Van Dessel, 2015).

1.5 Worcester residents feel heat stress in their homes, disrupting sleep and other essential activities.

Of the respondents who participated in *Survey question 3 (Heat Stress Moments*), 72% indicated that they have felt heat stress while in their homes, with a total of 300 responses coded to this location (n=259; Note that this survey question allowed respondents to submit three examples). The most commonly reported activities that caused heat stress for survey respondents while in their homes are trying to sleep, cooking, partaking in passive activities such as reading or watching TV, and studying or working from home.

Activity	Responses (n=295)	Proportion
Sleeping	127	43%
Cooking	79	27%
Passive activities	41	14%
Work/school	28	9%
Chores	18	6%
Exercising	2	1%

Table 6. *Activities that survey respondents reported have caused them heat stress while inside their homes. Note that the n-value corresponds only to responses coded as "inside home" that included an activity.*

Getting poor or not enough sleep due to excessive heat in one's bedroom can result in weakened resilience to stressful factors. About half of participants who responded to *Question 3 (Heat Stress Moments*) reported "trying to sleep" for at least one of their three instances of heat stress (n=259). Outside research confirms that temperature is an important factor for sleep. Ones' quality of sleep declines when bedroom temperatures exceed 75°F, or 80°F with the use of fans to promote air flow (Joshi, et al.). In addition to overheated bedrooms, the devices residents rely on for staying cool could impact their sleep as well. Resident E spoke about how the noise level in their room at night makes it hard to fall and stay asleep. They said, "I have an air conditioner… two or three fans [and] a dehumidifier, so it's very loud." Trouble sleeping could leave residents more vulnerable to extreme heat during the day. Getting enough sleep is essential for recovering physically and mentally in order to maintain resilience. Studies have shown that insufficient sleep can make individuals more emotionally and physically vulnerable to disturbances (Arora et al., 2022). Thus, Worcester residents could be more vulnerable to the discomfort or health risks posed by extreme heat due to difficulties sleeping.

Cooking was also shown to cause heat stress for Worcester residents. Research participants attributed their discomfort to the heat output of stovetops, ovens, and other cooking appliances, exacerbated by the physical movement required to cook. Residents also expressed how their discomfort while cooking often drives them to avoid the activity altogether. One survey respondent wrote that their "electric stove and oven throw a lot of heat so cooking [during] heat wave[s] has been unbearable," thus they have been "eating lots of take out". Landlord B told the researchers, "Cooking is especially difficult… [I] feel like I'm losing… five pounds whenever I cook a meal, and it causes me to not want to cook." Those opting to order food more frequently could be experiencing the negative repercussions of consuming less nutritious food as well as the financial strain of frequently ordering takeout.

Worcester residents also feel heat stress during more sedentary activities in their homes including relaxing, socializing, studying, or working. Discomfort due to heat in the home may be interfering with residents' ability to recuperate and enjoy their time outside of work or school, whether through spending time with loved ones or simply "relaxing on the couch", as many

survey respondents wrote. One participant captured this when they wrote, “It’s hard. Exercise is hard… Socializing is hard”, emphasizing the way that extreme heat makes them lose motivation for activities they typically enjoy. Again, these struggles suggest an inability for Worcester residents to prevent their homes from becoming too hot.

Since the onsight of the COVID-19 pandemic, many employees have begun to work in a hybrid or completely remote setting, thus, the comfort of one’s home has become an important factor of productivity for many residents. A review of 25 studies on room temperature and productivity in office settings concluded that the ideal temperature for working is 71ºF, with a noticeable decline in productivity at temperatures starting at just 74ºF (Seppanen, et al., 2006). Several residents expressed how their inability to maintain a suitable temperature in their homes poses challenges for completing necessary tasks for work or school. Landlord B, who works fully remotely, spoke about how it is difficult to sit still in their un-air conditioned home office. “It feels like a sauna in there,” they remarked, adding that they have to take frequent breaks while working. Meanwhile, Expert E told the researchers that because of extreme heat, “it's hard to think [and] it's hard to get motivated.” “Heat will make you brain dead,” remarked Resident B. Lastly, Resident F said that the energy depletion they experience during extreme heat results in them “not feeling like [they] want to conquer any task”. In summary, the discomfort residents feel in their homes contributes to interruptions to their daily lives ranging from poor quality sleep to depleted focus.

1.6 Extreme heat forces Worcester residents to be <u>more sedentary and stay indoors</u>, resulting in disruptions to daily life and general displeasure.

Research participants often described the impacts of avoiding movement and the outdoors during extreme heat. Two-thirds of the participants of select-all-that-apply *Question 7 (Cooling Measures)* indicated that they avoid going outside during extreme heat, while half reported avoiding physical exercise (n=319). These are natural responses in the face of extreme heat, however, those skipping their regular gym regimens or walks through the park are missing out on the physical and mental health benefits of exercise and spending time in nature, which can lead to worsened moods and energy levels. Many respondents commented about these types of disruptions in the survey’s final open-ended question. For example, participants wrote, “I basically can't go outside or exercise all summer because it's too hot and I get sun sickness”, “I get a bit stir-crazy inside all the time”, and “Some days it’s too hot to do anything”. Another resident claimed that they often experience “extreme humidity to the point of not enjoying being outdoors or out of air conditioned spaces.”

Research participants also told the researchers how these disruptions to exercise and going outdoors directly impact their mental state. While interviewing Resident A, an avid hiker, they said, “Normally I hike two [or] three times a week, and I just haven't been able to, so, that hits me hard,” acknowledging the way their mood is affected. Resident D, who has a neurological disability that interferes with mobility and heat regulation, described the way in

which their life is impacted during heat waves. They are forced to greatly limit their movement, which makes them feel as though they were “more disabled”. They also described how heat disrupts their ability to garden, one of their favorite hobbies. These resident accounts clearly illustrate how heat negatively impacts Worcester residents’ quality of life by disrupting exercise and other activities that are important to residents.

2. Populations in Worcester that are most vulnerable to extreme heat

Heat vulnerability studies typically analyze spatial patterns of populations who are viewed vulnerable to extreme heat, however all cities have different socioeconomic and cultural dynamics. In other words, a group who is very vulnerable in one part of the world might be less vulnerable in another. Thus, this objective seeks to gain a more thorough understanding of the inner workings of heat vulnerability in Worcester utilizing resident perspectives of their own resilience.

As described in the Methodology, this analysis utilizes responses to the following questions as dependent variables for heat vulnerability:

- *Survey question 4 (Feelings during Extreme Heat):* During extreme heat events, what best describes your experience? (Multiple choice)
    a. I do not feel any discomfort or concerns
    b. I feel discomfort but no major concerns
    c. I am concerned for my well-being
- *Survey question 11 (Heat Resilience in Residence):* How resilient to extreme heat do you feel in your residence? (Scalar)

Very vulnerable	1	2	3	4	5	6	7	8	9	10	Very resilient

2.1 <u>Low-income communities</u> in Worcester perceive themselves to be less resilient.

The Worcester Heat Survey demonstrates a clear connection between lower household incomes and feeling unsafe during extreme heat. A sizable 57% of respondents with incomes under $25,000 per year reported that their level of resilience to extreme heat in their residence is five out of ten or less, indicating that they feel more vulnerable than resilient (n=58). Within the same income group, 37% indicated that they feel concerned for their well-being during extreme heat (n=60). Average ratings for how resilient survey participants feel in their homes noticeably trend upwards with income, as shown in **Figure 12**. Further analysis demonstrates that Worcester residents with smaller household incomes are challenged in their ability to remain safe during extreme heat due to poorer living conditions and increased exposure to extreme heat.

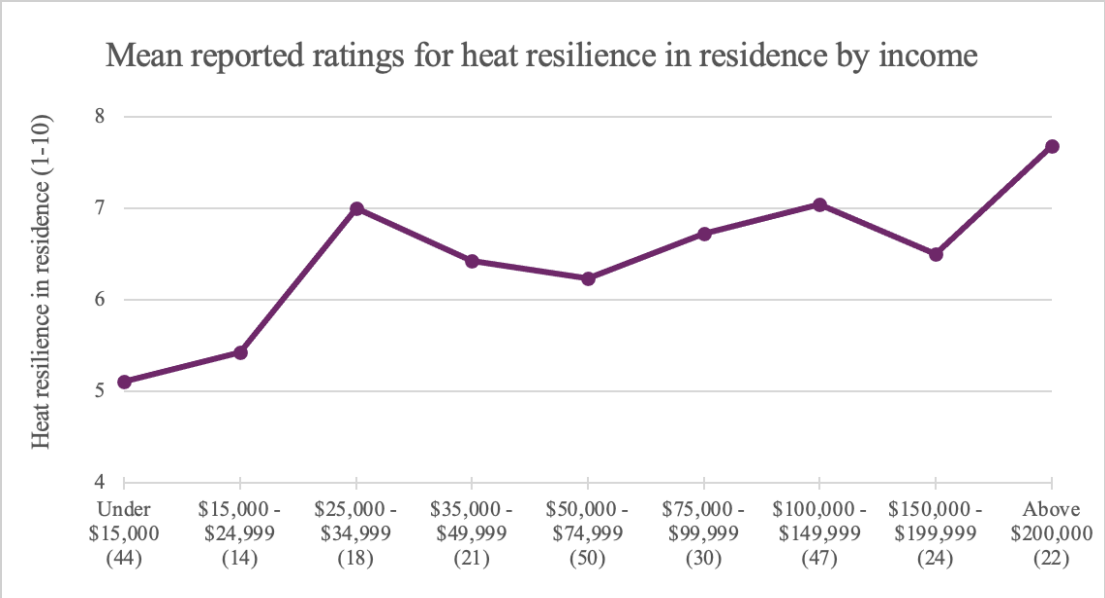


Figure 12. *Mean self-reported ratings for heat resilience in one's home by income group, with 1 being very vulnerable and 10 being very resilient.*

Worcester residents of lower income status are less likely to have air conditioning and more likely to face challenges associated with renting, including poorer quality homes and an inability to modify them. Income status prevents many residents from installing air conditioning units. As discussed in the following objective, this is due to initial purchasing costs as well as the knowledge that running air conditioning units will cause expensive utility bills. Regardless, research shows that air conditioning is an important predictor of heat-related deaths (Ashbaugh, & Kittner, 2024; Bouchama, 2004; Semenza, et al., 1996). Only 50% of respondents with household incomes of under $25,000 have fully functional air conditioning, compared to 76% of those with an income of $75,000 or higher ($n_1$=61 and n_2=124, respectively). As expected, survey respondents without fully functioning AC indicated feeling less resilient on average. Specifically, over half reported a resilience level of five or less out of ten (n=43).

Low-income individuals are also much more likely to be a renter rather than a homeowner, meaning they have less control over the condition of their residence.

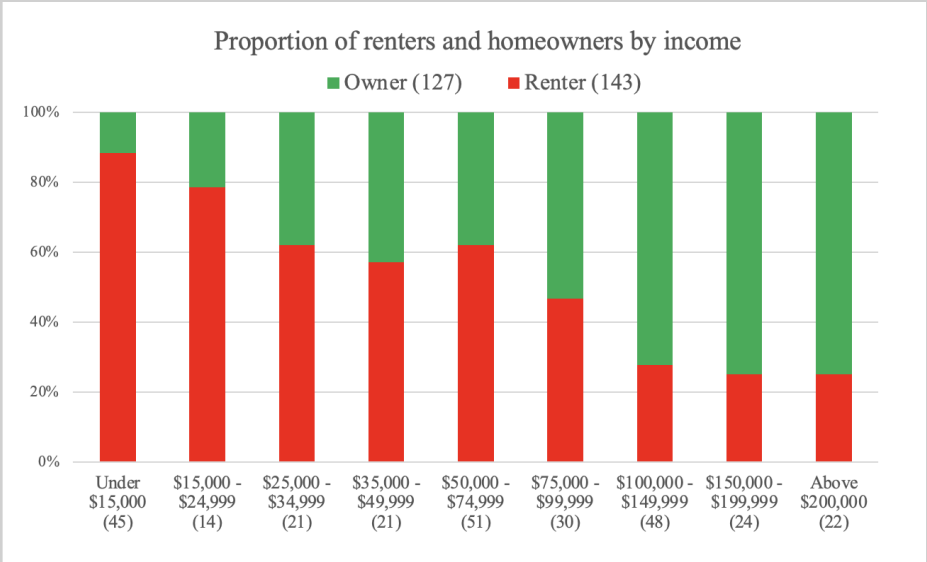


Figure 13. *Proportion from each annual household income group who are homeowners versus renters.*

As reported by survey respondents, rental properties in Worcester are often in worse condition, making them less energy-efficient and more costly to cool. Renters are also largely unable to modify their homes to be more efficient. **Assertion 3.3** will discuss how tenants fear rent increases, meaning they do not advocate for their landlords to carry out modifications. Discrepancies in housing conditions that impact cooling efficiency include the quality of insulation, roofing, windows and ventilation systems. Due to outdated elements, the mean summer electricity bill for those with "Average" condition homes is higher than those with "Good" condition homes. Residents of "Poor" condition homes actually have the least expensive summer utilities on average, but this is likely because these individuals are more limited by cost, leading them to choose not to run AC.

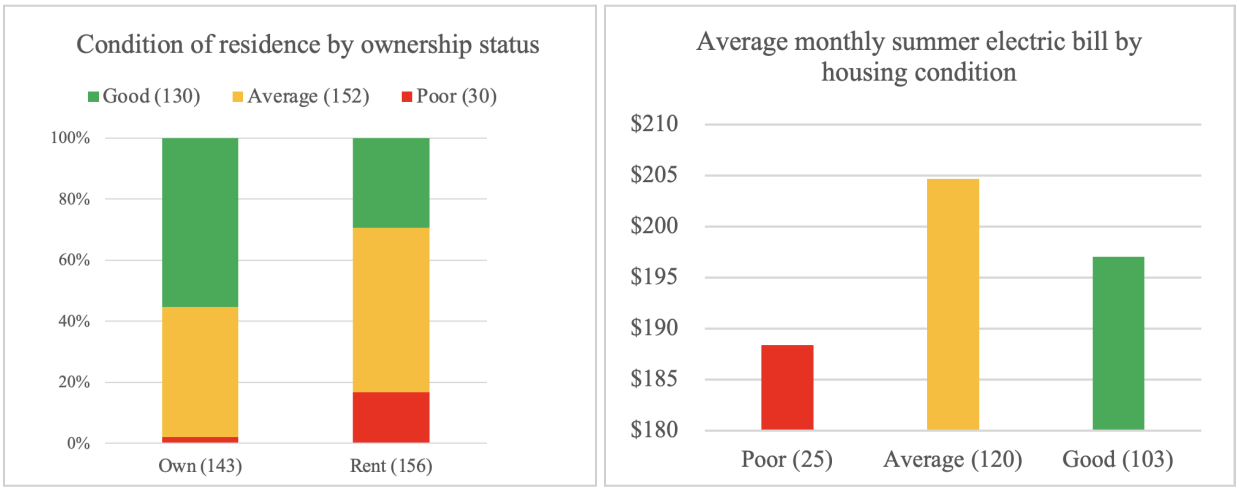


Figure 14. *Reported housing condition by whether residents rent or own their home (left), and mean monthly electric bill during summer months by housing condition (right).*

As a result, renters report feeling less safe than homeowners in regard to summer heat. While only 13% of homeowners report feeling concerned for their well being during extreme heat, this is true for 30% of renters (n_1=143 and n_2=154, respectively). Additionally, almost half of renters feel vulnerable to extreme heat in their homes (n=150).

