Assessing Heat Risks to Prepare Chelsea, Massachusetts for a Changing Climate

An Interactive Qualifying Project
Submitted to

The Faculty of the
WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

Submitted By:	Advisors:	Sponsors:
Ermina Damlamayan	Seth Tuler	John DePriest
Conrad Mera	Jennifer deWinter	Alexander Train
Michael Munroe		
Elizabeth Walkes		

Presented to the City of Chelsea Department of Planning and Development

Abstract

Chelsea, Massachusetts faces risks from extreme heat due to a changing climate. Many of its residents are vulnerable to rising summer temperatures because of low incomes, language barriers, and low education levels. The goal of this project was to identify the populations and geographic areas that may be particularly impacted by increasing temperatures and recommend best practices for the city's consideration to mitigate negative impacts from extreme heat on the vulnerable populations. We researched strategies used by other US cities and we interviewed city officials to gain insight into the city's capabilities and residents. We produced recommendations for strategies to be implemented in Chelsea, which we delivered to our sponsor, the Department of Planning and Development.

Executive Summary

Assessing Heat Risks to Prepare Chelsea, Massachusetts for a Changing Climate

Ermina Damlamayan, Conrad Mera, Michael Munroe, and Elizabeth Walkes

The Problem

The residents of Chelsea, MA are vulnerable to the effects of increasing temperatures. Furthermore, the City has yet to identify the extent of the risks on the vulnerable residents, because it is still a new area of research for the Metropolitan Area of Massachusetts.

Goal

The goal of this project was to identify the populations and geographic areas that would be particularly impacted by increasing temperatures and recommend the best practices that the city can further pursue to mitigate negative heat impacts on the vulnerable populations.

Methods

To achieve our goal we completed four objectives:

1. Qualitatively define heat vulnerability.

We researched heat vulnerability factors from both journals and previous projects in order to assess how characteristics contribute to one's vulnerability. The three dimensions of heat vulnerability are one's levels of: adaptive capacity, sensitivity, and exposure.

2. Identify the demographics in Chelsea who are vulnerable to extreme heat and their geographic distributions.

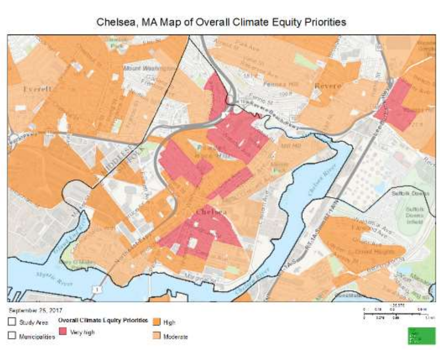

Figure 1

We relied on our sponsors as well as interviews with local stakeholders, such as Luis Prado of the Health Department and the Chelsea Restoration Corporation, who would be able to give us insight into which demographics are present in the city. We also sought any existing mappings like Figure 1 and discovered the Trust for the Public Land's Climate Smart Cities™ GIS tool. They gave us permission to use their tool for mappings of numerous vulnerable demographics in Chelsea.

3. Analyze strategies implemented in the US to lessen people's risks of and vulnerability to extreme heat.

We were able to identify strategies that affect vulnerable demographics represented in Chelsea. We then researched strategies that other cities in the area, like Boston and Cambridge, have used as well as interviewed stakeholders in those communities.

4. Identify the best management practices for Chelsea, MA to further consider.

We organized a matrix that contains all the strategies and practices resulting from our research and used it to identify and compare the potential solutions we intended to propose to the DPD. We then consulted Chelsea city officials about who is vulnerable, the geographic distribution of vulnerable demographics around Chelsea, city policies, recommendations they might have for us, etc. From this, we synthesized our matrix down to the six types of countermeasures that we felt would work best in Chelsea. We also sorted these methods based on level of importance and difficulty of implementation.

Recommendations

Our recommendations focus on six types of extreme heat countermeasures: Cooling Shelters, a Plan and Plant Methodology, Air Conditioning, Cool roofs, Public Risk Education, and a Community Action Plan. We have them organized individually by strategy and the recommendations for implementation.

Implementing and improving **cooling locations** around Chelsea.

A broader set of recommendations for Chelsea include:

- Establish new cooling shelters
- Partner with local transportation companies to provide free transportation to and from the cooling shelters
- Create a system to notify the citizens of extreme heat events (see Chapter 4.5)
- Produce programs to incentivize attendance at the cooling shelter
- Hire medical staff at each cooling shelter to assist those who need it.

Additional Work to implement Cooling Shelters:

- Contact transportation companies to arrange free transportation to and from cooling shelters
- Provide medical staff at cooling shelter through partnership with the Chelsea Fire Department or other local EMS Services

Recommendations for improving Parks:

- Install more shade
    - Tree Canopy
    - Artificial Canopy

Recommendations/Additional Work for Impromptu Cooling Shelters

- Advocate that a larger, regional organization purchase the misting tent and allow municipalities in the Metro-Boston area use it on a first come, first serve basis
- Co-purchase the misting tent with other cities in the area

Establishing a **Plan and Plant Methodology** to remind developers to produce locations that incorporate materials that will not compound the effects of extreme heat events and utilize green space to absorb greenhouse gases.

Recommendations:

- Developers
    - Incentivize the use of green space in new developments
- City Projects
    - Utilize cool surfaces
    - Plant trees in city parks
    - Plant green spaces
    - Install water appliances for hydration and cooling needs

Make **Air Conditioning** more accessible to the community

Recommendations/ Additional Work:

- Implement strategies to work with the one window policy
    - In-wall air conditioners
    - Portable air conditioners
- Advocate the state to provide cooling to low income populations
- Create policies so developers must use energy efficient air conditioning

Implement **Cool Roofs** to reduce indoor temperatures

Recommendations: *White Roofs*

- Contact local painting companies and try to come up with an agreement for more affordable service.
- Create a plan to financially help the low-income population of Chelsea.
- Advertise and promote cool roofs in order to familiarize the residents of Chelsea with this new idea.

Recommendations/ Additional Work: *Green Roofs*

- Conduct further research on what type of green roofs are appropriate for Chelsea

Establish **Public Risk Education** to raise awareness to the risks of extreme heat

Recommendations:

- Create a website with heat-related information
    - Make the URL short and easy to remember
    - Make it shared on major community social media pages
- Work with community organizations to spread information

Establish a **Community Action Plan**, delegating responsibility to key stakeholders during extreme heat events

Recommendations:

- Produce a Community Action Plan
- Partner with local stakeholders to have them be a part of the plan
- Benchmark plan to Milwaukee but benchmark climate to Boston

Deliverables

We provided the City of Chelsea, Department of Planning and Development with two additional deliverables to supplement our recommendations. First, a cooling shelter checklist. This can be used to ensure that all buildings being utilized as public cooling shelters are running efficiently and are up to date. Second, a mnemonic device “Plan and Plan”. That can be used as a reminder to the city and other developers of the impact of their designs on Chelsea’s Urban Heat Island.

Conclusion

The main objectives of our project were to define heat vulnerability, to identify the demographics in Chelsea who are vulnerable to extreme heat and their geographic distributions, to analyze strategies implemented in other locations, and to identify the best management practices for Chelsea, MA to further consider. In order to achieve these, we researched vulnerability factors and listed them in matrices, collected data from GIS systems, analyzed mitigation strategies that have been successfully applied to other places, and conducted several interviews with local officials to familiarize ourselves with the vulnerability of the city.

Chelsea will have to confront multiple challenges in order to create a solid mitigation plan. A major issue we have observed is the lack of green space. However, due to the density of the city, expanding green space is likely to be very challenging. Additionally, we are aware that there are a lot of people in Chelsea living in overcrowded apartments that surpass the officially recorded number of residents. We believe that the city might face difficulties encouraging those people to seek help in case of a heat-related emergency.

Chelsea needs a plan for how to overcome these challenges. We suggest that the DPD look into each recommendation carefully and consider conducting further research to evaluate whether they are appropriate solutions for Chelsea. Our project is a first step into providing the city a sense of direction on how it may go about planning for increasing temperatures rather than a comprehensive, professional-level climate resilience plan. We concede that our efforts to gain more insight into Chelsea itself from local stakeholders fell short. It is for this reason that we suggest the city next look further into the feasibility and suitability of our recommendations by taking actions such as finding what would be required to make certain policy changes and consulting the groups we recommended to get their feedback. If the city wishes to pursue strategies that involve resident expenses, such as implementing cool roofs or promoting air conditioning units, the city should perform analysis of methods to make these utilities as accessible and inexpensive for residents as possible.

Chelsea has the opportunity to become a leader in implementing strategies to reduce heat vulnerability and risk among its. As urbanization continues to cause increasing density in cities around the country, plans such as Chelsea’s will be key in providing a reference guide for how others may mitigate heat vulnerability and ensure the safety of their residents while working with such conditions.

Acknowledgements

We would like to thank our sponsors at the Chelsea Department of Planning and Development. John DePriest and Alex Train were very helpful and supportive through the whole process.

We would also like to thank our advisors, Seth Tuler and Jennifer deWinter, for guiding us through the entire project, and helping us to improve our writing.

We would also like to thank all of the different people that we interviewed throughout the Boston area, who helped us formulate recommendations for Chelsea.