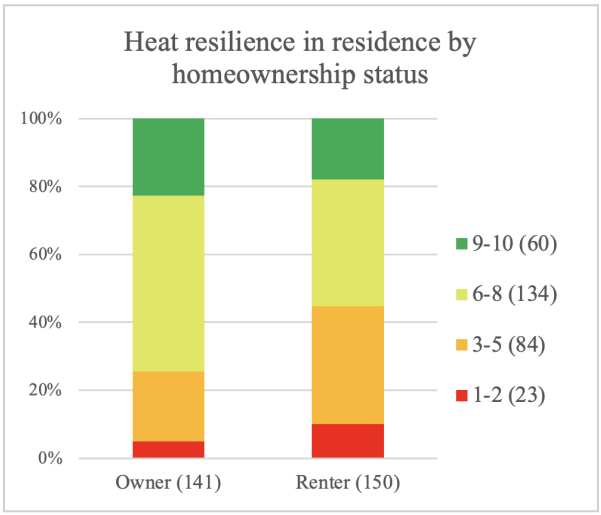


Figure 15. *Self-reported resilience to extreme heat in one's residence for homeowners versus renters.*

Similarly, the data demonstrates relationships between income and housing type, which also informs the housing condition. Triple-deckers and single family homes serve as the ends of the spectrum of Worcester housing quality, as triple-deckers are older and have the more outdated infrastructure compared to single detached homes. As a result, triple-decker apartments are more affordable, while single family homes are more expensive and more frequently occupied by residents with higher household incomes.

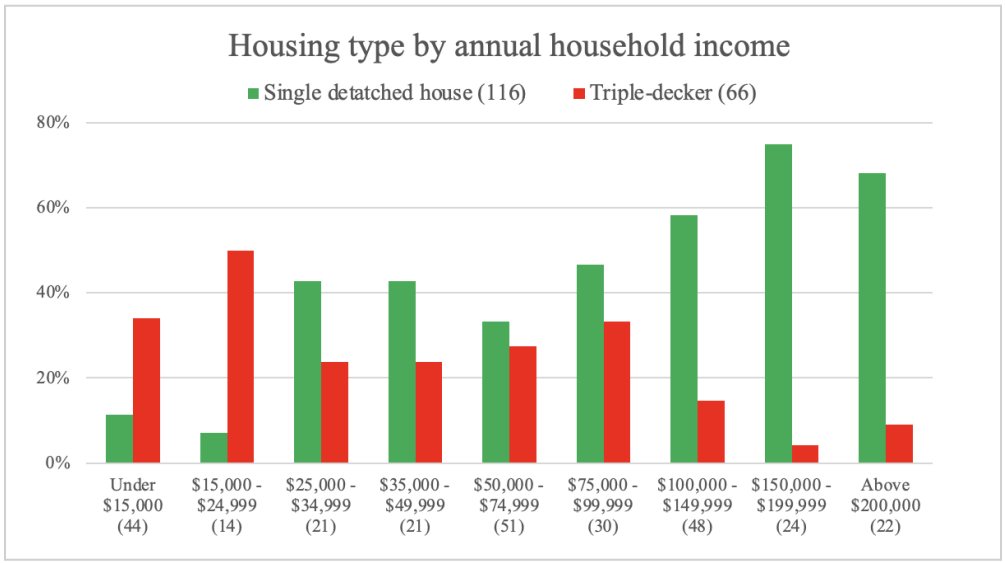


Figure 16. *Percentages of respondents living in triple-decker apartments and single detached homes from each income group.*

Due to discrepancies in the conditions between these two types of homes, individuals living in triple deckers perceive their level of risk to be higher than those in single family homes. In fact, 53% of survey respondents living in triple-deckers feel vulnerable to extreme heat in their homes, versus 26% of those in single family homes (n_1=74 and n_2=129, respectively).

Income is also a determinant of how exposed to ambient heat residents are, as lower income residents are more likely to live in areas characterized by more impermeable surfaces, less natural areas, and thus more intense heat islands. The previous WPI heat vulnerability research team observed that lower income residents are disproportionately represented by communities living within the city's hottest neighborhoods (McCauley, et al., in preparation). This finding is confirmed by the Worcester Heat Survey results. Most notably, over half of survey respondents living in the 01610 zip code–encompassing Main South's heat island–have an annual household income of under $50,000, with 33% making under $15,000 (n=27).

Beyond the housing sector, income influences the likelihood that a Worcester resident works outdoors, resulting in unavoidable exposure to heat throughout the summer. The proportion of respondents who work fully or mostly outdoors trends downward as income level increases. Survey participants who work outdoors reported feeling concerned for their well being more frequently than those who work or study indoors. Of respondents who work completely outdoors, 28% are concerned for their well-being, compared to 20% of respondents who work or study mostly or completely indoors (n_1=32 and n_2=226, respectively).

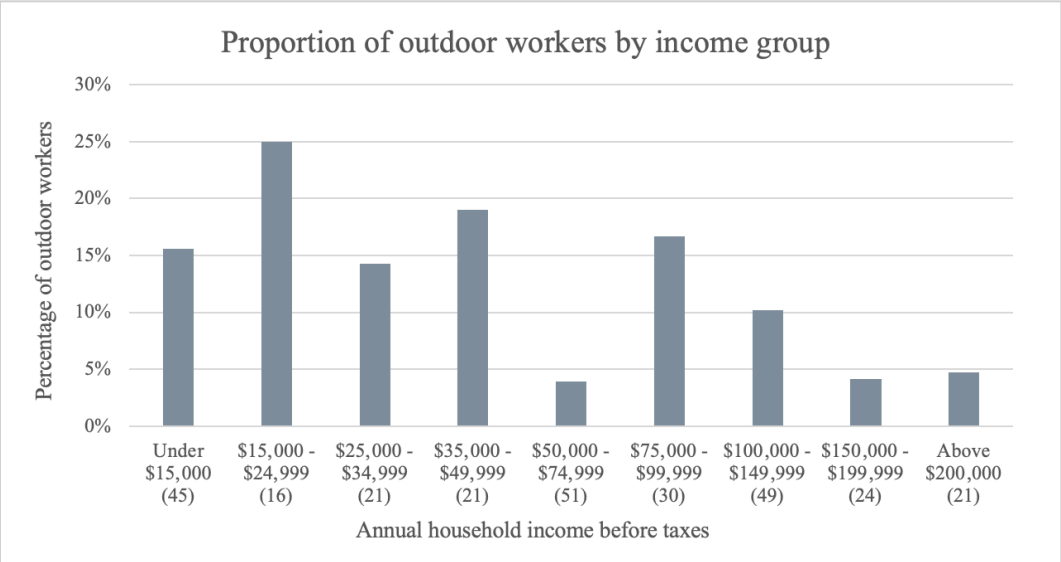


Figure 17. *Proportions of each income group who reported that they work outdoors.*

Lastly, Worcester residents of low-income status are more likely to utilize public transportation, further exposing them to heat while waiting at unshaded bus stops. As shown below, there is a strong relationship between income and whether a participant reported having felt heat stress while waiting for transportation in response to *Survey question 6 (Heat Stress Moments).* Survey participants also left comments on *Survey question 29 (Other Comments)*

regarding this problem. For example, one respondent wrote, “People without… cars are suffering the most while… waiting for buses without any… shelter”.

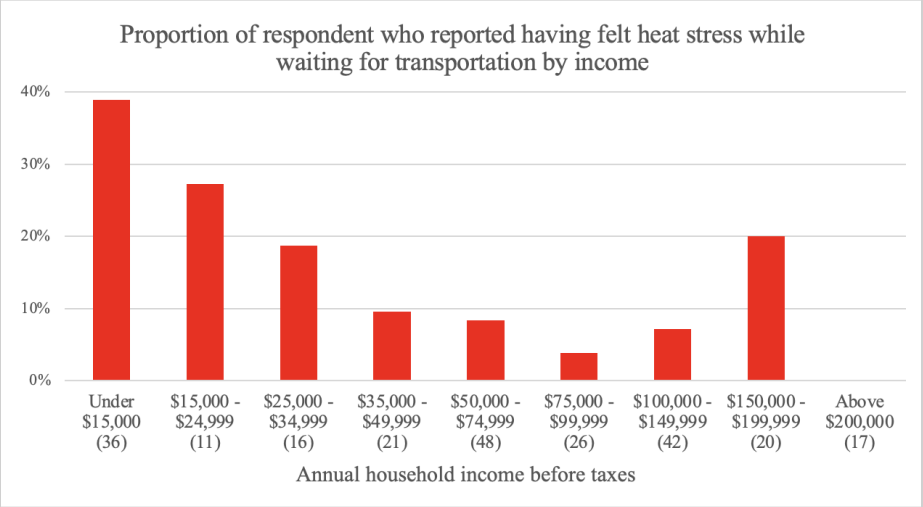


Figure 18. *Reports of having felt heat stress while waiting for public transportation versus income.*

2.2 <u>Elderly residents</u> and individuals with <u>chronic medical conditions</u> perceive themselves to be more vulnerable.

As expected, feeling concerned for one’s well-being during extreme heat was more frequently reported by older survey respondents. However, this correlation was not as strong as anticipated, considering that elderly populations are perhaps the most widely-regarded heat vulnerable population. The proportion of residents who feel concerned during extreme heat increases from 17% for respondents younger than 26 years old to 27% for respondents older than 65 (n_1=60 and n_2=26, respectively). The proportion of concerned residents is only a few percentage points higher for elderly residents than the overall survey average of 23% (n=324).

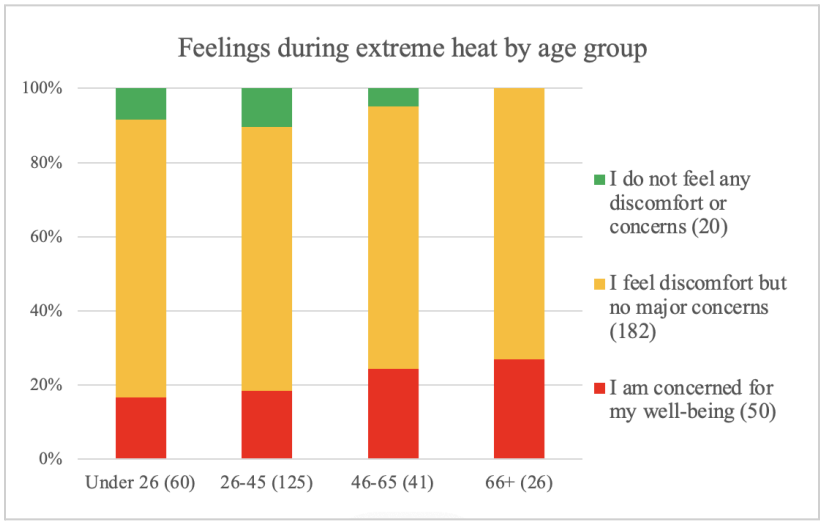


Figure 19. *Responses to Survey question 4 (Feelings during Extreme Heat) by age group.*

The level of concern for elderly Worcester residents is likely not as high as anticipated due to increased social connectivity for older residents. Meanwhile, higher levels of concern can be explained by more frequent cases of chronic illness for older individuals.

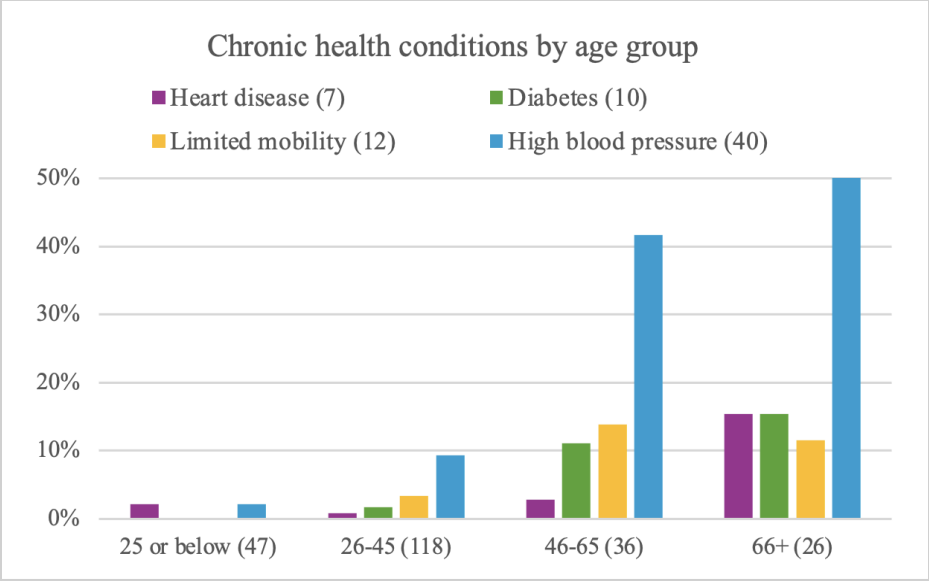


Figure 20. *Percentages of survey respondents from each age group who have chronic medical conditions that impact heat regulation.*

Reports of heart disease, diabetes, limited mobility, and high blood pressure trended upwards with the age of survey respondents. Correlating most strongly with age, high blood pressure was reported by only 2% of participants younger than 26 and 50% of participants older than 65 (n_1=47 and n_2=26, respectively). Because of the ways in which these conditions impact the body's ability to regulate heat, individuals who reported having heart disease, diabetes, limited mobility, or high blood pressure also more frequently reported feeling concerned about their safety during extreme heat events. Although the sample size is small, limited mobility appears to pose a significant threat to Worcester residents during extreme heat, as 62% of participants with limited mobility reported feeling concerned for their well-being (n=16). During the interview with Resident D, who has a condition that impacts mobility, they said, "I am not able to be active during heat [which] affect[s] my life enormously", making them feel as though they were "more disabled". Heart disease also has a notable impact on heat vulnerability, with 50% of respondents with heart disease reporting feeling concerned for their well-being during extreme heat (n=8).

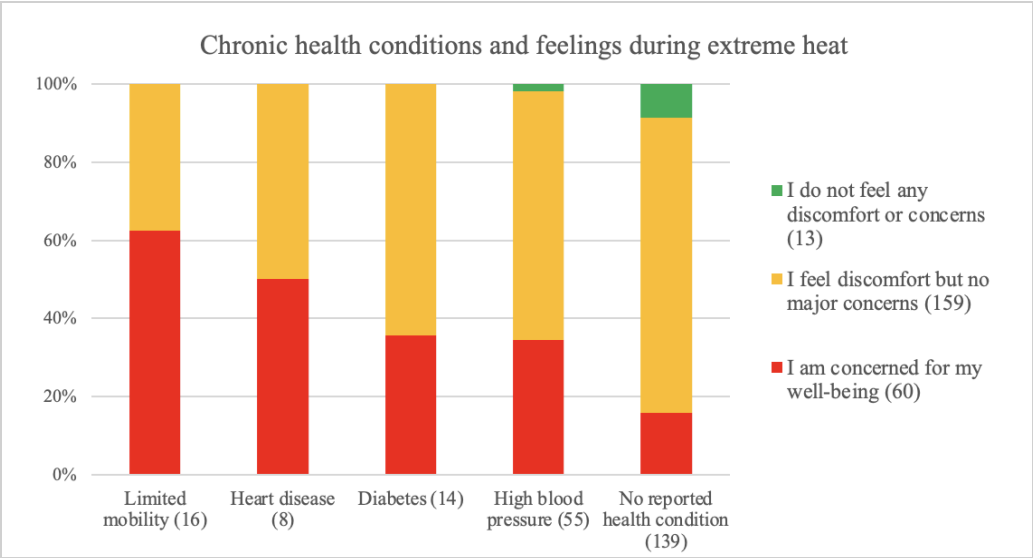


Figure 21. *Responses to Survey question 4 (Feelings during Extreme Heat) by chronic medical conditions.*

Fortunately, the survey data demonstrates that elderly individuals in Worcester tend to be more connected with their neighbors, which most likely explains why elderly research participants reported feeling concerned during extreme heat less frequently than anticipated. The number of neighbors survey respondents know by name clearly trends upwards with age. This suggests that many elderly residents in Worcester have people close by they could call upon incase they needed help during extreme heat. For example, an 85 year old resident we interviewed told us about how a close bond with their landlord who lives downstairs makes them feel safer with regards to extreme heat and other risks that arise with age. "If… I drop something heavy… she or her son will come upstairs and say, 'Are you okay?'" Resident C explained.

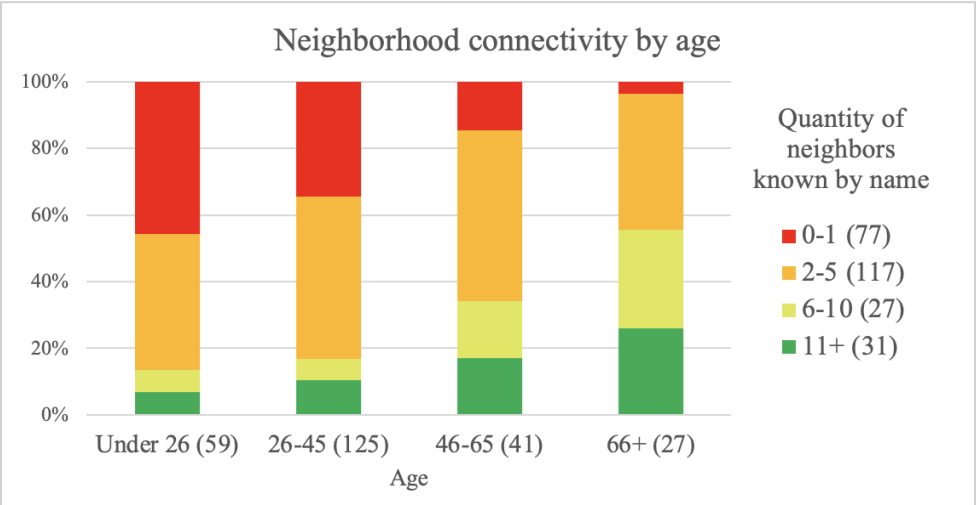


Figure 22. *Number of neighbors survey respondents know by name by which age range the respondent belongs to.*

This report finds that Colony Retirement Homes, apartments for senior independent living in Worcester, could be looked upon as a framework for alleviating heat vulnerability for the elderly population of Worcester. Although sample sizes are small, there are clear differences between the concern levels during extreme heat for Colony residents compared to other Worcester elders. Every Colony resident who responded to *Survey question 4 (Feelings during Extreme Heat)* reported feeling discomfort during extreme heat, but none of them indicated feeling concerned for their well-being (n=5). Contrastingly, 4 out of the 10 survey respondents who are older than 69 and do not live in Colony reported feeling concerned for their well-being. It is also interesting to note that the average age of Colony residents is 78.3, while the average age of non-Colony elders is 75.6. Thus, Colony residents feel more safe during extreme heat despite being slightly older on average.

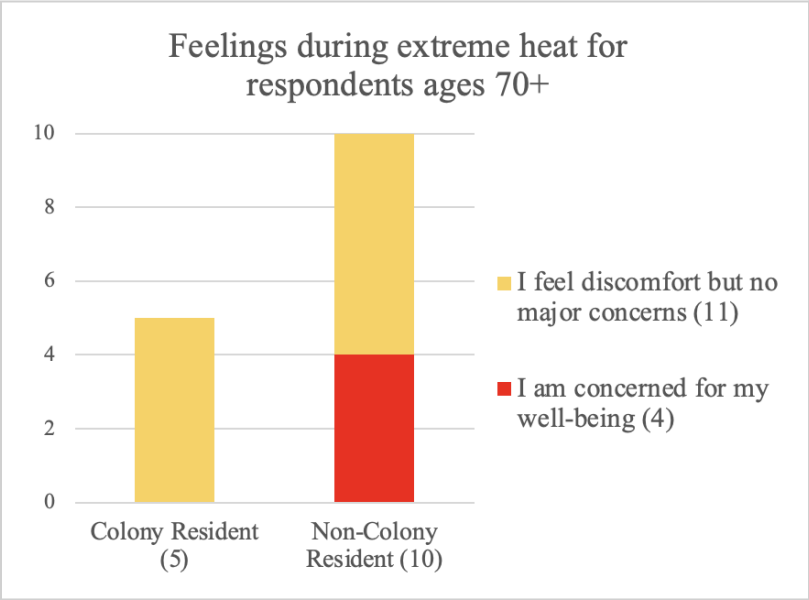


Figure 23. *How elderly survey respondents report feeling during extreme heat, by whether the respondent lives in Colony Retirement Homes. Note that the third option on this survey question was "I do not feel any discomfort or concerns, but no respondents over 69 years old selected this option.*

In addition to the health services Colony residents have closely available to them, their lower levels of concern during extreme heat can be attributed to the close social bonds between residents. The residents interviewed one senior at Colony who described the sense of community they feel at the retirement home. While they initially moved in simply "to have a place to put all [their] stuff" they quickly became enamored with the community of other seniors living there. "There's such an interesting variety of people," Resident H told the researchers, "Even when they get on my nerves, I love them". Regarding extreme heat, this resident was a perfect example of the importance of neighborhood connectivity for heat resilience. While they feel resilient as long as they stay inside their basement-level apartment during extreme heat, they worry about a friend who also lives at Colony, making sure to call or visit to check in on him. "He's an old friend of mine that I'm sort of looking after," said Resident H. From speaking with this interviewee as well

as observing interactions between Colony residents while looking for survey participants, it is clear that Colony is a tight-knit community where seniors are able to rely on each other. In fact, the Colony survey respondents knew far more of their neighbors than their non-Colony senior counterparts, with five out of the six Colony seniors knowing ten or more neighbors.

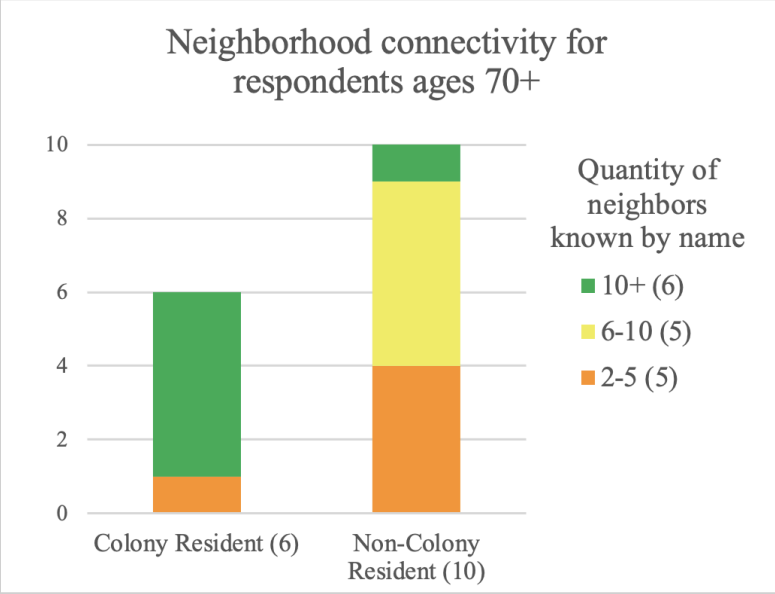


Figure 24. *Number of neighbors elderly survey respondents report knowing by name, by whether the respondent lives in Colony Retirement Homes. Note that the fourth option to this question was 0-1, but no respondents over 69 years old selected this option.*

3. Worcester residents' cooling adaptations and barriers to cooling

Any city-wide intervention should agree with the values and desires of residents, since they will be directly impacted by the interventions. The following describes the socio-ecological-infrastructural systems which either alleviate or contribute to heat vulnerability, according to residents themselves.

3.1 Worcester residents are becoming <u>increasingly reliant on air conditioning</u>.

For a city whose historical housing stock was constructed without the need to accommodate air conditioning in mind, the density of air conditioning units in residences throughout the city is surprisingly high. In fact, 83% of respondents to *Survey question 8: (Air Conditioning)* reported having some type of AC in their residence, whether central air, window units, or individual units such as mini-splits (n=317). It is clear that air conditioning ownership in Worcester has increased rapidly in the last decade, as summers become gradually less bearable without a cooling device.

Several survey and interview participants described how air conditioning was not necessary in Worcester until the past several years, which has driven many of them to purchase and install AC units. One resident said that they never needed air conditioning "until 3 years ago

when it became intolerable" to live without it. Another said that recently they had to install air conditioning in order to be able to continue their volunteer project during the summer, which involves ironing. Additionally, Expert D, a leader of a local community development center that residents have been considering investing in costly mini splits. This interviewee went on to tell the researchers that they also purchased an AC unit this year, calling it "a sign of the times [that] it's getting hotter". Others described how air conditioning was not necessary while they were growing up or attending college in Worcester, but feels necessary now. Expert E explained that if only about "five days over the course of the season [are excessively hot]... you can get through that," going on to state that in recent years, they perceive that the number of oppressively hot days is surpassing the threshold of what is bearable without air conditioning. "My attitude was always… that I [don't] want to trip over an air conditioner all year long [because of one] hot week," remarked Landlord A, "[but] now I'm getting more and more hot weeks", capturing the thought process of many residents as they weigh the adverse impacts of installing air conditioning with the fear of how summer heat will continue to intensify in the future.

Even residents who were previously opposed to installing air conditioning units due to financial or environmental concerns find themselves feeling as though they have no other option. Resident A, who said, "I'm energy conscious; I pay the bills", ultimately installed two air conditioning units in 2024, attributing this necessity to the more frequent heat waves of the past several summers. A former student of Clark University who still lives in Worcester described living in an un-air conditioned third floor apartment during their undergraduate studies. Exacerbated by medical issues, the lack of AC resulted in several trips to the hospital. "Now we have three AC units in a two bedroom [apartment]," they wrote, "and I feel guilty about it because I know AC use contributes to climate change, and at the same time, I get seriously ill without it". Resident B holds the same sentiment, telling us, "I don't like to turn it on… It's expensive… and not very green". They continued by saying, "We have to go to great expense and further damage the climate in order to keep doing what we're doing"–referring to their hobbies. Wrestling with this cognitive dissonance, Resident B eventually opted for two small air conditioning units, to which their spouse argued against. They reported that they have since both come to reluctantly acknowledge the necessity of using air-conditioning in moderation despite its many trade-offs.

3.2 The <u>utility costs</u> of running AC prevents residents from achieving a thermally comfortable home.

It is likely that most residents in Worcester have some form of air conditioning, as 85% of survey respondents reported having central air, window units, or another type (n=315). However, the fact that only 27% of survey respondents with functioning air conditioning rated their level of heat resilience in their residence over five out of ten reveals a disconnect in residents' ability to ensure a safe climate within their housing units (n=202). Many residents cited the cost of running their air conditioning as a limiting factor. Survey respondents vented such frustrations in

response to *Survey question 29 (Other Comments)*. One wrote, “The electricity prices make it hard to stay cool and comfortable”. Citing their most recent utility bill, one resident described how delivery fees more than doubled the total to $330, adding, “That is not sustainable in the long-term for many people.” Another complained about emails from National Grid (NG) meant to “scold” residents who are using too much energy:

> “Either NG needs to allocate resources to have a system that can handle this stuff, reduce its price, or step aside so somebody else can do it. I believe municipal or state intervention on this point would be absolutely justified and popular. NG is already ridiculously expensive compared to electricity in the Boston area so this is just [an] insult to injury.”