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1.0 Introduction

Like many urban areas, the City of Chelsea, MA is vulnerable to the threat of increasing temperatures. Global average temperatures are increasing year over year with twelve of the hottest years ever recorded occurring within the past twenty years (NOAA National Centers for Environmental Information, 2017). Since 1895, average temperatures have risen by almost 2 degrees Fahrenheit in most parts of the United States, nearly half of which is due to a human factor: the greenhouse gas effect (Melillo, et al., 2014). Temperatures continue to rise at such a rate that by the middle of the 21st century, parts of the Northeast are expected to see over 60 days each year with temperatures above 90 °F (Melillo, et al., 2014). These additional hot days are classified as extreme heat days, the definition of which varies from place to place but is generally when the temperature of an area rises above the average for that specific place for an extended period of time (Reid et al., 2012; Bao, Li, Yu, 2015; AzEIN Staff, 2017). Boston, in particular, defines these events as heat waves, which is when 3 or more days of ≥ 90°F temperatures occur (NWS Boston, 2017).

Some of the major risks extreme heat poses to people are: cardiovascular problems, heat stroke, and respiratory problems (Melillo, et al., 2014). These heat-related illnesses are a serious health concern, as extreme heat is one of the leading weather-related causes of death and injury in the U.S. despite being preventable (National Weather Service, 2015, 2016; City of Cambridge, 2015). Though extreme heat poses risks to the entire population of affected areas, there exist groups of people who are more susceptible to health threats due to their exposure, sensitivity, and ability to cope to extreme heat. These vulnerable populations include: the elderly, infants and children, people with chronic health problems, and low-income populations (National Weather Service, 2015).

While everyone is affected by rising temperatures, those who live in cities such as Chelsea are more vulnerable due to the Urban Heat Island effect (Hajat, O'Connor and Kosatsky, 2010). This is the effect where temperatures within a city are higher than its neighboring non-urban areas. This occurs for several reasons, the main ones being: tall buildings blocking wind movement, lack of vegetation to remove excess carbon dioxide, and lack of shade (Stone, Vargo and Habeeb, 2012). Within its 2.0 square miles, Chelsea contains an estimated population of 37,000 people with a 20.9% poverty rate and a rental rate of 73%. The majority of the residents are ethnic minorities, including non-English speaking immigrants of Hispanic backgrounds (City-Data, 2017). What makes these statistics relevant is the fact that some characteristics of a city being susceptible to heat-related effects are: low-income populations, non-English speaking populations, a high percentage of renters, older and/or less expensive infrastructure, and an urban setting (Stone, et al., 2010). In the event that Chelsea's residents are vulnerable to extreme heat events, it would be in the city's best interest to take measures to ensure their safety.

Vulnerable populations in urban areas are put at the highest amount of risk when temperatures rise (Melillo, et al., 2014). To mitigate these problems, many agencies, such as the Center for Disease Control, World Health Organization, Environmental Protection Agency, etc., have given communities advice to prepare themselves for extreme heat days (Minnesota, 2012; State of Wisconsin, 2016; Kansas, 2014). This advice is fairly universal, often repeating the same few pieces of advice across the aforementioned organizations, making it fairly accessible and mostly focused towards vulnerable populations, such as the elderly and infants. Cities must then take the universal knowledge and tailor it to their own specific needs. In some cities, such as

Chicago, vegetation is added through the use of green roofs and tree planting initiatives to manage carbon dioxide emissions (Stone et al., 2012). However, many studies have found that combinations of adaptation methods such as adding vegetative cover, albedo enhancement (reflection of solar radiation from the Earth back to the sun), and reductions in waste heat emissions reduced city-wide temperatures by between 2° and 13 °F (Stone et al., 2012; Kikegawa et al, 2006; Zhou et al., 2010; Lynn et al., 2016).

The Chelsea Department of Planning and Development (DPD) has taken measures in the past decade to get a better grasp of how climate change will affect the city. Previous projects in Chelsea have identified some climate change risks; Assisting Chelsea's zoning board to create a climate change adaptation plan as well as identifying public buildings at risk for flooding (Guay, Hennessy, Richard, & Rojas, 2014; Heaney, Sesma, Turchiarelli, & Vega, 2015). However, preparations specifically regarding the risks from rising temperatures upon Chelsea's vulnerable populations have not yet begun. While the city has added cooling fountains in a number of city parks and the Chelsea City Library is an established cooling shelter for residents to enter during extreme heat, the DPD has not conducted formal research towards: identifying vulnerable groups in Chelsea, assessing the extent to which increasing temperatures will affect the city's residents, or identifying best practices that can feasibly be employed in Chelsea to protect its vulnerable people from heat. With temperatures increasing and its citizens potentially being at risk, the city is now embarking on this effort to create an in depth plan to keep them safe.

The goal of this project was to help the City of Chelsea better prepare for the risks of rising temperatures on its residents. We worked with the DPD to identify the demographics of Chelsea that are vulnerable to extreme heat. We analyzed the strategies that other cities have used to lessen the risks and vulnerabilities imposed on their citizens by extreme heat. Lastly, our project team synthesized all information that was gathered to identify best management practices applicable to Chelsea, MA for the DPD to further pursue. Through this project, we hope that the City of Chelsea may be more knowledgeable and better prepared for the effects of rising heat.

2.0 An Analysis of Rising Temperatures and the Vulnerabilities of Extreme Heat

In this chapter we first discuss temperature predictions for the Northeast region of the United States. Second, we focus on cities and how the Urban Heat Island (UHI) effect amplifies the risks of extreme heat in urban areas. Third, we then discuss how extreme heat events negatively affect people as well as what causes populations in United States to be vulnerable to extreme heat under three categories of vulnerability: exposure, sensitivity, and capacity to cope.

Many people in Chelsea share characteristics of those who are vulnerable during extreme heat events, as discussed in section 2.3. To start, of the city's occupied 11,888 housing units, only about 3,400 of them are occupied by their owner. This leaves 73% of the properties at renter only occupancy (Area Connect, 2000). Another vulnerable portion of the population that we found in most cities is the elderly. In Chelsea, 22% of the population is over the age of 50 years old (City-Data, 2017). A final assessment found that about 16% of the population in Chelsea is between the age of 0 and 9 years old, fitting them into the portion of the vulnerability profile regarding infants and children. We have matched these portions of the population to characteristics of vulnerable populations in other cities that we have encountered throughout our research, and we will later see if these populations in Chelsea fit the trends highlighted in other cities.

Fourth, we present many cities in the United States have already begun to take action to protect their citizens from extreme heat, which can cause cardiovascular injuries, heat stroke, and many other medical emergencies. Cities like Milwaukee, Wisconsin, and Chicago have taken steps to institute protective measures in their regions of the United States. Closer cities like Boston and Cambridge, Massachusetts have also taken steps right here in the Northeast which will provide a closer representation to the effects that high temperature days are having in Chelsea. The Department of Planning and Development is looking to follow suite and find the best ways to mitigate and adapt to extreme heat.

2.1 Global Rising Temperatures Reflected in the Northeast

Greenhouse gas (GHG) emissions from industry and transportation trap heat in the atmosphere, which are increasing global temperatures (Environmental Protection Agency, 2014). These increasing temperatures are year round, not only are the summers getting warmer, but so are the winters.

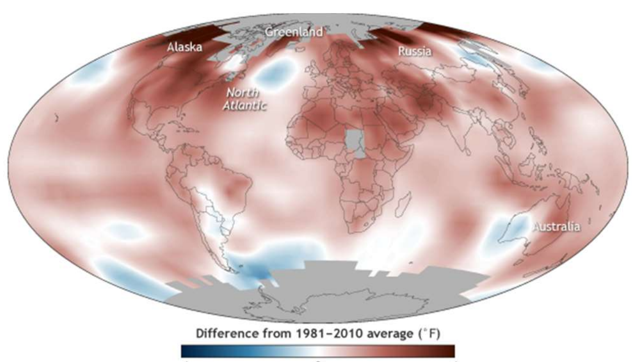

Figure 1: Increasing World Temperatures. This diagram shows the difference of the 2016 average surface temperature compared to the average surface temperatures of the years 1981-2010 (Dahlman, 2017).

This rise in global temperatures is pertinent to the Northeast of the United States, because the current infrastructure is built for a harsh winter, absorbing more heat than it dissipates. During the summer months, rising temperatures will increase the number of extreme heat days in the Northeast (Melillo et al., 2014). The Northeast is comprised of the following states:

- Connecticut
- Delaware
- Maine
- Maryland
- Massachusetts
- New Hampshire
- New Jersey
- New York
- Pennsylvania
- Rhode Island
- Vermont

Extreme heat is defined as when the temperature of a given area stays above the average for an extended period of time. Researchers have projected that for the years 2041-2070, current emission trends will result in an additional two months' worth of days above 90 ^{o}F per year in the Northeast. As seen in Figure 2 below, the largest increase in these extreme heat days will occur in and around coastal cities (Melillo et al., 2014).