This resident’s complaint about discrepancies in electricity rates compared to Boston are justified. Worcester’s provider National Grid charged 18.213¢ in July 2024, while Eversource, which services the Boston area, charged 17.216¢ (Odogwu, 2024). Many others shared the sentiment of wishing for more support from the city with summer utilities. One wrote, “I wish the city would offer homeowners more resources to secure better utilities,” describing how the rates Worcester residents must pay are simply too high. For most residents, utility costs limit them from running their air conditioning as intensely as they would like, however there is a population that feels unable to afford any AC use. “I chose to not run AC because it's too expensive,” wrote one survey participant.

Residents are also impacted by rising utility costs, contributing to further concerns about their safety in the following years. As shown below in **Figure 25**, rates have almost doubled since 2012, having a major impact on many Worcester residents (National Grid, 2025). One survey respondent wrote, “Utility costs seem to rise in a big way every year even though we continue to make efficiencies or insulate”. Resident D told us, “As I become more disabled and my husband–who's 10 years older than I am–becomes more disabled, I worry that we may not be able to afford as much cooling as we'd like” due to increasing utility costs. These data and accounts imply that rising utilities are the largest barrier to air conditioning use, rather than the cost of purchase and installation.

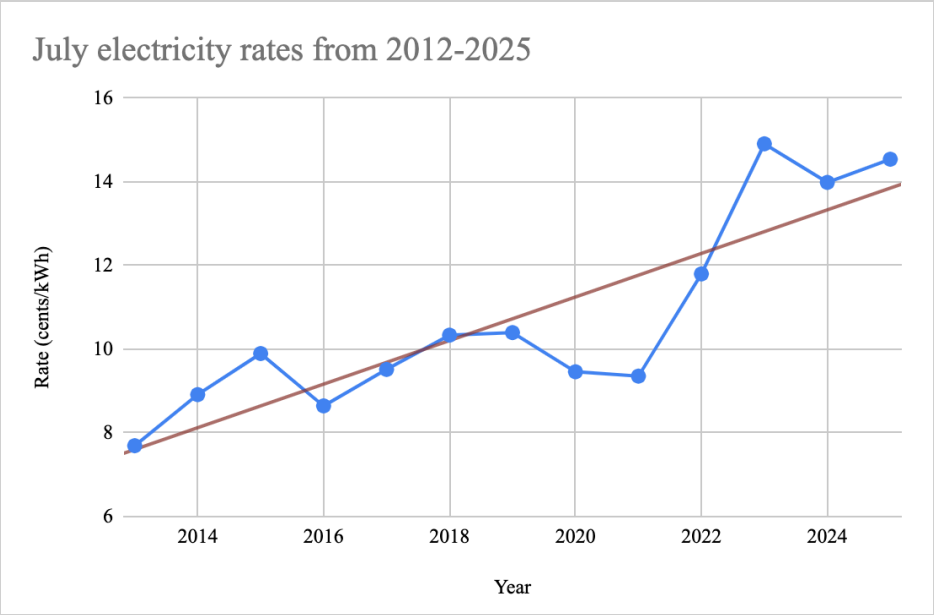


Figure 25. *Massachusetts National Grid rates for the month of July over time (National Grid, 2025).*

The air-conditioning type most frequently reported in the Worcester Heat Survey was window units, accounting for 37% of responses to *Question 8: Air conditioning*, however survey data shows that those with window units are less likely to feel that the temperature of their home is comfortable (n=317). Almost 40% of residents with window units rated their level of heat resilience in their home five or less out of ten, compared to under a quarter of residents with central air (n_1=114 and n_2=105, respectively). This is likely because window units are much less energy efficient than central air or heat pumps, meaning higher energy bills for the same or even reduced levels of cooling.

Several research participants reported that they do not have enough window air conditioning units to cool their entire residence. Of the survey participants with window AC, 64% reported that they move to a cooler part of their residence during extreme heat, while that is only true for 39% of those with central air (n_1=115 and n_2=110, respectively). This suggests that residents with window ACs are more likely to have overly hot areas within their home. Due to the costs associated with running window units, many residents opt to install only one unit. However, the researchers heard many accounts detailing residents' dissatisfaction with their single AC unit due to its cooling limitations. In other words, rooms with the window unit stay cool but the remainder of rooms become too hot during extreme heat.

Expressing this single window unit phenomena, Landlord B told the researchers, "the rest of the house is still in the 80[ºF]s," while their window unit is running in their bedroom. Similarly, Resident E said, "During a heat wave, [even] when I [run] the AC… for [about] two full days straight… it'll be, at best, 86[ºF] in the living room". In the Worcester Heat Survey, one resident described living through a heat wave without enough AC units, writing, "We were basically trapped in the bedroom for a week because the rest of the unit was unlivable". Resident A had two window units but had to purchase two additional units in 2024, reluctantly adopting a

financial strain in order to keep their entire residence cool. These accounts demonstrate the frequency with which residents struggle to keep their entire living units cool due to utility costs, impacting their quality of life.

3.3 Much of Worcester's aging housing stock needs upgrading, but homeowners and landlords face financial barriers.

Due to the historical nature of residences in Worcester, issues emerge about whether modern cooling solutions are compatible with existing infrastructure. As aforementioned, half of Worcester residences were constructed before 1967, and almost a third before 1940, when summer averages were milder and heat waves less persistent (Jones, 2024; NOAA, 2024). For example, tube and knob wiring was standard at the time. "The neighborhoods today look basically like they did 110 years ago", confirmed Landlord C. Residents–primarily renters–shared their accounts of issues resulting from outdated infrastructure in their homes, demonstrating the existence of a variety of logistical problems. In Landlord B's single family home, the windows are too small to accommodate air conditioning units. Expert E described how even houses built in modern years can quickly become insufficient for residents' needs. "If [a resident is] in a home where the AC was designed 20-40 years ago, it may be undersized… old, and inefficient," they told us, "Some folks don't run the air conditioning because… they're afraid their electric bill will go out the roof." Another interviewee spoke of the outdated electrical system of their triple-decker apartment. Resident G noted that many triple-deckers only have 15 amp wiring. "If I run an air conditioner in the same room as my computer [or in my kitchen], I'll trip the breaker," they said, going on to describe the negative impacts that living on the third floor without AC has on their health. When we asked whether there are any upgrades for efficiency or cooling this interviewee would like to make in their home, they replied, "I'd love to make modifications, but I'm not the landlord," expressing a sense of powerlessness in alleviating their struggles. Similarly, in the Worcester Heat Survey, one respondent described how the electrical system in their triple decker apartment can only support running two of their three window AC units at one time, and they also cannot run AC in the kitchen because of the current drawn by their appliances.

Like these residents, tenants in Worcester are incapable of modifying their outdated homes due to their renter status, but many acknowledge the likelihood of a rent increase if their landlords were to finance updates. One research participant reported, "[We] fear that reporting… needed upgrades would negatively impact our relationship with [our] landlord for fear of rent increases." From a landlord perspective, there is little financial incentive to retrofit properties. Unless landlords have extensive funds saved in advance, they would likely have to upcharge rent, possibly pricing out current tenants. "I believe it would be cost prohibitive for [my landlord] to upgrade all of the electrical in this house," said Resident G, "The building would need extensive retrofits, and… he'd be inclined to evict me in order to create the space that he needs to do all of that retrofit work." Due to this conundrum, Resident G said they feel "trapped"

in their situation, growing increasingly uncomfortable and noticing their physical health decline every summer. When asked about the biggest challenge Worcester landlords are currently facing, Landlord C, who is heavily involved with the Worcester Property Owners Association, replied "manag[ing] the expenses of how much we can put into the house, while also keeping the renters happy." Furthermore, Expert D explained that tenants in Worcester do not request major infrastructural changes from their landlords because they "are already stretched on their rents [and] they look upon improvements and additions as something that's going to [raise] their rent."

Landlord C described two modifications they decided to make to their triple-decker properties, demonstrating the difficult barriers they had to overcome in order to do so. These upgrades include rewiring electrical systems in order to accommodate air conditioning and making the fire blocking up to code. "It is very, very expensive to rewire a building… and there's no immediate return on investment," said Landlord C, "You can't [charge] 40% more rent, because people can't afford that, and nobody really understands why [those upgrades] matter". In other words, there is no market value for such modifications. "There are very few people who could have afforded to do that," they added, "because you have no rent coming in at the time." In order to afford the upgrades as well as the interruption to rent payments, landlords have to save up and be prepared to see minimal return on the investment. As Landlord C explained, this also applies for all of the other infrastructure upgrades landlords must finance, including roofing every 30 years–which they shared costs about $50,000 for a triple-decker–as well as updating and maintaining kitchens, appliances, and boilers. Since landlords are already struggling to save up for these necessary upgrades, they have little remaining budget for heat resilience modifications, illustrating why such modifications are largely unfeasible. A lack of large-scale upgrades can make further modifications logistically challenging. Landlord C told us that the cost of modifications means that property owners often focus on small changes they are able to make. "A lot of these buildings end up with systems that have been partially upgraded… in a piecemeal fashion for a century or more by multiple different owners," Landlord C told us. Because of this, it can be difficult to know whether buildings are fully updated, adding to the complications landlords face in maintaining properties.

Homeowners also experience conflicts surrounding whether upgrading their homes is worth the initial cost. Resident B reported that they are considering installing heat pumps, but worries about the return on investment due to their age. They shared,

> "Heat pumps are costly to put in, even with the subsidies. I don't know how long I'm going to live… and we have a limited income… so… I can't make that kind of investment at this point, because I want to get the return [on my] savings in a reasonable time."

The subsidies they are referring to are provided by Mass Save, which offers income-based incentives for heat pump units and installation. Even with maximum rebates and federal tax credits, installation costs total between $4,000 and $10,000, depending on which program residents qualify for (Mass Save, n.d.).

	Standard Incentive	Income-Based Enhanced Incentive
Average Installation Cost[***]	$22,000	$22,000
Mass Save Rebate (Whole-Home)	$10,000	$16,000
Federal Tax Credit[**]	$2,000	$1,800
Net Project Cost	$10,000	$4,200

Figure 26. *Standard and low-income incentives for heat pump installation based on the 2022 average whole-home heat pump installation cost as well as maximum Mass Save rebates and federal tax credits.*

Number of Household Members	Income Eligible Program
1	≤ $49,196
2	≤ $64,333
3	≤ $79,470
4	≤ $94,608
5	≤ $109,745
6	≤ $124,882
7	≤ $127,720
8	≤ $130,559

Figure 27. *Eligibility for the Mass Save low-income incentive based on household members and income.*

Landlord B, when discussing their own residence, said that the expense of installing mini splits prevents them from doing so. They feel the age of their home–built in 1910–makes it not worth investing so much money in. Similarly, Resident B is unable to install central air due to the cost. These accounts demonstrate the financial barriers homeowners and landlords face in updating Worcester's historical housing infrastructure.

3.4 Fans and shades are supplementary, low-cost solutions for cooling residences.

Relying solely on air-conditioning is suboptimal for many residents due to the associated financial burden and environmental harms, but fans and window shades can alleviate these problems when used on their own or in conjunction with air conditioning. Survey data suggests that Worcester residents who use fans along with air conditioning are saving on summer utilities. The mean summer electricity bill reported by residents who use fans with any type of air conditioning is $208, while AC-only users pay about $223 ($n_1$=164 and n_2=35, respectively). Additionally, several research participants who have some type of air conditioning in their homes reported that using fans allows them to run their air conditioning less, saving money on electric bills and reducing their carbon output. "I think a fan with central AC is really great. We don't have to put the AC up as much," said Resident D. "I use one fan to circulate the air, " Resident F

explained, “It reduces the air conditioning costs, and it… keep[s] the air moving” to prevent stagnant cold spots. A survey respondent indicated their contentment with this method, writing, “As long as my window fan and window AC are on, for the most part I’m fine.”

Cooling devices	Responses	Mean electricity cost
AC only	36	$223
Fans and AC	164	$208
Fans only	38	$157
Neither fans not AC	4	$121
Survey average	242	$201

Table 7. *Average monthly electricity bills during summer months for survey respondents who cool their homes using air conditioning, fans, both, or neither.*

Furthermore, fans appear to be more reliable for Worcester residents than air conditioning, saving residents money on repairs and replacements. Only 11% of fans in residents’ homes were reported as not fully functional versus 26% of air conditioning systems (n_1=271 and n_2=292, respectfully).

While many residents perceive that maintaining a livable home is not feasible without some form of air conditioning, using fans only is far preferable to omitting cooling devices altogether. Survey respondents without AC who use fans report paying about $160 a month for summer utilities, meaning they could save $50 or more per month compared to AC users (n_1=38 and n_2=200, respectively). About half of residents with fans and no air conditioning report feeling more resilient than vulnerable in their home (n=44). This suggests that some Worcester residents can live relatively comfortably without AC as long as they utilize fans. Drawing again from Landlord A’s experience living in one of Worcester’s heat islands without air conditioning demonstrates that it can be feasible. “You'd be surprised how comfortable you can be sleeping with a fan when it's sweltering hot,” they told us. Meanwhile, a survey respondent reported, “The lack of AC and humidity is hard but manageable with fans, water, and somewhere else to go if needed”.

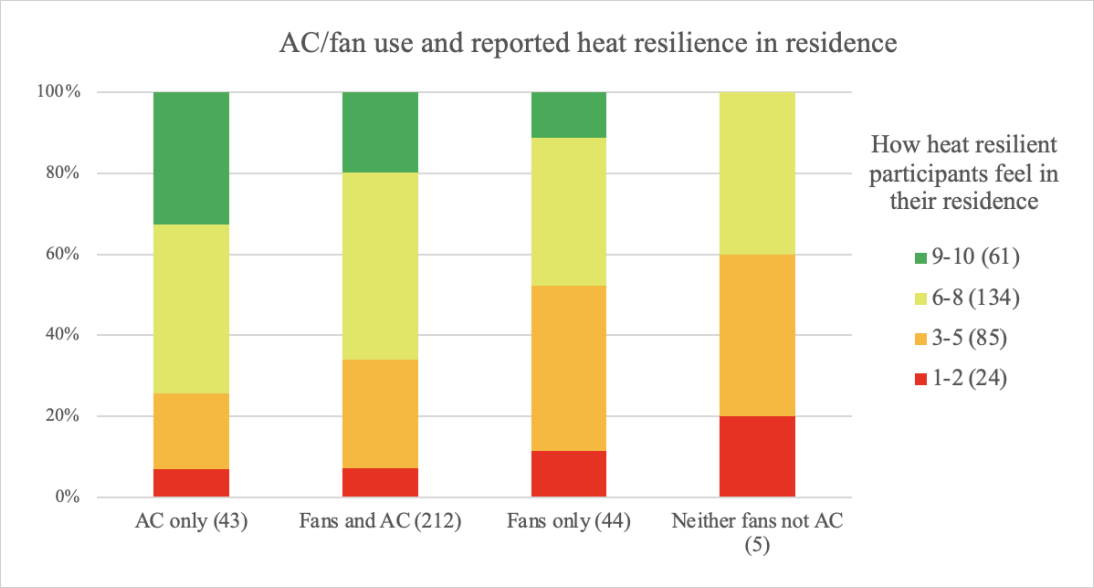


Figure 28. *Responses to Survey question 11 (Heat Resilience in Residence) by use of air conditioning and fans.*

Similarly, residents who utilize window shades to block out the sun spoke favorably of this low-cost but relatively impactful solution. Landlord A also uses shades to partially regulate the temperature of their home without air conditioning by employing strategic sun-blocking. "I close all the windows and… blinds in the daytime… to keep the sun out," they said, "Then, as soon as it cools off at night, I open everything up on both floors… and the heat finds its way back out". Furthermore, when speaking with Resident D, they reported that closing the curtains is their most important behavioral adaptation for cooling. Lastly, Expert C told the researchers, "Paper shades are very affordable, and something as simple as closing curtains does create a break for that radiant heat transfer". These accounts demonstrate the relatively high impact yielded by closing shades, despite their low cost and environmental impact.

3.5 Residents perceive inequities in the amount of tree canopy throughout Worcester.

The most prevalent theme that emerged from *Survey question 29: Other comments* was that there should be more trees in Worcester. However, Worcester is actually quite forested compared to other U.S. cities. Landlord A said, "Our urban canopy is significantly greater than most of the other cities around us." Despite this, many residents feel passionately that the city needs more trees, writing comments such as, "We need more shade trees… Less asphalt, more green spaces." Several residents noted difficulties walking their dogs through the city due to the hot pavement and a lack of shade from trees. During their interview, Expert E, who served on the Worcester School Committee for ten years, shared how they believe the city needs more street trees to improve students' walking routes to school. "For secondary school students, if [they live] within two miles of the school, [they are] expected to walk to school," they said, "Those kids are

very frequently walking on sidewalks… that aren't shaded." These desires for more trees can be confusing when considering the city's overall amount of tree canopy, but further analysis suggests a vacancy of trees within Worcester's central neighborhoods.

Survey responses to a multiple-choice question asking about how respondents feel about the quantity of trees in their neighborhood demonstrates that residents living in the city's heat islands perceive that there are not enough trees in their neighborhood, while those living in cooler, more forested areas were more likely to be content with tree coverage. Additionally, only 4% of respondents reported that there are too many trees in their neighborhood, suggesting that this is an unpopular opinion for Worcester residents (n=303). Over half of respondents in zip codes 01604, 01607, 01608, 01609, and 01610 indicated that they believe there are not enough trees near their home (n values shown in **Figure 29)**.

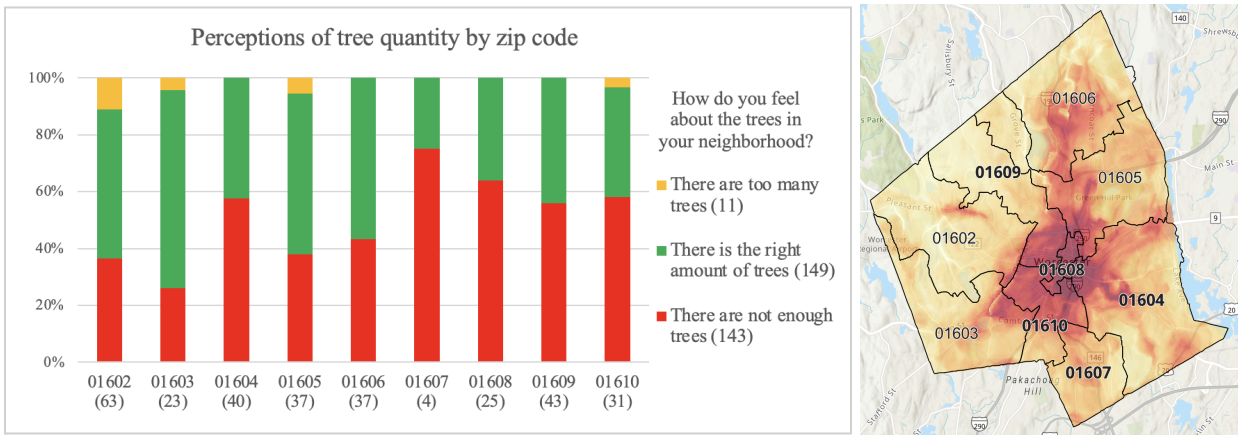


Figure 29. *Left: Survey respondent's feelings about trees in their neighborhood by zip code; Right: Worcester Heat Map overlaid with the city's zip codes (McCauley, et al., in preparation). Bolded text indicates that over half of survey respondents from those zip codes desire more trees in their neighborhood.*

When comparing this data to the Worcester Heat Map, it is apparent that respondents were more likely to indicate that there should be more trees in their neighborhood if they live in the zip codes that compose Worcester's central heat island. In zip codes along the outskirts of the city, individuals enjoy more tree coverage and lower temperatures, making them more likely to feel content with the amount of trees.

Respondents who live in more forested areas indicated that they enjoy the cooling benefits, which allow them to save on utilities. One resident said, "We live on a conservation property which is heavily shaded... It's not unusual for me to [enter] the driveway and notice that the thermometer in the car drops by as much as 10 degrees". Because the ambient heat around their home is so low, they are able to live in a comfortable home without air conditioning. Another research participant reported, "Trees are my 'AC'... My south facing windows are shaded in summer, but the sun shines in during winter months," providing both passive cooling and heating as needed. They also described how their home was built for efficiency, with good

insulation and new windows. These aspects work in conjunction to ensure a relatively comfortable home.

These discrepancies between tree canopy throughout the city reflect equity issues in regards to heat vulnerability. Residents appear to be well-aware of this problem. One participant commented that the "more affluent neighborhoods [on the] West-side with good tree cover immediately feel cooler", while another shared, "I feel very fortunate that I live in a neighborhood with a shaded park and many trees… There are definitely areas of the city that need more trees." One respondent wrote, "Create equity with trees in all neighborhoods," reflecting their understanding of varying levels of access to trees across the city. It is very clear that tree coverage in Worcester correlates with socio-economic vulnerability. In other words, areas with more affluent individuals are more forested compared to low-income neighborhoods.

In addition to the higher density of built infrastructure in central Worcester, the differences in tree densities are likely due to tree-planting initiatives relying on resident input or volunteering. Landlord A explained, "Poor neighborhoods are harder to plant in," because those areas have more densely built infrastructure and less individuals able to volunteer time and resources towards caring for trees, meaning that "tree survival is probably worse in those places." Thus, planting trees there might not be viewed as a good investment. Expert C confirmed this by reaching out to the director of Public Works after noticing that the amount of trees in South Worcester was "virtually none". According to this interviewee, the director replied, "'I plant trees where people ask for them, because I know they'll take care of them.'" To confirm this, **Figure 30** shows an example of the city's efforts to expand tree canopy though giving residents the opportunity to request trees. Expert C explained why more vulnerable populations are less likely to request trees, saying, "If you're a renter who can barely keep food on the table... you're not going to call up the city and say, 'I don't have a tree in front of my apartment.'"

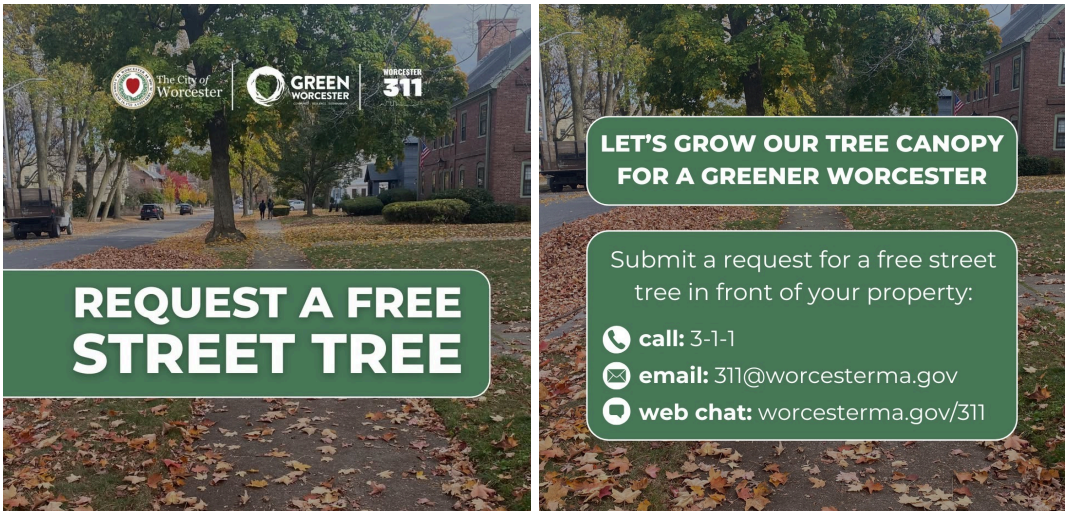


Figure 30. *A Facebook post by the City of Worcester posted on February 20, 2025 as a call for residents to request street trees on their property (City of Worcester, 2025).*

Similarly, some interviewees and survey respondents shared their thoughts on the Worcester Tree Initiative (WTI), claiming that it did not make an adequate impact in restoring Worcester's tree canopy after the Asian Longhorned Beetle infestation. The WTI launched in 2009, aiming to replant the 30,000 trees that were cut down to halt the spread of the invasive insect (Middaugh, 2019). Many research participants seemed skeptical whether the WTI's efforts came close to restoring Worcester's forests because the program relied on the assumption that each tree planted would survive and mature. One research participant said, "The city does not have a good tree policy," because the tree replacement ratio should be "three to one" rather than one to one (Resident B). Another commented that the ratio "should be four to one since three out of four plantings will not reach maturity". These residents are justified in thinking that the replacement ratio should be greater than one new tree for each tree removed. A study on the survival rates of new trees in Worcester that took place between 2011 and 2017 found a 27% mortality rate for 1,868 trees studied within the first four to six years after planting (Elmes, et al., 2018). Thus, it appears that the Worcester Tree Initiative did not completely restore Worcester's tree canopy.

This is not to say that restoring 30,000 trees is a task without great challenges. In discussions with residents, many brought up difficulties the city encounters in the process, namely growth time and sidewalk obstruction. "We need street trees that will form a canopy, not smaller ornamental trees," one resident commented. The issue is that trees take literal decades to mature to a level where they are providing significant shade. Sidewalk accessibility is also a critical component in the discussion of planting street trees. Expert D said that street trees in Worcester are sometimes cut down when the root structure begins to interfere with passage. "We've replaced them with [trees] that were about as tall as [a person], and they don't provide the same sort of shade," they told the researchers. In summary, the city is well-aware of discrepancies in tree canopy across the city but faces challenges in alleviating it.

3.6 Worcester's blue spaces are an essential cooling solution, particularly for low-income communities.

Blue spaces, which include swimmable natural bodies of water, pools, and splash parks, are important resources for residents because they are typically free or low-cost to visit. Over a quarter of respondents to select-all-that-apply *Survey question 7 (Cooling Measures*) reported that they visit lakes or ponds during extreme heat, while just under a quarter utilize pools, showing that users of blue spaces in Worcester represent a sizable number of the community (n=319). The survey also showed a correlation between visiting blue spaces and having a low income status. The proportion of survey respondents with a household income of under $15,000 who utilize Worcester's lakes or ponds during extreme heat total 34%, meanwhile, 30% in the same income bracket report visiting pools to stay cool (n=44). Expert A, who works for the Worcester Department of Sustainability and Resilience, explained this relationship, saying, "We are very cognizant of the fact that our lakes… are used by the environmental justice community

[often, because] not everyone can… drive for two hours… to the Cape or to Maine". In other words, many residents rely on Worcester's beaches as a more feasible adaptive measure than leaving town during extreme heat. In fact, only 5% of respondents to *Survey question 7 (Cooling Measures*) indicated that during extreme heat, they travel outside of Worcester until it becomes cooler. (n=319). Research participants commented about the demand for these spaces during heat waves. One survey respondent wrote, "Sometimes, [the heat is] unbearable, and the lakes and pools are filled with people," while another commented, "People enjoy Coes Pond, and the beach should be expanded".

Despite the widespread reliance on Worcester lakes and ponds, these areas often have issues with bacteria and algae concentrations, resulting in frequent swimming bans. The most persistent causes for pond and lake closures in Worcester are unsafe levels of E. coli and cyanobacteria, an algae bloom that is harmful to humans, pets, and the surrounding ecosystem (Caffrey, et al., 2019). These hazards spike during warmer seasons and are exacerbated by nutrient runoff from road salt, fertilizer, and sewage (Caffrey, et al., 2019). Recent swimming bans in Worcester include one at Indian Lake during August and September of 2023 due to cyanobacteria exceeding the state-regulated threshold, as well as the closure of Coes Pond in July of 2023 after high E. coli levels were measured (City of Worcester, 2023; City of Worcester 2024). Survey participants shared their frustration over inconsistent access to Worcester's blue spaces, writing, "The lakes [and] ponds are too full of bad bacteria" and "Keep the waters clean! Every year the ponds and lakes close". Expert C shared that the city is well-aware of this issue and has recently been demonstrating a "greater emphasis on making sure the beaches are open and accessible."

Meanwhile, Worcester's public pools and splash parks are somewhat few in number. The city's official website advertises only three pools and two spray parks (City of Worcester, n.d.). The Worcester Heat Survey confirmed a demand for these spaces. One resident shared that there should be more "splash areas or pools for kids in this neighborhood"–referring to North Lincoln Street and Burncoat–"and they should have expanded hours. Another wrote, "Fund ALL the pools! [It was a] shame that Vernon Hill didn't open on time", referencing the Dennis F. Shine Memorial Swimming Pool that remained closed for the majority of Summer 2024 due to safety concerns. After a fight occurred there on June 20th, the Department of Conservation and Recreation mandated that the pool would need a police detail but experienced difficulties securing one (Mancini, 2024). The limited number of blue spaces as well as resource difficulties in keeping them open lead to a demand to invest in them further as a cooling solution.