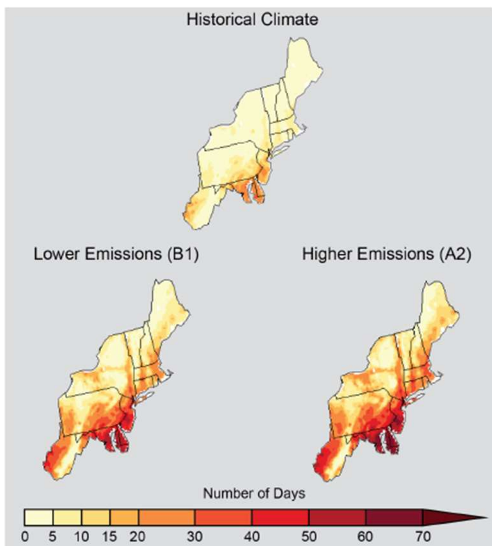

Figure 2: Northeast Heat Predictions. This graphic depicts the projected increase in number of days per year with temperatures above 90 °F in the Northeast (Melillo et al., 2014).

This projected increase in frequency and severity of extreme heat poses public health risks to all inhabitants of these areas. Due to these risks, increasing temperatures are a cause for concern in the Northeast, particularly with regard to urban environments.

2.1.1 Rising Temperatures in Cities

Several forces cause cities to be even hotter than their non-urban surroundings, increasing the risks to their populaces. When a section of a city is warmer than its outlying neighbors, the phenomenon is known as the ***Urban Heat Island (UHI) effect***. According to Michael Adler in *Preparing for Heat Waves in Boston*, "[t]he Urban Heat Island effect occurs because of lack of vegetation, dark colored infrastructure and impermeable surfaces, design of tall infrastructure that blocks wind and create urban canyons that trap heat as well as other anthropogenic heat sources" (2011, p. 18). The following table (Table 1) is a synthesis of factors that compose the UHI effect from these sources: Adler et al., 2010; Environmental Protection Agency, 2017.

Contributing Factor	Description	Examples	Effect
Impermeable/Impervious Surface	Solid surfaces that do not allow water to pass through	Asphalt, concrete	Collects and traps solar heat
Lack of Vegetation	Lack of shade-providing trees in cities	N/A	Sunlight reaches surface unimpeded
Dark Infrastructure	Dark surfaces with low solar reflectance and heat emittance	Asphalt, dark-colored roofs	Absorbs solar energy Releases back into atmosphere slowly
Tall Infrastructure	Infrastructure taller than the surrounding environment	Tall buildings, highways	Blocks wind that would promote cooling Creates urban canyons that trap heat

Table 1: Urban Heat Island Effect Contributing Factors. This is a table of factors contributing to the UHI. Several factors have not been included due to a lack of evidence including, but not limited to flooding and emissions (Adler et al, 2011).

Ultimately, the UHI effect manifests as increased temperatures in cities during heat waves, with the biggest differences in temperature usually occurring at night. This is because all of the solar energy stored in a building's pavement during the day gets reradiated out at night, keeping city temperatures high. In the most severe cases, cities can get to be 22 °F hotter than their surroundings at night, which means that even after being exposed to high temperatures during the day, residents are unable to cool off at night (Adler, et al., 2010). The dangers of increasing temperatures in cities are evident and pose serious risks to vulnerable populations.

2.2 The Health, Social, and Economic Impacts of Heat

Extreme heat is a primary health concern for municipalities due to its adverse effects on the human body. The human body can only do so much to adapt to high temperatures, which can cause people to suffer from several health risks, including (Crimmins, et al., 2016; Melillo et al., 2014; Mayo Clinic Staff, 2014):

Sun Burns	Dehydration	Heat rash	Heat exhaustion
Heat cramps	Heat edema	Heat stroke	Death

The human body's natural cooling mechanism is to release sweat from the skin. When faced with high temperatures, the body sweats more in an attempt to cool itself down. Due to the fact that sweat is almost entirely water, profuse sweating quickly dehydrates the body, leaving it vulnerable to the health risks of ***dehydration***. Many medications also dehydrate patients, compounding the threat of profuse sweating. Furthermore, the act of sweating is only effective in cooling the body to a certain extent, meaning that it cannot protect oneself from all of the negative effects of high temperatures, especially during the prolonged duration of extreme heat events (Kahn, 2016). Some health impacts that exposure to extreme heat can have on the human body are heat exhaustion and heat cramps, which occur from exercising in intense heat or in a hot and humid environment (Mayo Clinic Staff, 2014, 2015). ***Heatstroke*** is one of the most severe threats extreme heat poses to heat-vulnerable populations. Heatstroke occurs when the body overheats and results in the rise of its temperature to a dangerous level, usually above 104 °F or 40 °C (Mayo Clinic Staff, 2014), that requires emergency treatment. If not treated properly, it could result in an increased chance of death. Approximately three of every million people in the United States die annually from heat related incidents, see Appendix B (Environmental Protection Agency, 2016). This translates to approximately one-thousand deaths per year. Furthermore, heat waves cause significant death tolls around the world. The following table (Table 2) serves to highlight the scope of recent heat wave mortality rates, from these sources: California Heat Adaptation Workgroup, 2013; National Disaster Management Authority, 2016.

Location	Year	Death Toll
Philadelphia	1993	118
Chicago	1995	739
Europe	2003	70,000
California	2006	650
Russia	2010	11,000–50,000
India	2013; 2014; 2015	1,216; 1,677; 2,422

Table 2: Heat Wave Death Tolls. This table lists the largest heat waves in the world during the last 25 years (Rodriguez et al., 2013).

Extreme heat also impacts a community socially. People may be reluctant to leave their houses to go to cooling shelters that are crowded and lack entertainment or alternative purposes. In poorer communities, there exists the prospect of having to stand around strangers, the homeless, or drug addicts (Teferra, 2017). This is a potentially strong disincentive to those who do not wish to be around these people. Furthermore, extreme heat has historically promoted public unrest that may lead to increases in crime. For example, during a 2012 Chicago heat wave, more than twenty people were shot and three were killed in just three days of 100 degree heat. (Dahl, 2012).

The constant rising of temperature during the summer months is responsible for a series of economic related issues to the areas impacted. For example, during the summer of 1980 across the United States, the economic losses were estimated to be $16 billion mainly due to high energy demand, livestock losses, and damages to crops and highways (Karl and Quayle, 1981). As temperature increases, the productivity of the working population decreases, resulting into a loss of millions, if not billions, of dollars each year (Kjellstrom, 2014). A significant problem that also occurs in summer, especially during extreme heat days, is the extended use of air conditioners, which often results into grid overload and power outages (Madison Park, 2017). Extreme heat can also have a negative effect on the health care system. During the 2006

California Heat Wave, in a 2-week long period 16,166 ER visits and 1,182 hospitalizations occurred statewide because of heat-related health problems (Knowlton et al., 2009).

2.3 Heat Vulnerability

Though extreme heat poses risks to all residents of an area during a heat wave, the degree to which each person is vulnerable to these negative effects can vary. In the context of this project, ***vulnerability*** is defined as being "the degree to which a system is susceptible to injury, damage, or harm" due to one's levels of exposure, sensitivity, and capacity to cope to extreme heat (Manangan et al., 2014, p. 4). High exposure, high sensitivity, and low adaptive capacity are undesirable characteristics because people with these characteristics are more likely to be affected by the impacts of extreme heat while having less ability to help themselves (City of Cambridge, 2015).

Agencies like NOAA rely on ***heat vulnerability indices*** like the one in Figure 3 below to evaluate the level of exposure that a person has to extreme heat, by comparing the temperature versus the humidity. The higher the comparison gets, the more vulnerable an individual will become.

Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Figure 3: NOAA's National Weather Service Heat Vulnerability Index. A Heat Vulnerability Index comparing Temperature and Humidity (NOAA, n.d.).

Groups of people characterized by certain traits share similar degrees and manners of vulnerability. These vulnerable characteristics compound the vulnerability described in NOAA's Heat Vulnerability Index and increase the individual's exposure, sensitivity, and capacity to cope to extreme heat. We found the categories below to fall into our definition of vulnerability: (FEMA, 2008)

- Elderly
- Renters
- Sick/Disabled People
- Income
- Babies/Children
- Non-English Speakers
- Walkers
- Undocumented immigrants
- Special Needs
- Floor Level
- Socially Isolated
- Education Level
- Access to Cooling Shelters
- Access to Green Space
- Access to Air Conditioning
- Pets
- Density of House
- Construction of House

Many of these characteristics prevent the individual from coping with the vulnerable position that they have been put into. For example, renters often do not have control over updates to their home without the owner's permission. Babies fully rely on others to keep them safe so they have a high sensitivity, a low capacity to cope and are very vulnerable to extended exposure. Many cities around the world have worked to make sure that these different groups stay safe during extreme heat events by trying to increase their capacity to cope.

2.4 Circumstances in Chelsea Affecting Vulnerability

Chelsea has numerous circumstances and characteristics that contribute to and affect the manners in which heat vulnerability propagates in the city. One of the factors our sponsors informed us of is that there exists a significant portion of the population that does not speak English. Approximately 68% of the population speaks a language other than English at home, the most prevalent language being Spanish at 56.9% of the city's total population (Statistical Atlas Staff, 2015). However, Chelsea having a **large Hispanic community** plays more of a role in the city's vulnerability to heat than solely presenting a language barrier. Regarding ethnic minorities being affected by extreme heat events, Hispanic communities have historically fared better than others, such as during the 1995 Chicago heat wave (Klinenberg, 2002). This is due to Hispanic communities often being in densely populated areas and having strong social networks, which decreases their degree of social isolation.

Though the characteristic of being densely populated is beneficial in reducing isolation in Chelsea, it presents challenges as well. A con to this dense population in Chelsea is that many residences are **overpopulated**, often containing more residents than officially recorded. For instance, during our time in Chelsea, a two-family household caught fire, from which six children and eighteen adult residents were evacuated. This brushes upon an aspect of **legality** that renders Chelsea people more vulnerable. Even in the case of a health emergency, residents in overcrowded residences may not wish to call emergency services to their location. Similarly, undocumented workers in Chelsea may be reluctant to rely on emergency services for fear of their status being revealed. The risks of these situations are further compounded by Chelsea's low education level.

Chelsea residents generally **do not realize the severity of extreme heat risks**, nor are they widely aware of appropriate responses to extreme heat events. 36.3% of the City's population over 24 years-old does not have a high school diploma, which is a staggering rate compared to the Massachusetts average of 10.6% (Statistical Atlas Staff, 2015). Many residents in Chelsea do not know the extent of rising temperatures and are not concerned with extreme heat. We learned from speaking with the Chelsea Restoration Corporation that it may be difficult for residents in Chelsea to internalize that extreme heat is a serious issue. This challenge is a combination of two factors: people from warmer countries may not see rising temperatures as an issue because they like and are accustomed to the heat, and residents may chalk extreme heat events up to New England's strange weather patterns. However, extreme heat is in fact a concern of Chelsea residents during such events.

There is an **increase in emergency service usage during heat waves** in Chelsea (Prado, 2017). During heat waves, some residents call 911 and go to hospitals even when they are not in danger, which places an unnecessary load on the city's emergency resources. These incidences are often a result of people simply not knowing what to do during extreme heat events and relying on their last line of defense, emergency services. Furthermore, from our research and discussions with John DePriest and Alex Train, we learned that Chelsea has a prevalent homeless population, crime rate, and abuse of drugs. These present direct challenges to certain adaptation strategies, such as people not feeling safe spending the night in parks to cool off due to the crime rate in the city (Klinenberg, 2002). Challenges such as these are further explored in the individual sections of Chapter 4.

Many members of the Planning Board and Conservative Commission in Chelsea are familiar with or have backgrounds in environmental matters. This eliminates a barrier that is common in cities with regard to taking action on climate change.

2.5 Summary

Rising temperatures increasing the severity and frequency of extreme heat events poses significant risks to the City of Chelsea. Chelsea represents numerous social, economic, and cultural characteristics that cause its residents to be vulnerable to extreme heat in varying manners and extents. In order for the city to be able to prioritize countermeasures targeting its most vulnerable residents, it requires an understanding of what methods are available as well as which would be most suitable for Chelsea. This next chapter will discuss how we went about doing this.

3.0 Methodology

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The goal of this project was to identify the populations and geographic areas that may be particularly impacted by increasing temperatures and recommend the best practices that we felt the city would be able to further pursue to mitigate negative heat impacts on the vulnerable populations. In order to accomplish this goal we completed the following objectives:

1. Qualitatively define heat vulnerability.
2. Identify the demographics in Chelsea who are vulnerable to extreme heat and their geographic distributions.
3. Analyze strategies implemented both in the US and around the world to lessen people's risks of and vulnerability to extreme heat.
4. Identify the best management practices for Chelsea, MA to further consider.

This methodology chapter will go over these four objectives in more depth.

3.1 Qualitatively define heat vulnerability.

One of the most important aspects of our project was understanding what heat vulnerability is, whom it affects, and how it affects them. We sought to establish a qualitative definition of heat vulnerability that we could use as a basis for comparing differing vulnerable populations in Chelsea as well as our recommendations. We researched heat vulnerability factors from both journals and previous projects in order to assess how characteristics contribute to one's vulnerability (i.e., reducing adaptive capacity, increasing sensitivity, or increasing exposure). Table 3 shows how characteristics negatively affect certain dimensions of one's vulnerability to heat.

Characteristic	Exposure	Sensitivity	Adaptive Capacity
Babies/Children		x	x
Dependent on Medical Devices		x	x
Elderly		x	x
High Density Household	x	x	x
Isolated Socially			x
Lack of Air Conditioning			x
Low Cooling Shelter Access			x
Low Green Space Access			x
Low Education			x
Low Income		x	x
Non-English Speaking			x
Old Residency Construction	x	x	
Outdoor Worker	x		
Pet Owner			x
Renter			x
Sick/Disabled		x	x
Special Needs			x
Top Floor Level	x		
Undocumented Workers			x

Table 3: Factors that Contribute to Vulnerability. This table depicts how characteristics contribute to an individual's extreme heat vulnerability differently from one another.

We intended to use this in conjunction with a heat vulnerability index that we adapted from the City of Cambridge's Climate Change Vulnerability Assessment (2015). The index consisted of two matrices, the first of which compared adaptive capacity against sensitivity in order to evaluate the severity of consequence when exposed to extreme heat, and the second of which compared consequence against exposure to evaluate a level of vulnerability (City of Cambridge, 2015). We unfortunately could not find enough information in our research to qualitatively compare how much each of these characteristics negatively affects one's sensitivity, adaptive capacity, or exposure. Realizing that we could not effectively incorporate the index to establish our own vulnerability assessment, we decided to utilize assessments from our research to then compare to Chelsea.

3.2 Identify the demographics in Chelsea who are vulnerable to extreme heat and their geographic distributions.

We understood from our research that every municipality varies in vulnerability due to one's specific set of circumstances and characteristics, so we sought to understand how Chelsea specifically is vulnerable to heat. We intended to identify which vulnerable characteristics Chelsea's population represents and to map their geographic distributions in the city. The areas with the most overlap of all three dimensions of vulnerability would be the most vulnerable. We **originally intended to interview residents** with the vulnerable characteristics that we had previously identified; however, we soon realized that we would be unable to perform these interviews due to time constraints, potential risk inherent in our questions, and the logistical challenge of reaching out to many residents during our working hours. As such, we decided to instead rely on our sponsors as well as **interviews with local stakeholders**, such as Luis Prado of the Health Department and the Chelsea Restoration Corporation, who would be able to give us insight into which demographics are present in the city.

We intended to use our qualitative data of heat vulnerability and connect it to our information on Chelsea to identify where the vulnerable populations are located in the city. We originally intended to use GIS systems to create mappings of heat vulnerability in Chelsea based on our findings. However, we realized that we did not have the time to carry this out, nor was our project suitable to develop this type of data-rich analysis with reliable accuracy. As such, we sought any existing mappings of this type and discovered the Trust for the Public Land's Climate Smart Cities™ GIS tool. They gave us permission to use their tool for mappings of numerous vulnerable demographics in Chelsea (Appendix C) along with other useful components of urban heat islands. and we interviewed a number of stakeholders who are familiar with Chelsea. Identifying the distribution of vulnerable populations in the city enabled us to analyze the layout, buildings in close proximity, and potential areas for solutions to be implemented. Many solutions to heat vulnerability are location-dependent, like cooling shelters and parks. Other strategies are material-dependent, which involves whether the buildings are primarily wood or masonry. Using GIS mapping, we were able to strategically mark locations around a map of the city, making connections between neighborhoods.

3.3 Analyze strategies previously and currently implemented in the US to lessen people's risks of vulnerability to extreme heat.

After identifying who is vulnerable and where they are, we analyzed strategies used elsewhere to see when they are implemented and whom they affect. From this we were able to identify strategies that affect vulnerable demographics that Chelsea represents, making the strategies easier to implement. In order to complete this we identified and assessed cooling measures already in place in Chelsea. From the Keep Cool app, we were able to visit established cooling centers and saw that the majority were small parks with water stations, the only different one being the city pool. We also researched strategies that other cities in the Boston area have used as well as interviewed stakeholders in those communities. When conducting this research, we came across a number of strategies that we originally believed could be useful, such as water barrel usage in Chicago; however, we ultimately dropped them from consideration due to either lack of substantial evidence supporting their usage or lack of feasibility in Chelsea.

In order to realize how and where strategies are useful, we created a causal model of a extreme heat, interrupting it where certain strategies could be utilized. This allowed us to identify a causal diagram of heat vulnerability, organizing strategies researched into two categories: proactive and reactive. Proactive approaches are strategies that mitigate the effects of extreme heat event before it occurs, i.e. "Plan and Plan". Reactive approaches, on the other hand, are strategies that are implemented during an extreme heat event to get immediate results, i.e. cooling shelters.

3.4 Identify the best management practices for Chelsea, MA to further pursue.

In order to achieve the goal of our project, we needed to identify which of the methods we have found through our research are suitable for Chelsea. We planned to achieve this by interviewing local stakeholders in the city in order to get feedback on the feasibility of our recommendations. We unfortunately could not make contact with all of the groups we reached out to, so we had to assess the suitability of our recommendations based on a somewhat limited understanding of the city. We organized a matrix that contains all the strategies and practices resulting from our research and used it to identify and compare the potential solutions we intended to propose to the DPD. Determining which populations would be impacted by which practice was one of the main factors we took into consideration, along with the strategies' costs and caveats. We consulted Chelsea city officials about who is vulnerable, the geographic distribution of vulnerable demographics around Chelsea, city policies, and recommendations that they might have had for us. Using these, we were able to synthesize our matrix down to the six types of countermeasures that we felt would work best in Chelsea. We also sorted these methods based on level of importance and difficulty of implementation.