3.7 Wellness checks between Worcester residents are not common practice during extreme heat.

While most residents likely have support systems in place if they need assistance, survey data suggests that it is not common practice for Worcester residents to check in on loved ones or other community members during extreme heat. As explained previously, having a social network is a preventative means for resilience, while individuals who live alone and do not leave

home are considered highly vulnerable (Gronlund, 2015). Fortunately, only 5% of survey respondents were unable to name a person or public service they would contact if they needed help during an extreme heat event, suggesting that the majority of Worcester residents are likely either connected socially or aware of public services available to them (n=257). However, less than one-fifth of respondents reported that they habitually check in on family, friends, or neighbors during extreme heat (n=319).

Interview participants who do not reach out to others during extreme heat said that this is because they are unfamiliar with their neighbors, revealing a lack of neighborhood connectivity across the city. Residents E and D told us, "I guess I don't know my immediate neighbors," and "We don't know a lot of people here," respectively. Even some residents who are friendly with their neighbors do not check in with them closely. Expert E says when they see their neighbors during a heat wave, they say, "'Hey, it's really hot, huh?'... [but] that's it," describing their surface-level interactions. Meanwhile, Resident A said they do not check in on anyone during heat waves because they "really don't know of anybody locally that needs help". This lack of neighborhood connectivity could have deadly results for residents living alone, as demonstrated by the heat waves in Chicago in 1995, Paris in 2003, and Portland in 2021 (Ashbaugh & Kittner, 2024; Bouchama, 2004; Semenza, et al., 1996).

3.8 Worcester lacks free drinking water in outdoor spaces.

Another theme that emerged from *Survey question 29: Other comments* was the lack of free drinking water across Worcester, which can exacerbate the heat stress felt within the city's heat islands. Residents shared comments such as, "We need more resources for people to stay cool; Make water more accessible." One survey participant, who described themselves as an avid runner and cyclist, reported the challenges of exercising without access to water. "There is very little publicly available water in the city, which has become an issue on a number of very hot multi-hour runs or bike rides," they wrote, "I carry a credit card on my bike and can stop in a convenience store, but not everyone has that privilege," alluding to the cost of bottled water. Several respondents mentioned installing water fountains specifically at Worcester Common due to the high temperature of the surrounding area as well as the community of unhoused individuals who live there. "We need [a]water dispenser in the Commons," wrote one participant, while another commented, "[Does] the unhoused population who congregate in the shaded areas of Worcester Common have access to clean drinking water?"

3.9 Cooling centers in Worcester have limited hours and are under-advertised.

Cooling centers are a vital component of a city's capacity to withstand extreme heat, however research participants identified shortcomings in Worcester's cooling centers which could be minimizing their potential impact. During the summer of 2024, the city posted announcements on their website and social media pages prior to predicted heat waves that

detailed which cooling centers would be "activated" for the duration of the heat wave. Looking at a map of these locations, the existing cooling centers seem to be adequately located with regards to serving the most vulnerable communities, perhaps with the addition of cooling centers in Piedmont or Main South (see **Figure 31**). The barriers to cooling centers having a bigger impact on the community as identified by research participants was not their number or location, but rather their hours of operation as well as how they are advertised.

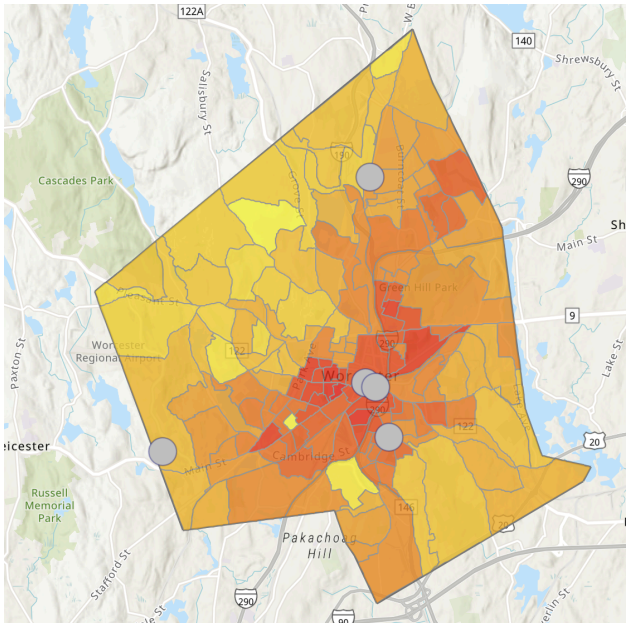


Figure 31. *Cooling centers activated during the 2024 summer shown in gray, overlaying the Worcester Heat Vulnerability Index, with yellow indicating a resilient neighborhood and red indicating a vulnerable neighborhood (City of Worcester, 2024; McCauley, et al., in preparation).*

Limited hours of operation impact residents' ability to utilize cooling spaces. One research participant noticed that most of the cooling centers closed between 4:00 and 5:00 PM, "which is often the time of peak heat". In other words, heat can linger long into the evening, after cooling centers are closed for the day. Another said that during "a high heat day [in 2024] that was also a holiday… all the municipal cooling centers were closed", with just one church open for public cooling. As these participants alluded to, extreme heat does not subside with the end of the workday, nor during holidays.

Residents also had concerns about whether other individuals in the city were aware of cooling centers as a resource due to their perception that these spaces receive inadequate advertising. Expert D from a Worcester Community Development Center said, "there are some cooling centers around here, but they're not very well advertised." We can ultimately attribute this to the fact that the city does not have designated spaces to be used consistently as cooling centers. In a correction to a previous statement that the city would not share a list of cooling centers with the Department of Sustainability and Resilience, Expert A clarified that such a list does not exist because the city wishes to keep cooling center options flexible. The issue that arises as a result is that residents must rely on these announcements rather than knowing that a

certain building will be accessible throughout the duration of the summer. Expert E from the Worcester School Committee believes utilizing school buildings could improve consistent access to cooling centers. “We now have these new giant high schools [that are] all air conditioned,” they said, “Let's use them.”

3.10 Residents believe certain <u>non-residential spaces</u> in the city are <u>cooled excessively</u>.

During interview coding, an interesting theme that emerged was concerns that Worcester universities, offices, and other non-residential buildings might be using air conditioning to an excessive extent, over-using their share of energy and producing heat and carbon outputs that impact nearby residents. Resident G lives on the top floor of a triple-decker with no air conditioning because of outdated wiring. They also live adjacent to some of Clark University’s residence halls. They described how they are impacted by Clark’s use of air conditioning, saying, “They're dumping all of their interior heat through those units”. Resident G shared that, “an envelope of heat [is] pushed above my house,” when the wind blows in their direction, preventing heat from escaping their home. Meanwhile, Expert E told the researchers, “It always seems ridiculous to me that we have giant air conditioned spaces that aren't actually being used for people to be able to get out of the heat when it's hot”. Citing the atrium at Saint Vincent’s Hospital downtown, they said, “This giant atrium space [is] all air conditioned [but if you are] someone who's just trying to avoid the heat” by sitting inside, “you're going to get shuffled along”. They believe that spaces like these should accommodate folks in the community who need access to air conditioning. Otherwise, the extensive cooling is a misuse of energy. Lastly, the researchers spoke to a Worcester university employee who disclosed a concerning fact about their office space. When the air conditioning is on, it constantly blows 50ºF air, cooling the office to the extent that several staff members have to use space heaters during the summer. The staff has complained about the problem multiple times with no results. These examples demonstrate cases of excessive air conditioning use and the impact this has on residents.

Recommendations

The following suggestions for the City of Worcester are ranked in order of least to most resources required relative to the impact they would have in alleviating heat vulnerability.

1. Incorporate heatwave alerts into the city's alert system.

Many of the barriers to remaining cool identified in this report involve a lack of knowledge of certain adaptations. Further outreach can help to ensure that residents are aware of best practices for avoiding heat-related illness as well as what resources are available to them. An analysis of heat-related deaths during the 1995 heat wave in Chicago identified media coverage as an important tool for the prevention of heat mortalities. The researchers wrote that as soon as a heat wave is forecasted, residents need to be altered of information regarding avoiding heat-related illness (Semenza, et al., 1996). Heat wave alerts could be integrated into the existing opt-in system for emergency alerts–ALERTWorcester–and included in media coverage.

In addition to the signs of heat stress, heat wave alerts should include helpful information for staying cool. This report identified several behavioral adaptations or city-wide resources that appear to be cost-effective methods of cooling, but are not employed by the entire Worcester population, likely because residents are unaware of their benefits. For example, over 30% of survey participants do not use fans during extreme heat, meaning they are missing out on this energy-saving resource (n=319). Similarly, alerts could describe how to partially regulate the temperature of one's home by opening and closing shades and windows. Less than one-fifth of survey respondents reported that they check in on others during extreme heat, so residents–particularly those living alone–should also be encouraged to reach out to each other during extreme heat because of the dangers of social isolation (n=319). Heat wave alerts should include these types of adaptations for any residents who are unaware of their benefits. Finally, alerts should include city-wide heat resilience resources, including locations and hours for cooling centers, pools, splash parks, and beaches.

2. Ensure consistent access to cooling centers.

Cooling centers are a key resource for heat resilience. In addition to providing refuge from the heat, they act as locations for sharing resources and building community (Ashbaugh & Kittner, 2024). While often overlooked, social connectivity is a critical component of any type of resilience. Not leaving the home is regarded as a predictor for heat-related mortality, while visiting a public air-conditioned location boosts resilience (Ashbaugh & Kittner, 2024; Bouchama, 2004; Semenza, et al., 1996). Additionally, utilizing existing public spaces that are air-conditioned and staffed allows for the benefits of cooling centers without much additional resources.

Research participants identified that although there are cooling centers in Worcester, several factors prevent them from having the maximum impact on residents, namely their limited hours and advertising. Cooling centers should remain open for longer hours rather than closing at

the end of the workday, since extreme heat can last long into the evening. Further analysis would be helpful in determining the time of day where heat is usually subsided to a safe level. Additionally, residents felt uninformed about cooling centers, suggesting a need for more communication. The city has a rotating register of cooling centers that are activated during heat waves. This lack of consistency can result in confusion as to which locations are open when. To combat this problem, this report suggests creating a more concrete schedule for cooling centers, with availability throughout the duration of the summer. This could also help to foster the social benefits of cooling centers, as frequent visitors might start to develop a community. As described in the first recommendation, cooling centers should be advertised in the city's alert system.

This project did not gather significant evidence regarding whether residents believe there should be additional cooling centers established in the city. If more cooling centers are deemed necessary by further research, the city should utilize public buildings such as libraries and senior centers. Schools can also act as cooling centers, although they require additional resources for staffing.

3. Install water fountains in the hottest high-trafficked areas of the city.

Since research participants identified a lack of free public drinking water as a concern during extreme heat, the city should work to improve water access. Priority locations for water fountains should be determined based on level of traffic and relative ambient heat. Worcester Common, for example, should have a water fountain because of its location downtown as well as the large quantity of people who frequent the park. Installing water fountains in public parks and in front of municipal buildings would benefit all residents, with a significant impact for unhoused individuals and residents who exercise outdoors.

4. Continue to invest in keeping blue spaces clean and staffed.

Worcester's beaches, pools, and splash parks are frequently used by residents during extreme heat, but these spaces have historically faced issues remaining open due to cleanliness and staffing issues. Due to their importance to the community, keeping blue spaces open should be a priority. There is already ongoing research to identify the causes of eutrophication in Worcester's lakes and ponds, and these efforts should be continued in order to identify preventative interventions. Additionally, the city should ensure that swimming pools are staffed as necessary.

5. Shade priority bus stops.

This report found that waiting for transportation is more frequently a concern for low-income communities in Worcester, who are less likely to drive cars. Thus, improving the experience of waiting for public transportation would help relieve heat stress for vulnerable individuals. Bus stops can be kept cooler by installing shade structures or planting trees. Priority bus stops for this intervention should be the most frequently used, unshaded bus stops in warmer

areas of the city. Shading more bus stops might also encourage the use of public transportation, reducing heat and carbon outputs from the use of cars.

6. Encourage social connectivity among seniors.

The findings of this project suggest that social connections lead to higher levels of resilience for Worcester seniors. In order to expand these benefits, local senior centers should utilize advertisements to encourage visitors. Additionally, further research could be completed to investigate the potential impacts of a "Buddy System" to connect seniors who live alone.

The residents of Colony Retirement Homes appear to feel well-supported during extreme heat due to their vast social networks in addition to the health resources provided by the housing community. It is likely that developers should utilize Colony as a framework while designing future senior living facilities, but this should also be confirmed by future research.

7. Continue to execute greening initiatives in heat islands with vulnerable populations.

There are clear equity issues in the distribution of tree canopy across the city. Survey participants living in central Worcester were more likely to report there are not enough trees in their neighborhood. The Worcester Tree Initiative concluded its work in replanting trees after the ALB infestation after planting 30,000. However, during this study, questions arose as to what proportion of these new trees are still alive and will reach maturity. Further research should be done to investigate the survival rate of these trees. If there were a significant amount of tree mortalities, the WTI should continue their work in restoring Worcester's tree canopy.

Interventions that rely on the community volunteers–such as the WTI–struggle to improve tree canopy within residential areas that have the least tree density. Individuals living in these areas are more likely to be low-income, and are thus less likely to volunteer their time. Because of this, the city should investigate alternative ways to foster tree planting in these communities–either by relying on volunteers from more affluent neighborhoods or by compensating individuals for their work. The WTI reports that the non-profit hired a group of at-risk teens to help with tree planting (Worcester Tree Initiative, n.d.). These types of initiatives should continue as the city installs street trees, pocket parks, and Miyawaki Forests in vulnerable neighborhoods.

8. Offer summer utility rebates for low-income residents.

This study suggests that utility costs–which have increased greatly in recent years–are a significant barrier to residents achieving a thermally comfortable home. This most greatly impacts low-income individuals and renters. The most vulnerable communities should have financial support in keeping their home livable through the summer.

9. Incentivize landlords to upgrade their properties.

Another prominent barrier to livable homes is the aging nature of much of Worcester's housing stock. Insufficient insulation and roofing decrease efficiency, and outdated wiring prevents individuals from installing more efficient cooling devices, such as heat pumps. Landlords are not likely to retrofit their properties because they would have to have extensive savings in order to finance the upgrades without needing to raise rent. MassSave seems effective in encouraging homeowners to upgrade their homes, but it appears that landlords require additional resources in order to opt-in to retrofitting programs.