4.0 Recommendations to Chelsea for Mitigating Extreme Heat Vulnerability

While the focus of our project is in Chelsea, populations in many cities across the United States are vulnerable to the effects of rising temperatures. Information on the strategies that other cities within the country have adopted to combat the negative effects of extreme heat is valuable to understand what is effective. Understanding the methods that have been adopted, what logistically makes them feasible in their respective locations, and to what extent they benefit different vulnerable populations is necessary to assess what would be most suitable for Chelsea. We analyzed and made connections based on: Cool Locations, a “Plan and Plant” Methodology, Air Conditioning, Cool Roofs, Education Programs, and a Community Action Plan.

4.1 Utilizing Cool Locations

During a heat wave, municipalities can implement many programs to help their residents cool off. In this chapter we will discuss cool locations such as cooling shelters, public parks, and impromptu cooling shelters. The discussion of this topic will range from what other cities have done, where these strategies currently are in Chelsea or where they could be implemented, and ways to improve these strategies. The tree diagram below (Figure 4) breaks down the chapter, with each section resulting in the deliverable for improvement.

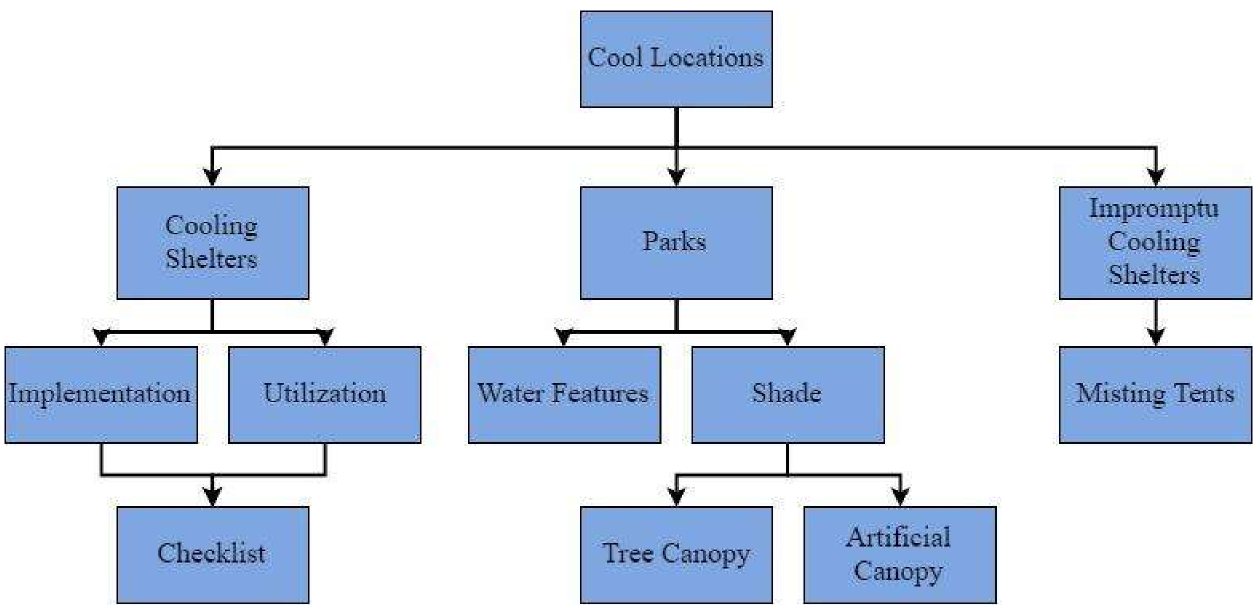

Figure 4: Cool Locations Tree Diagram. This tree diagram breaks the method of cool locations into each of its subcategories and follows them through to a deliverable.

4.1.1 Cooling Shelters

Cooling shelters are used in the United States, Canada, and Europe to provide people with an increased capacity to cope to extreme heat. A ***cooling shelter*** is, by definition, “An air-conditioned public facility where people may go for relief during periods of extreme heat” (Oxford Dictionaries, n.d.). These centers can be air conditioned public buildings such as libraries or schools, pools associated with an air conditioned building, or a combination of the two. Many municipalities across the United States, like Boston, Phoenix, and New York City have utilized these in an attempt to mitigate the effects of extreme heat days (BCYF, 2017; Widerynski, et al., 2017; NYCEM, 2016).

Two aspects make cooling shelters successful: implementation and utilization. Proactive planning incorporates the logistics of establishing a cooling shelter. Reactive planning incorporates the utilization of cooling shelters during extreme heat events. When extreme heat is present, the city must react to get people to the shelters, get key stakeholders to the cooling shelters, and keep the people in the shelter. The most important step to utilizing cooling shelters is to ensure that they are open and operational because, they are not productive if people do not make use of them. One of the largest reasons that people do not utilize cooling shelters is because they do not want to just sit around. There must be something there to keep them entertained (Teferra, 2017). Looking at the causal model for cooling shelters below (Figure 5), the initiating factor is extreme heat, while the ideal solution is in blue "Go to Cooling Shelter". The city must have programs in place and solutions to the fears that are preventing people from using them so that the causal model stops and does not proceed toward the two results in red.

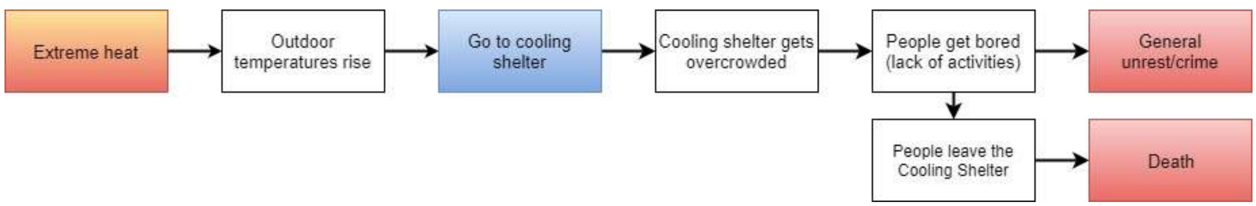

Figure 5: Causal Model of Cooling Shelters. As heat rises, the method of cooling shelters is supposed to stop the model in the blue. If the cooling shelters is not running properly it puts people at risk of moving towards drastic consequences in red.

As we studied the utilization of cooling shelters throughout the world, we searched for results that showed a direct correlation between usage and medical incidents. The goal was to find trends that either confirmed or denied that opening more cooling shelters, in key locations, would lower the number of individuals seeking medical attention at the hospital. Though evidence supports that reducing exposure to extreme heat lessens one's health risks, a correlation between cooling shelter access and hospital usage has not been measured or recorded. Therefore, the largest area of our focus was on the implementation and utilization of cooling shelters as a means to reduce exposure (Widerynski, et al., 2017).

Boston has over 30 cooling centers and pools under the Boston Centers for Youth and Families (BCYF, 2017). Each location offers education programs, workout classes, and sports teams to keep participants busy during extreme heat. Maricopa County, Arizona; home to nearly 4.2 million people and temperatures above 90 degrees for 6 months (April to October) out of the year; surveyed 52 cooling centers within their jurisdiction to gather information on the utilization of the facilities. 62% of the facilities reported back that utilizing their facility for the means of a cooling shelter had no effect on their normal operating cost. The same amount indicated that the hottest parts of the day, noon to four resulted in the highest numbers of visitors to their centers (Widerynski, et al., 2017).

We used the Metropolitan Area Planning Council's (MAPC) application, Keep Cool, as well as interviews with the Chelsea Health Director, Luis Prado, to learn about Chelsea's current use of cooling shelters. We found that within the city limits exists one state-run public pool;

multiple buildings that double as cooling shelters, including the Chelsea Public Library and the Senior Center; and ten parks that have cooling fountains (Prado, 2017). The map below (Figure 6) is a representation of the geographic layout of cooling shelters in the city. Blue dots represent parks, purple dots represent public cooling shelters and pools, and yellow dots represent other public buildings (schools, city hall, and fire stations). We would like to note the lack of cooling shelters in the South West section of town, around Second Street. This is because it is a commercial sector, where the New England Produce Center is located. Because our research and findings were associated with residents, we did not focus on solutions to extreme heat within that section.

Figure 6: Chelsea's Cooling Shelters. This map is a geographic representation of the existing cooling shelters, as well as buildings commonly used in other cities as cooling shelters.

When looking at the map of cooling shelters (Figure 6), there are nine public buildings currently not being used as cooling shelters. These are mainly schools and fire departments, which are ideal for both their size and accessibility. Schools are a great asset because they provide accessibility to the handicap population, public restrooms, and areas sufficient in size to hold events to keep those utilizing the facility busy. Based off of the locations of the schools and fire stations, we believe that these locations will complement the existing water parks well. Therefore, the two densest neighborhoods: Addison Orange and Shurtleff Bellingham should have at least two air conditioned buildings, each to seek protection from the heat.

Currently, to the North West of the Addison Orange neighborhood is the Vietnam Veterans pool (Figure 7), which is run by the Massachusetts Department of Conservation and Recreation.

Figure 7: Vietnam Veteran's Pool. Pictured is the Vietnam Veteran's Pool, a public swimming pool run by the Commonwealth of Massachusetts, by the Department of Conservation and Recreation (DCR). Also seen in the background is Chelsea High School.

Adjacent to the pool is the Chelsea High School, which currently is only being used by the city as a cooling shelter in extreme events, so that residents do not interfere with the school's operation (Prado, 2017). We recommend that the city utilizes this building as a cooling shelter at all necessary hours, during extreme heat; when school is not in session. During the extreme heat this building would serve as an important asset to the neighborhood, because the city can control its operation, which they cannot do with the state run pool. Therefore, if there can be coordination with Chelsea Public Schools, the Chelsea Police, and Fire departments, as well as other stakeholders; an agreement should be met to have the building utilized for cooling purposes when classes are not in session. The city would also need to make sure that school programs can be run without citizens using the other areas of the building and interfering with the school's main purpose. We recommend that the other Chelsea Public Schools are used as well, but that special attention is put towards the High School, because the pool is entirely state run and if they close, it could adversely affect the North West side of Chelsea.

A broader set of recommendations for Chelsea include:

- Establish new cooling shelters
- Partner with local transportation companies to provide free transportation to and from the cooling shelters
- Create a system to notify the citizens of extreme heat events (see Chapter 4.5)
- Produce programs to incentivize attendance at the cooling shelter
- Hire medical staff at each cooling shelter to assist those who need it.

To help Chelsea achieve these we modified a checklist from Milwaukee's Community Action Plan (Table 4 below), which was separated into two categories: Essential Recommendations and Additional Recommendations, as can be seen in Appendix A.

Essential Recommendations			Communication services (internet, translators, etc)
	Air conditioned		Back- up generators
	Publicly Advertised		Transportation services, including wheelchair access
	Accessible to people with disabilities		Adult and Child activities
	Access to potable water		Expanded hours of operation
	Public Restrooms	**Additional Recommendations**	
	Access to 911 services		Area for Pets
	Medical Staff		Parking Access
	Proximity to Public Transit		Facility Security

Table 4: Cooling Shelter Checklist: This checklist would be used to make sure that the building that is being utilized as a cooling shelter is fully functioning to all residents.

The recommendations outlined in the checklist would help the city when opening new cooling shelters and making sure that existing facilities are running sufficiently.

Additional work for the city to look into regarding cooling shelters would include reaching out to local transportation companies and finding medical staff to be stationed at the cooling shelters. Since the MBTA already has numerous routes through the city we encourage further work to see if they would provide free transportation from residential areas to the city's cooling shelters, and vice versa. We also encourage reaching out to TLP Transportation who "provides flexible, safe, reliable, and affordable door-to-door transportation for children of various ages to and from schools, camps and special events. TLP Transportation also offers transportation to/from local hospitals for appointments" (TLP, 2016). Given their description, they may be willing to help vulnerable residents get to cooling shelters, so that they are no longer at risk of needing hospital care. A final transportation company that we suggest the city reach out to is Paul Revere Transportation LLC, because most of their shuttle vans and buses are wheelchair accessible and turbocharged, which reduces their emissions (Paul Revere Transportation LLC, 2017). Therefore, they would be a beneficial asset in transporting people such as the elderly and those with disabilities to and from cooling shelters without adversely affecting the city with high emissions. Our first recommendation for medical staff at cooling shelters would be a partnership with the Chelsea Fire Department, but we also recommend the Cataldo Ambulance Service. The presence of EMS at cooling shelters may encourage residents to go to cooling shelters to stay safe from the heat, rather than going to hospitals for minor reasons.

4.1.2 Using Parks as a Cool Location

Many parks around Chelsea have been updated but require further attention to keep the citizens safe from extreme heat. We conducted a field study of the parks listed in the Keep Cool app on September 11, 2017. The day that we conducted this study was forecasted at 80 degrees Fahrenheit, approximately 6 degrees above the historic average for that day (AccuWeather, 2017). Physically being in the parks felt much hotter than the forecast for that day, which is understandable, as they reside in some of the darker locations on the Average Surface Temperature Map, see Figure 8 below.

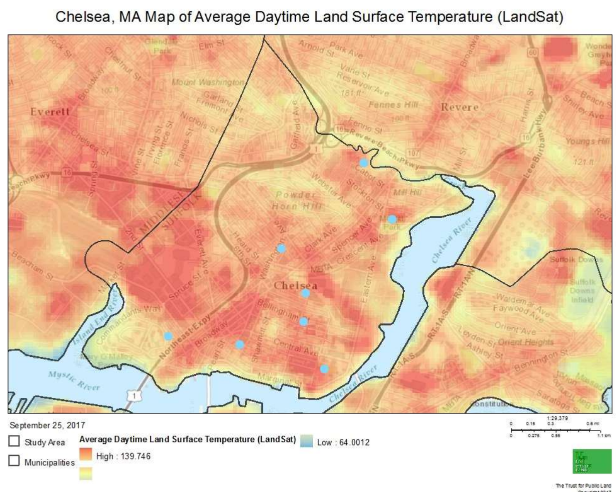

Figure 8: Parks in the Heat. This map marks out the parks containing water features and where they are with regards to the Average Land Surface Temperature Map (The Trust for Public Land, 2017).

Being in the parks on a hot day we noticed a few things:

The city parks **have**:
- Fountains to cool off in
- Light colored surfaces in play areas

The city parks **lack**:
- Shade
  - Tree Canopy
  - Artificial Canopy

A large part of our recommendation for cooling shelters focused on advancing these parks further to provide shade from the heat, in addition to the water features, as seen in the foreground of Figure 9.

Figure 9: Ruiz Park. This park is located near the Orange Addison Neighborhood and has been updated to include water features, as seen in the foreground, but does not have very much shade.

Shade Trees

The first method considered to help bring the parks closer to being a safe zone from the heat is shade through the implementation of an increased tree canopy in the parks. The pictures below, taken at two in the afternoon, show a very modern, open park with fountains, but the current trees lack the ability to produce ample shade.

Figure 10: The Box District Park. This very modern park incorporates a large amount of greenspace with a playground and water features.

We highly recommend the city to continue to plant trees in these parks, as they are one of the few places in the city with ample space suitable for trees. Shade-providing trees would also increase the degree to which the parks may help vulnerable populations: most likely children and their elders looking after them to cope with extreme heat. The implementation of shade trees would extend Chelsea's tree canopy, as much as possible in this dense city, while helping to reduce greenhouse gasses and the UHI. For further analysis of the usage of shade trees as a cooling method, see Chapter 4.2.

Artificial Canopy

A second recommendation to advance the parks is through artificial coverage, like shade sails. Shade sails are used around the world for a modern look with a coating of UV protection

(RainbowShade, 2016). This has already been used in Creekside Common park in Chelsea, as seen in the figure below.

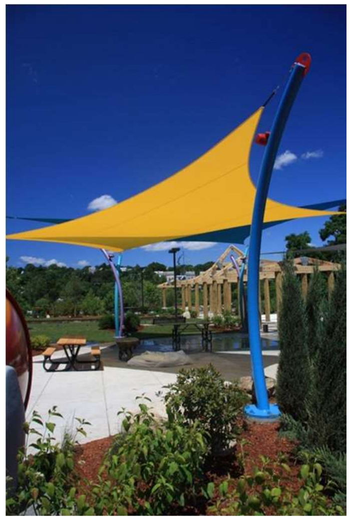

Figure 11: Creekside Commons Park. This park in Chelsea was equipped with a shade sail to provide shade on hot days.

The picture of Creekside Common Park shows the use of a shade sail to protect against the sun's heat. This park was redesigned approximately 10 to 12 years ago, which is when these shade sails were installed (DePriest, 2017). We recommend implementing similar strategies in the other parks around the city. Two things that must be kept in mind with this strategy are:

- Location within the park
- Structural integrity

First, when installing a structure to provide shade, it is important to make sure that it will be effective during the peak hours of the day, which are between noon and four when the sun is directly above and slightly to the West (Widerynski, et al., 2017). These are often the hottest parts of the day, and as mentioned before, the largest portion of the community turns to cooling shelters and parks to cool off during this time. The National Institute of Building Sciences recommends studying the angle of the sun in order to determine the orientation and material for one of these structures. The second aspect to consider when selecting a design and material is: structure. Being in New England, Chelsea experiences large amounts of snow. During the winter of 2015 the Boston area experienced record snowfall of 64.8 inches (AccuWeather, 2017). Through a conversation with John DePriest we learned that Chelsea does not leave these sails up year round because they are not designed to carry a snow load and could tear if they experience strong winds from a storm. Therefore, when providing shade in the parks, Chelsea must decide if they are willing to take the time to install and take down 8 to 10 more of these structures, or if it will be more beneficial from an economic and time standpoint to install a permanent, year round structure.

4.1.3 Providing Relief at Outdoor Events

A final consideration for cooling shelters would be to implement the use of impromptu cooling shelters during large events put on throughout the city, when extreme heat is expected. The Western Region Homeland Security Advisory Council (WRHSAC) has implemented misting tents as part of a strategy to encourage hydration, nutrition, and shade at major events in Western Massachusetts. The large inflatable tents, which can be seen in Figure 12 below, use a water sources to rain mist down onto people as they walk below.