10. Continue to update building standards to promote efficiency and passive cooling.

The city should continue to draft policies that will foster heat resilience in existing homes as well as future developments. Massachusetts law dictates a temperature threshold that residential buildings must be able to stay above during the winter, but so such law exists for the summer (Mass.gov, 2023). Residential building codes should require homes to have the capacity to stay under a certain temperature in the summer.

In order to promote a heat resilient yet affordable housing stock, the state or municipal government needs to regulate future housing developments. In July 2024, the city adopted the Specialized Stretch Code for residential buildings, which contains opt-in standards for energy-efficiency and passive house principles. Residential building standards should continue to incentivize energy-efficient cooling devices such as heat pumps as well as standards for insulation and roofing. These standards could also incentivize the presence of trees on the property to further employ passive cooling.

11. Research additional sectors that could inform heat resilience.

This report uncovered several aspects that could inform heat resilience but must be researched further before any conclusions can be made. These include preventable causes of excess energy usage and heat outputs as well as vulnerable communities. Research participants speculated that some non-residential buildings are using air conditioning to an excessive extent, negatively impacting neighboring residences and contributing to climate change. Similarly, residents thought that car traffic might contribute to excess heat in the city. If these factors are deemed significant, further research can be completed to identify ways to mitigate them.

While the scientific community largely understands which populations are most heat vulnerable, more research can be done to understand further intersections as well as how communities are impacted in Worcester specifically. An interesting dialogue arose with a couple of interviewees regarding the impact of absentee landlords versus owner-occupying landlords. These participants believed that a landlord who lives in or close to their rental property is more likely to ensure that it is well-maintained than a landlord who lives outside of the city. Thus, it is possible that live-in landlords provide more heat resilience homes. If this is deemed true, the city could explore incentivising landlords to live locally. Additionally, individuals with mental illnesses who participated in the survey are disproportionately impacted by extreme heat, but this

project was unable to gather further insight on how mental illnesses impact Worcester residents with regard to heat vulnerability, nor how to best support this community.

Conclusion

This study utilized field-based data collection and mixed-methods analysis to understand the dynamics of heat vulnerability in Worcester, MA. It attempted to fill gaps in previous studies–which drew from aggregated Census data–through resident outreach. The data collected was used to create assertions regarding: Worcester residents' perspectives and experiences of extreme heat; the socio-economic variables that relate to higher self-reported levels of heat vulnerability; cooling resources that residents rely on; and factors that impede heat resilience. These findings ultimately informed 11 recommendations for social, environmental, and infrastructural heat resilience interventions the city should pursue.

This project acts as a starting point for future heat resilience interventions in Worcester, but should be followed by additional research due to several limitations. Input from about 340 individuals was used to understand the perspectives of a population of 208,000. Thus, the assertions included are subject to sample bias. Furthermore, those who agreed to participate in the research instruments might have been disproportionately individuals who are impacted by extreme heat, as they might feel more motivated to volunteer their time for the project. There were also aspects about the survey distribution and survey questions that could have resulted in bias. For instance, the researchers distributed survey flyers at several events in downtown Worcester, often during very hot days. Thus, many participants took the survey while actively experiencing extreme heat, possibly influencing responses. Additionally, the researchers approached residents of Colony Retirement Homes who were at events or sitting outside talking with other residents. While the findings suggest that Colony residents are very socially connected, this could have resulted from bias in how these participants were found. One survey question that could have biased responses is *Survey question 6 (Heat Stress Moments)* because of the example response provided (see Appendix A). Additionally, it is possible that responses to *Survey question 11 (Heat Resilience in Residence)* were impacted by the researchers' omission to define resilience.

Many of the recommendations provided correspond to interventions which are currently in the planning or execution process, such as creating and maintaining green and blue spaces. This signals that city officials are largely aware of the types of initiatives that would best support heat resilience for Worcester residents. However, Worcester–like any other city– faces resource limitations, making larger-scale changes difficult. For example, updating the city's housing stock will require extensive incentives due to the associated financial barriers, particularly faced by landlords. In Portland, Oregon, a law establishing a 1% tax on businesses making over $1 billion passed in 2018 (Ashbaugh & Kittner, 2024). This has led to the generation of hundreds of millions of dollars to be used for public services (Ashbaugh & Kittner, 2024). After the 2021 heat wave, the city utilized $6.3 million to install heat pumps in 15,000 residences in order to improve preparedness for the next record breaking heat wave (Ashbaugh & Kittner, 2024). These types of policies can be monumental in easing socio-economic inequities.

Many populations are vulnerable to extreme heat due to social inequities rather than inherent physiological factors, meaning that these communities are underserved. Furthermore, these vulnerabilities extend far beyond the sector of extreme heat. After speaking with hundreds of residents across Worcester neighborhoods during the data collection process, there is undoubtedly a significant population in the city who is struggling financially. When the researchers approached one individual to ask about taking the Worcester Heat Survey, they responded, “Heat? Heat isn’t an issue. The issue is that my rent increases every year and my pay doesn't catch up. How am I supposed to feed my son?” For the future of a more healthy, equitable, and climate resilient city, it is clear that large-scale socio-economic reform is in order. The recommendations provided in this report can support heat resilience in Worcester as the city works towards broader systemic change.

Works Cited

Arora, T. et al. (2022, April). A systematic review and meta-analysis to assess the relationship between sleep duration/quality, mental toughness and resilience amongst healthy individuals. Sleep Medicine Reviews (62) 101593. Retrieved from https://doi.org/10.1016/j.smrv.2022.101593

Ashbaugh, M. & Kittner N. (2024, July). Addressing extreme urban heat and energy vulnerability of renters in Portland, OR with resilient household energy policies, Energy Policy, Volume 190, 2024, 114143, ISSN 0301-4215. Retrieved from https://doi.org/10.1016/j.enpol.2024.114143.

Bouchama, A. (2004, January 1). The 2003 European heat wave. Intensive Care Med 30, 1–3 (2004). Retrieved from https://doi.org/10.1007/s00134-003-2062-y

Caffrey, D., Galvez, D., Liang, Z., Pesce, A. (2019, May 1). Management Strategies for Harmful Algal Blooms in Worcester. Retrieved from https://bpb-us-w2.wpmucdn.com/wp.wpi.edu/dist/1/156/files/2019/04/Algal-Blooms-IQP-Report.pdf

CDC (n.d.). People at Increased Risk for Heat-Related Illness. U.S. Centers for Disease and Control and Prevention. Retrieved from https://www.cdc.gov/heat-health/risk-factors/index.html

City of Worcester, MA (2023, July 5). Shore Park Beach, Coes Pond Beach Closed Due to High Bacteria Levels. City of Worcester, MA. Retrieved from https://www.worcesterma.gov/announcements/shore-park-beach-coes-pond-beach-closed-due-to-high-bacteria-levels

City of Worcester, MA (2024, September 20). Indian Lake to Reopen Following Cyanobacteria Closure. City of Worcester, MA. Retrieved from https://www.worcesterma.gov/announcements/indian-lake-to-reopen-following-cyanobacteria-closure

City of Worcester, MA (2024, September 4). Coes Reservoir Algae Treatment Thursday, Sept. 5. City of Worcester, MA. Retrieved from https://www.worcesterma.gov/announcements/coes-reservoir-algae-treatment-thursday-sept.-5#id_WcQF6L7OSHI0KDXRrVNQA

City of Worcester, MA. (2024, June 17). Worcester to Activate Cooling Centers Tuesday Through Friday. City of Worcester, MA. Retrieved from https://www.worcesterma.gov/announcements/worcester-to-activate-cooling-centers-tuesday-through-friday

City of Worcester, Massachusetts. (2025, February 20). Let's Grow our Tree Canopy for a Greener Worcester [Social media post]. Retrieved from https://www.facebook.com/share/1DGZYFu3CA/

City of Worcesterer, MA (n.d.) Beaches, Pools & Spray Parks. City of Worcester, MA. Retrieved from https://www.worcesterma.gov/parks/activities/beaches-pools-spray-parks

Data USA. (2023). Worcester, MA. Deloitte & Datawheel. Retrieved from https://datausa.io/profile/geo/worcester-ma/

Department of Public Health. (2023, June 23). 105 CMR 410.00: Minimum standards of fitness for human habitation. Trial Court Law Libraries. Retrieved from https://www.mass.gov/regulations/105-CMR-41000-minimum-standards-of-fitness-for-human-habitation-state-sanitary-code-chapter-ii

Dhainaut, JF., Claessens, YE., Ginsburg, C. et al. (2003, December 4). Unprecedented heat-related deaths during the 2003 heat wave in Paris: consequences on emergency departments. Crit Care 8, 1 (2003). Retrieved from https://doi.org/10.1186/cc2404

Elmes, A. et al. (2017, June). Effects of urban tree canopy loss on land surface temperature magnitude and timing. Clark Digital Commons. Retrieved from https://commons.clarku.edu/faculty_geography/635/

Elmes, A., et al. (2018, March). Predictors of mortality for juvenile trees in a residential urban-to-rural cohort in Worcester, MA. Urban Forestry & Urban Greening (30) 138-151. Retrieved from https://doi.org/10.1016/j.ufug.2018.01.024

EPA. (n.d.). Protecting Children and Maternal Health from Extreme Heat. U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/children/protecting-children-and-maternal-health-extreme-heat

Forster, P.M. et al. (2023, June 8). Indicators of Global Climate Change 2022: annual update of large-scale indicators of the state of the climate system and human influence. Earth System Science Data, 15, 2295–2327. Retrieved from https://doi.org/10.5194/essd-15-2295-2023

García-Herrera, R., Díaz, J., Trigo, R. M., Luterbacher, J., & Fischer, E. M. (2010, March 5). A Review of the European Summer Heat Wave of 2003. Critical Reviews in Environmental Science and Technology, 40(4), 267–306. Retrieved from https://doi.org/10.1080/10643380802238137

Gronlund, C.J. (2014, July 1). Racial and socioeconomic disparities in heat-related health effects and their mechanisms: a review. Curr Epidemiol Rep. 2014 Jul 1;1(3):165–173. Retrieved from https://doi.org./10.1007/s40471-014-0014-4

Heat Action Platform. (n.d.). Identify Heat-Related Vulnerabilities and Impacts. Heat Action Platform. Atlantic Council. Retrieved from https://heatactionplatform.onebillionresilient.org/modules/identify-heat-related-vulnerabilities-and-impacts/

Jones, J. (2024, January 12). American Cities With the Oldest Homes. Construction Coverage. Retrieved from https://constructioncoverage.com/research/cities-with-the-oldest-homes

Joshi, S.S., Lesser, T.J., Olsen, J.W., O'Hara, B.F. (2016, November 1). The importance of temperature and thermoregulation for optimal human sleep. Energy and Buildings (131) 153-157. Retrieved from https://doi.org/10.1016/j.enbuild.2016.09.020

Kolokotsa, D. et al. (2022, April 23). Analyzing the Impact of Urban Planning and Building Typologies in Urban Heat Island Mitigation. Buildings 2022, 12(5), 537. Retrieved from https://doi.org/10.3390/buildings12050537

Leach, O.K., Cottle, R.M., Fisher, K.G., Kenney, W. L. (2024, August 26). Sex differences in heat stress vulnerability among middle-aged and older adults. American Journal of Physiology. Retrieved from https://doi.org/10.1152/ajpregu.00114.2024

Mancini, R. (2024, July 1). Worcester pool can only open with environmental police detail after fight. MassLive. Retrieved from https://www.masslive.com/news/2024/06/worcester-pool-can-only-open-with-environmental-police-detail-after-fight.html

Mass Save. (n.d.) Mass Save. The RCS Network. Retrieved from https://www.masssave.com/en

MassGIS. (2024, June) MassGIS Data: 2020 Environmental Justice Populations. Mass.gov. Retrieved from https://www.mass.gov/info-details/massgis-data-2020-environmental-justice-populations#downloads-

McCauley, S., Shah, T., Henbest, A. (In preparation). Heat Vulnerability Index for Worcester, MA.

Middaugh, P. (2019). Worcester's response to Asian longhorned beetle: Reforestation, stewardship, and sustainability. Department of Agriculture Forest Service: 104-115. Retrieved from https://doi.org/10.2737/NRS-GTR-P-185-paper7

National Grid. (2025, February 1). Basic Service Rates. Massachusetts Electric Company National Grid. Retrieved from https://www.nationalgridus.com/media/pdfs/billing-payments/electric-rates/ma/resitable.pdf

NOAA (2024). xmACIS2. NOAA Regional Climate Centers. Retrieved from https://xmacis.rcc-acis.org/

Palmer, S., Martin, D., DeLauer, V., Rogan, J. (2014, September 16). Vulnerability and Adaptive Capacity in Response to the Asian Longhorned Beetle Infestation in Worcester, Massachusetts. Human Ecology 42, 965-977 (2014). Retrieved from https://doi.org/10.1007/s10745-014-9695-z

Paterson, S.K. & Godsmark, C.N. (2020, March 30). Heat-health vulnerability in temperate climates: lessons and response options from Ireland. Globalization and Health 16, 29 (2020). Retrieved from https://doi.org/10.1186/s12992-020-00554-7

Ritchie, H. (2024, July 1). How many people die from extreme temperatures, and how this could change in the future. Our World in Data. Retrieved from https://ourworldindata.org/part-one-how-many-people-die-from-extreme-temperatures-and-how-could-this-change-in-the-future

Semenza, J.C., et al. (1996, July 11). Heat-Related Deaths during the July 1995 Heat Wave in Chicago. New England Journal of Medicine 1996;335:84-90. Retrieved from https://www.nejm.org/doi/full/10.1056/NEJM199607113350203

Seppanen, O., Fiskm W.J., Lei, Q.H. (2006, July). Room temperature and productivity in office work. Lawrence Berkeley National Laboratory. Retrieved from https://escholarship.org/uc/item/9bw3n707

Targhi, M.Z. & Van Dessel, S. (2015, September 14). Potential Contribution of Urban Developments to Outdoor Thermal Comfort Conditions: The Influence of Urban Geometry and Form in Worcester, Massachusetts, USA, Procedia Engineering, Volume 118, 2015, Pages 1153-1161, ISSN 1877-7058. Retrieved from https://doi.org/10.1016/j.proeng.2015.08.457.