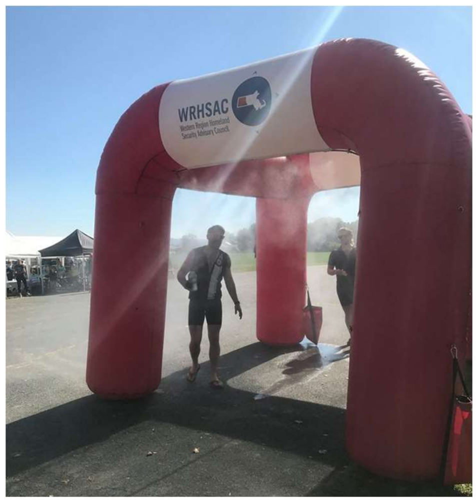

Figure 12: Misting Tent. This misting tent, used in Western MA, allows users to run underneath to be cooled off by a cool mist (WRHSAC, 2017).

Systems like this have been paired with medical staff at large events like the Big E, to decrease the exposure and sensitivity to heat; of individuals who are expected to be outside for an extended period of time.

Further research discovered that multiple companies sell these massive structures, but their price tags are rather large as well. One 14’ x 14’ x 13’ misting tents costs nearly $13,000 and weighs 426 pounds (BPA, 2006). Therefore, we recommend that further work should be done to implement this strategy in Chelsea. The first method to implement this would be to advocate that a larger, regional organization purchase the misting tent and allow municipalities in the Metro-Boston area use it on a first come, first serve basis; like they are doing in Western Massachusetts. The other option would be to cut out the larger organization and have Chelsea co-purchase the misting tent with other cities in the area. In order to do this, Chelsea would need a strong strategy to convince the other cities that this is a good investment. Potential cities would include Boston and Cambridge, where work to keep people safe from extreme heat is already underway, and large outdoor events occur often.

4.2 Plan and Plant Methodology

Around the world, there has been a huge push to counter extreme heat through the use of vegetative cover to cool infrastructure and ambient temperatures (U.S. Environmental Protection Agency, 2008).

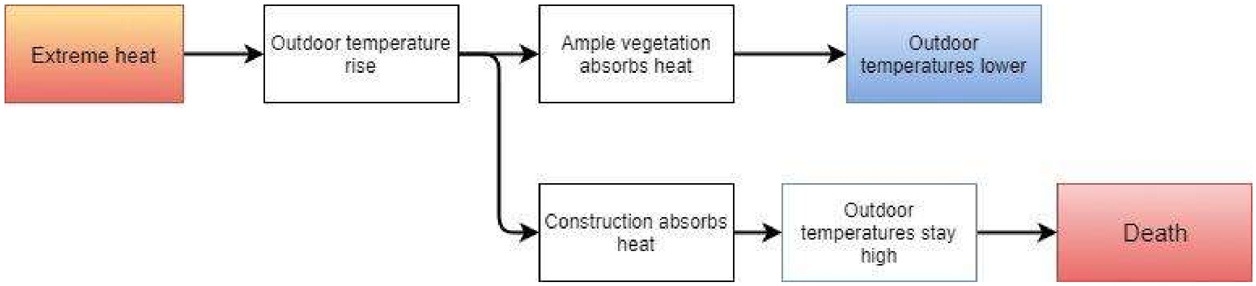

Figure 13: Plan and Plant Causal Model. This causal model shows a positive resolution in blue where the vegetation added during construction absorbs heat, however it can lead to a negative resolution, in red, if no vegetation is added.

A primary component of vegetative cover is trees, which provide cooling by both shade and evapotranspiration. ***Shade trees*** are an increased vegetation plan throughout a city in order to reduce the UHI effect and greenhouse gas emissions (City of Chicago, 2009). Shade trees reduce the UHI by absorbing excess Carbon Dioxide from the air. Research on what type of trees are appropriate for the climate of the city is essential for this idea to be successful. Several cities in states like Illinois, Idaho, Maryland, Arizona, etc. encourage residents to plants trees individually or organize tree planting events (The Arbor Day Foundation, 2017). The Arbor Day Foundation even donates trees to its new members. They recommend using the trees to shelter your whole house, keeping it out of direct sunlight. They also suggest just covering your air conditioning unit so that it works more efficiently. Another successful initiative was implemented in Littleton, MA, where the Littleton Electric Light & Water Department (LELWD) will give two trees per year to one hundred different households that apply to their program. The process also defines the optimal locations for the homeowners to plant their new tree and that the homeowners are responsible for caring for the tree.

After researching other cities' actions around shade trees we spoke with the Department of Planning and Development and read a 2016 Interactive Qualifying Project through Worcester Polytechnic Institute, to learn what Chelsea had done in recent years (Lanni et al., 2016). Two particular initiatives that stuck out were that Chelsea had planted nearly 2,000 trees in recent years, 30% of which have died due to methane gas leaks underground. This large initiative lead us to research the current tree canopy in Chelsea, MA, which can be seen in Figure 14 below.

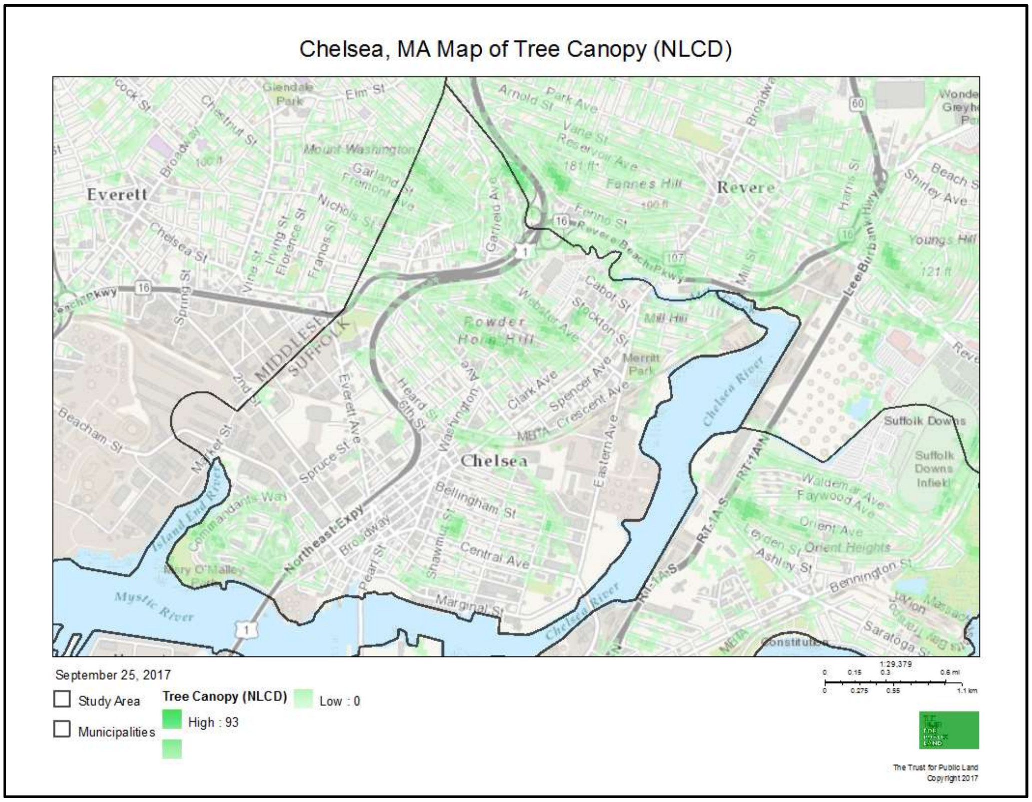

Figure 14: Chelsea's Tree Canopy. This GIS Map from the Trust for the Public Land shows that Chelsea lacks plant life and a tree canopy.

Chelsea has a very sparse tree canopy because of its density and lack of room for trees to be planted. The second initiative, recommended by the WPI students involved raising community awareness about ongoing tree planting programs.

The "Plan and Plant" Methodology is a mnemonic device that could be used to initiate policy and incentivize developers to remember the impacts that their designs will have on the entire population of Chelsea. The current layout of buildings in Chelsea are a great representation of the density of the population. Very few of the houses have much to consider for a yard; they are all built close to the sidewalk and within close proximity to each other, as seen on Bloomingdale St. in the Orange Addison neighborhood (Figure 15).

Figure 15. Bloomingdale Street. Three houses sit very close together and very close to the sidewalk.

Numerous new developments were recently completed, are in progress, or are set to begin soon. As mentioned in Chapter 4.1, at least ten parks have been developed within previous years to incorporate cooling features like fountains and shade sails. There has also been recent additions of a large Market Basket complex which incorporates other shops on the far side of a large parking lot; and numerous housing complexes built by outside developers.

Recommendations:

- Parks
  - Plant more trees for shade
- Developers
  - Incentivize the use of green space in new developments
- City Projects
  - Utilize cool surfaces
  - Plant green spaces
  - Install water appliances for hydration and cooling needs

In most cities our recommendations would include an extensive program to initiate tree planting, but because of previous work already conducted, and Chelsea's density we do not think that this is a viable solution to lessen the UHI and protect the vulnerable populations. However, we do recommend planting trees wherever possible. In Chapter 4.1 we discussed planting trees in open spaces in the city parks, to provide shade to pair with pre-existing water features. We would also like to recommend that the Department of Planning and Development initiate a policy to require all new developments on public and private lands to incorporate a certain amount of green space based on the size of the project. After talking to Axum Teferra with the Metropolitan Area Planning Council she highly recommended the usage of MAPC's tool that maps natural gas leaks, that way they can be fixed during the development process and will not kill the green space after the work has been completed.