United States Census Bureau. (2024, July 1) QuickFacts Worcester city, Massachusetts. United States Bureau. Retrieved from https://www.census.gov/quickfacts/worcestercitymassachusetts

Urban Climate Consulting LLC. (2022, December). Worcester Heat Risk Assessment [GoogleSlides]. Retrieved from https://drive.google.com/file/d/1aPFeO5mroc6kd8neq2p2QzOlvizYnWHH/view?usp=sharing

Wallace, W. (2019, May 1). Exploring Worcester's History [Video]. Center for Community Media at Worcester State University. Retrieved from https://www.youtube.com/watch?v=bKYSxf0YmI8&ab_channel=CenterforCommunityMediaatWSU

Whitman, S., Good G., Donoghue E.R., Benbow N., Shou W., and Mou S., (2011, August 30). Mortality in Chicago attributed to the July 1995 heat wave. American Journal of Public Health 87, 1515_1518. Retrieved form https://doi.org/10.2105/AJPH.87.9.1515

Worcester Department of Sustainability & Resilience. (n.d.). Sustainability & Resilience. City of Worcester, MA. Retrieved from https://www.worcesterma.gov/sustainability-resilience

Worcester Tree Initiative. (n.d.). Worcester Tree Initiative: an Independent Program of Tower Hill Botanic Garden. Tower Hill. Retrieved from https://www.treeworcester.org/

Yingdong, H., Wenhua, C., Zhe, W., Zhang, H. (2019, July 1). Review of fan-use rates in field studies and their effects on thermal comfort, energy conservation, and human productivity. ENergy and Buildings (194) 140-162. Retrieved from https://doi.org/10.1016/j.enbuild.2019.04.015

Appendix A. Worcester Heat Survey, including consent statement

We are conducting a study with support from Worcester Polytechnic Institute (WPI) about how summer heat affects Worcester and its residents. This survey aims to gather valuable insights into Worcester resident's experiences with summer heat. With this information, we hope to help the City of Worcester plan and prioritize actions for managing extreme heat events. Your input is important to us, and we appreciate any information you are willing to share.

Your participation is voluntary, and your responses will be kept anonymous and confidential. This survey should take approximately 5 minutes to complete. If you have any questions about this survey, please contact researchers Varun Bhat (vpbhat@wpi.edu), Sol Giesso (sgiesso@wpi.edu), or Stephen McCauley (mccauley@wpi.edu).

Note: There is a chance to win one of two $25 Amazon gift cards if you provide your contact information at the end of the survey. Your answers will remain anonymous and confidential.

1. Do you understand?
    - ☐ Yes

2. What Worcester zip code do you live in? _____

3. What is your address? _____

4. During extreme heat events, what best describes your experience?
    a. I do not feel any discomfort or concerns
    b. I feel discomfort but no major concerns
    c. I am concerned for my well-being

5. Since living at your current address, have you personally experienced any of the following? Select all that apply.
    - ☐ Heat wave (high heat for multiple consecutive days)
    - ☐ Heat-related health issue that required medical attention
    - ☐ Heat discomfort or stress
    - ☐ Loss of electricity during an extreme heat event
    - ☐ Inability to concentrate or perform daily tasks due to heat
    - ☐ None

6. Describe up to three moments (including activity, location, and time) when you have felt the most heat stress in Worcester.
   Example: Waiting for the bus, Union Station, in the morning
   - Moment 1: _____
   - Moment 2: _____
   - Moment 3: _____

7. When you experience extreme heat in Worcester, what measures do you take? Select all that apply.
   - ☐ Open the windows
   - ☐ Turn on the fan
   - ☐ Turn on the air conditioning
   - ☐ Drink or purchase more water
   - ☐ Carry water with me
   - ☐ Eat cold foods (i.e., ice cream)
   - ☐ Move to a cooler room or location in my residence
   - ☐ Go to a car and turn on the AC
   - ☐ Go outside
   - ☐ Go to a pool
   - ☐ Go to a lake, pond, or beach
   - ☐ Avoid physical exercise
   - ☐ Avoid outdoor activities
   - ☐ Go to air-conditioned public/commercial spaces (i.e., museum, library, school, restaurant)
   - ☐ Go to air-conditioned private spaces (friend's house)
   - ☐ Stay in the shade
   - ☐ Take a cold shower
   - ☐ Use a cold compress
   - ☐ Check on my family, friends, and neighbors
   - ☐ Sleep outside
   - ☐ Leave town until it becomes cooler
   - ☐ Other: _____
   - ☐ None

8. Do you have air conditioning at your residence? What is its functional state? Select all that apply.

	Fully functional	Intermittently functional	Not functional	I don't have this
Central cooling system	○	○	○	○
Window AC units	○	○	○	○
Individual/other AC units	○	○	○	○
Fans	○	○	○	○

9. If you needed help during a heat wave, who would you contact? Please do NOT write personal names or information, rather describe their relationship to you (i.e., my mom, my neighbor, a public service). _____

10. How many of your neighbors do you know by name?
    a. 0-1
    b. 2-5
    c. 6-10
    d. More than 10

11. How resilient to extreme heat do you feel in your residence?

Very vulnerable 1 2 3 4 5 6 7 8 9 10 Very resilient

12. What upgrades have you already made or do you want to make to your residence? Select all that apply.

	I have already done this	I am planning on doing this	I want to do this but am limited by resources	I don't want to do this
Install a central cooling system	○	○	○	○
Install window or other AC units	○	○	○	○
Install mini-splits or heat pumps	○	○	○	○
Buy/install fans	○	○	○	○
Plant trees and shrubs	○	○	○	○
Roof upgrade	○	○	○	○
Install rooftop solar panels	○	○	○	○
Improve insulation	○	○	○	○
Improve electrical systems	○	○	○	○
Build/repair my pool	○	○	○	○
Install shade structures	○	○	○	○
Paint my residence a lighter color	○	○	○	○
Buy a generator	○	○	○	○
Install a home battery	○	○	○	○
Window replacements	○	○	○	○
Home energy audit/assessment	○	○	○	○
Other:	○	○	○	○

13. What is your age? _____

14. What is your gender?
    - ☐ Female
    - ☐ Male
    - ☐ Nonbinary
    - ☐ Other: _____

15. How long have you lived at your current address?
    - ☐ Less than two years
    - ☐ 2-5 years
    - ☐ 5-10 years
    - ☐ 10-15 years
    - ☐ 15 or more years
    - ☐ Transitional/temporary housing

16. What best describes your residence?
    - ☐ Single detached house
    - ☐ Townhouse/rowhouse
    - ☐ Apartment in a triple-decker house
    - ☐ Low-rise apartment building (less than five stories)
    - ☐ High-rise apartment building (five or more stories)
    - ☐ Other: _____

17. How would you describe your building condition?
    - ☐ Poor
    - ☐ Average
    - ☐ Good

18. How do you feel about the trees in your neighborhood?
    - ☐ There are not enough trees
    - ☐ There is the right amount of trees
    - ☐ There are too many trees

19. Do you rent or own your residence? If you are part of a family unit but do not personally own or rent, please respond on behalf of your family unit.
    - ☐ Rent
    - ☐ Own
    - ☐ Other: _____

20. Do you or someone living in your housing unit pay for utilities? Please circle all that you pay for:
    - ☐ Water
    - ☐ Gas
    - ☐ Electricity
    - ☐ None

21. How much money per month do you typically spend on utilities during the summer?
    - Water: USD$_____
    - Gas: USD$_____
    - Electricity: USD$_____

22. How many people in each age bracket live in your housing unit with you? Do not include yourself or neighbors.
    - 0-5 years old: _____
    - 6-25 years old: _____
    - 26-64 years old: _____
    - 65+ years old: _____

23. What is the highest level of education you have completed?
    - ☐ Some formal schooling
    - ☐ High school graduate, or GED
    - ☐ Any university degree
    - ☐ Other: _____

24. What best describes your work/school environment?
    - ☐ Indoors
    - ☐ Outdoors
    - ☐ Mostly indoors
    - ☐ Mostly outdoors
    - ☐ I don't work or study

25. What is your annual household income before taxes (in US dollars)?
    - ☐ Under $15,000
    - ☐ $15,000 - $24,999
    - ☐ $25,000 - $34,999
    - ☐ $35,000 - $49,999
    - ☐ $50,000 - $74,999
    - ☐ $75,000 - $99,999
    - ☐ $100,000 - $149,999
    - ☐ $150,000 - $199,999
    - ☐ Above $200,000

26. Do you have any of the following pre-existing medical conditions? Select all that apply.
    - ☐ Diabetes
    - ☐ Heart disease
    - ☐ High blood pressure
    - ☐ Skin disorders
    - ☐ Limited mobility
    - ☐ Mental health conditions (such as developmental impairments, depression, schizophrenia, severe anxiety, bipolar disorder, dementia, substance abuse disorder)
    - ☐ None

27. Do you have medical insurance?
    - ☐ Yes
    - ☐ No
    - ☐ Don't know

28. Since living in Worcester, have you noticed any changes in the summer weather?

    _____

    _____

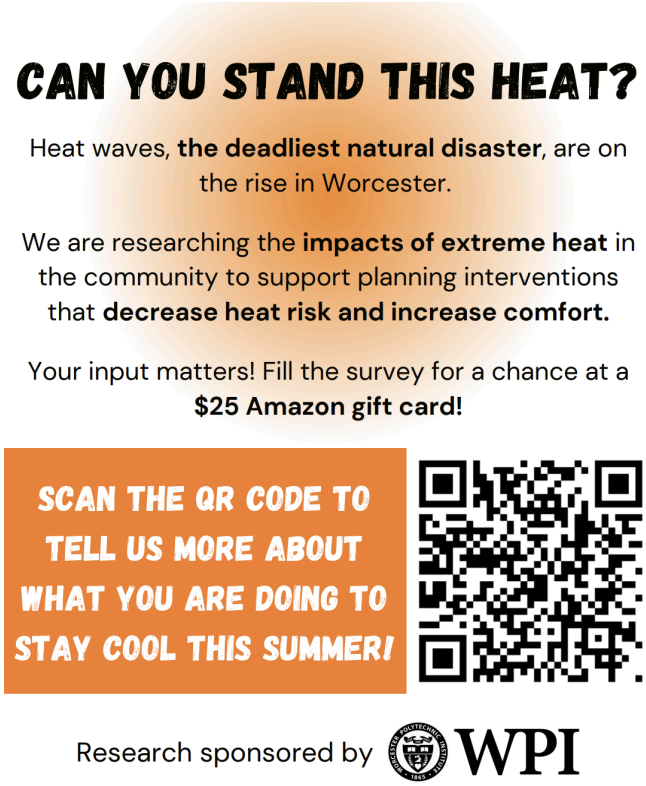
29. Do you have anything else to say about your experience with extreme heat in Worcester?

    _____

    _____

Appendix B. Flyers and handouts utilized to gather survey participants

Left: 8.5x11” flyer pasted inside local businesses in order to obtain survey participants; Right: 4.25x5.5” flyer handed out to individuals on the street, at the train station, and at community events around the city in order to obtain survey participants.



Appendix C. Interview guides and consent statement

Note that questions varied for other types of experts.

Consent Statement

Hello, thank you so much for agreeing to meet with us. Let me start by telling you a little bit about our project. The goal of this project is to broaden understanding of heat events in Worcester by learning more about how the community experiences and adapts to heat. This project is sponsored by Worcester Polytechnic Institute.

This interview will take between thirty and sixty minutes. Your participation is completely voluntary and you can withdraw from the study at any time without penalty. You may request that we not use the information you have provided to us. We do not foresee any risks to you due to participation in this study. You may ask questions regarding this research project, and they will be answered fully. In the end, the information in this interview will be used for our reports, presentations, conferences, lectures, etc.

The purpose of this interview is to learn about your expertise regarding the intersections of your professional work and extreme heat in Worcester. Your responses will help us contextualize what we hear from residents and fill some of the gaps in our knowledge. Your answers will be anonymous and confidential unless you want to waive that right. If you do not wish to answer a question, that is totally fine and we can move on to the next. To make it easier to keep track of the interview we wish to record the audio of the conversation. The recording will only be used by our team of researchers at WPI. Is that OK with you?

Resident

1. Can you tell us a little bit more about yourself? What is your occupation?
2. Where in Worcester do you live? Can you describe your residence? Who do you live with (age, gender, relation, disability)?
3. How long have you lived in Worcester? How long have you lived in your residence?
4. Have you noticed any changes in summer heat since living in Worcester?
5. Do you own your residence or rent it? Do you pay your own utilities?
    a. Do you own any other properties?
    b. Are you a landlord?
6. What is your life like during a heat wave?
    a. How does extreme heat disrupt your daily life?
    b. Can you tell us about a few specific moments when extreme heat has impacted you?
7. Do you perceive extreme heat as a health risk to yourself or your family? Why or why not?
    a. Have you ever suffered medically because of it?
    b. Do you have any pre-existing medical conditions?
8. When there is a heat wave, what actions do you usually take to remain cool? Is it enough to relieve you from the heat? Why or why not?
9. Have you or do you make any preparations or modifications to your home to make it cooler? What barriers keep you from making these changes?

10. Do you interact with neighbors, family, tenants, and friends regarding extreme heat events?

Landlord

11. What modifications would you like to make to your residence to make it cooler?
    a. How much would you be willing to spend on these modifications?
    b. What are barriers that keep you from making changes?
12. Do your residents pay for their own utilities?
13. Do your tenants raise concerns about summer heat? Are you concerned about the heat in your properties?
14. Have you taken any measures to alleviate heat in your rental properties? Are there any additional measures you are considering?
15. How much would you be willing to spend on modifications that benefit your tenants? What do you see as the returns on investment for these modifications/retrofits?
16. Have you ever had an energy audit or evaluation of your properties?
17. What are the main issues that landlords are experiencing in Massachusetts? How does climate change affect landlords?
18. How do you feel about proposals that require landlords to provide air conditioning or other means of cooling for all properties?
19. What steps can researchers take to include landlords in this discussion and encourage them to take crucial steps towards decreasing heat vulnerability in Worcester?

Community leader

20. What do you hear from community members about the heat in Worcester?
21. Based on your experience as ___, do you think extreme heat is an important planning issue?
    a. Do you think that the risk of extreme heat in Worcester has changed over time? Why? (Development, climate change, landscape changes, EJ concerns)
22. From your perspective, what are the biggest heat vulnerabilities/weaknesses in Worcester?
23. What do you think should be done to improve Worcester's resilience to heat?
24. What kinds of data do you think should be collected to improve decision making and solutions for extreme heat events?