A large section of our recommendation for "Plan and Plant" came after John DePriest informed our group of a project to redesign Broadway. Being the busiest part of Chelsea, located in front of City Hall, this street is home to numerous restaurants, apartments, and businesses. Because of the large amount of car and bus traffic, masonry construction, and commercial activity; Broadway is one of the darkest sections in the Average Land Surface Temperature Map (Appendix B). Developing this section of the city with the "Plan and Plant" Methodology in mind, would involve examining and implementing new surface material, green space, and public water features. A few smaller recommendations that we have is using light colored, very reflective materials for sidewalks and streets; as well as lining any available space with vegetation to produce a green space in this area. This area also has a high amount of foot traffic and numerous areas for the citizens to board public transportation, like the MBTA bus routes. Therefore, we would also recommend similar efforts to those already utilized in Cambridge, to implement public hydration stations like the one shown below (Casanova-Davis, 2016).

Figure 16. Hydration Station. Stations like these could be implemented in public parks and along broadway to keep people hydrated in the heat.

By utilizing similar appliances, the city would be able to counter the affects that dehydration have on the body during extreme heat. Therefore, they are reducing the vulnerability of people who are outside during the day. A second positive aspect that hydration stations bring, which was recognized in Cambridge is that when the appliance is equipped with a water bottle filler as well, it reduce waste and littering throughout the area (Casanova-Davis, 2016). However, through a discussion with John DePriest we discussed that one concern that these would bring to Chelsea—which contains a large homeless population—is how to prevent individuals from misusing these hydration stations for hygiene purposes.

Our recommendations for "Plan and Plant" are an approach to be taken by the city to implement policies and ideas on new projects so that new infrastructure does not adversely affect vulnerable populations and the UHI. By working with light colored surfaces, hydration stations, green spaces, and other features; the city will take advantage of as much space as possible in an already dense city.

4.3 Air Conditioning

A properly working air conditioning system can cool a room down to a comfortable temperature, lessening the vulnerability of those inside the building.

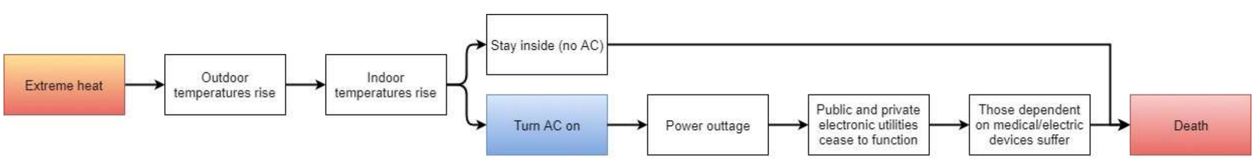

Figure 17: Air Conditioning Causal Model. This causal model shows a positive resolution in blue of A/C being turned on and people staying safe, but if they do not utilize A/C or the power grid cannot support such a heavy load, then the causal model continues toward the potential for death.

New York State has extended their Home Energy Assistance Program (OTDA n.d.) to incorporate cooling. The state has a list of eligibilities for the program including the income table below (Table 5), which is based off of household size.

Household Size	Maximum Gross Monthly Income
1	$2,300
2	$3,007
3	$3,715
4	$4,423
5	$5,130
6	$5,838
7	$5,971
8	$6,103
9	$6,236
10	$6,369
11	$6,671
Each Additional	Add $520

Table 5: Household Income. This table outlines the maximum income per household size to qualify for heating and cooling help (OTDA, n.d.).

Through the program, an eligible family can receive a fully installed air conditioner for $800. New York's strategy to lessen the financial burden of air conditioners prioritizes the low income community, while also having the potential to decrease the vulnerability imposed on other populations, which include but are not limited to: children, the elderly, and renters. A significant challenge with promoting air conditioner usage in Chelsea is their installation cost. From our research and discussions with John DePriest, we learned that one fifth of the population in Chelsea lives below the poverty line, making the cost of air conditioners out of reach (City-Data, 2017). Massachusetts also has a Low Income Home Energy Assistance Program (LIHEAP), but they have yet to extend the funding of this program to cover the costs of cooling.

Through discussion with John DePriest we learned that another issue seen in Chelsea is a building code that prevents people from installing an air conditioner into a window if the room only contains one window. Currently the only solution to this issue is for the individual to get a letter from their doctor, stating that the air conditioner is needed for medical reasons (Bebinger, 2017). A solution to this problem would be installing an in-wall air conditioner, which does not affect this requirement of the building code. We observed this method on Addison St. in Chelsea, as seen below (Figure 18), which speaks to the ability of this method to be implemented.

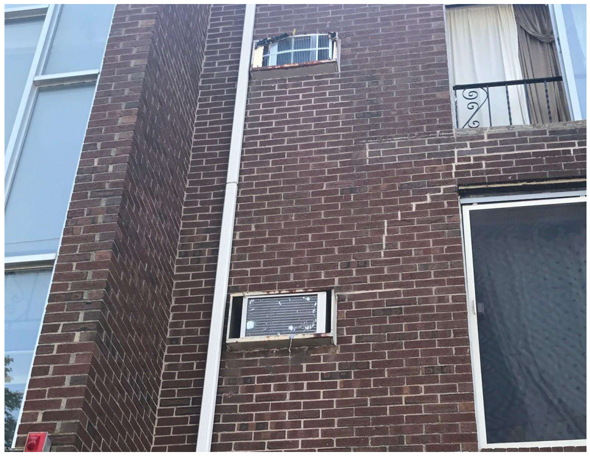

Figure 18: In-wall air conditioners. At this condo on Addison Street the air conditioners were installed in the wall, rather than in windows.

We would recommend advocating for this method in places like the Chelsea Housing Authority complex, where the one window policy is prominent. Another solution is portable air conditioners, which sit within the room and only have a small tube in the window (Prado, 2017). Both of these solutions leave the window open as an egress point, in case of emergency.

The use of air conditioners can help the residents of Chelsea avoid the negative health effects of extreme heat. Without air conditioning, staying in during a hot day can be dangerous to the health of vulnerable populations like the elders. Meanwhile, with a high usage of air conditioning, a challenge Chelsea could potentially face is power outages. The majority of the structures in Chelsea are old, which gives a higher chance of a grid overload or failure. Another challenge that arises with air conditioning is ensuring that citizens, as well as developers, are using energy efficient systems so that the heat dissipated from the appliance is not increasing the UHI.

Our recommendations for Chelsea, regarding air conditioning, involve working with older policies and advocating for new policies to make air conditioning more accessible to lower income populations:

- Implement strategies to work with the one window policy
    - In-wall air conditioners
    - Portable air conditioners
- Advocate the state to provide cooling to low income populations
- Create policies so developers must use energy efficient air conditioning

This project did not cover all aspects of work for air conditioning. Further work would involve reaching out to the state to extend the LIHEAP to include cooling, using New York as a benchmark for this strategy. The Department of Planning and Development must also work with the Housing Authority to show residents the positive aspects of introducing in-wall air conditioners.

4.4 How to Reduce Heat on Higher Levels of Buildings

One of the leading causes of mortality during the 1995 Chicago heat wave was the temperature of living spaces on the top floor of apartment buildings with black roofs, which have low reflective properties (Sproul, et al., 2014). By increasing the reflective properties of the roof, the building can become safer for those inside, as seen in the causal model below (Figure 19).

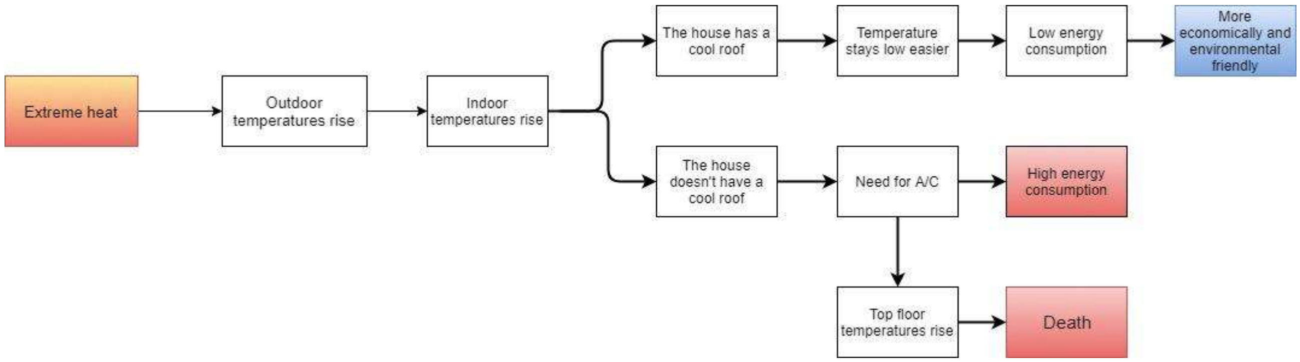

Figure 19: Causal Model of Cool Roofs. This model shows a positive resolution in blue where cool roofs reduce energy consumption. It also shows some negative resolutions where cool roofs either do not work, resulting in higher energy consumption, or death in people who live on upper floors and do not have air conditioning.

One way to combat this deadly effect is to turn the roof into a ***cool roof***, which is a type of roof with high levels of solar reflectance and thermal emittance (Saint-Gobain, 2017). These methods are not only useful for private residences but also for public buildings. Installing cool roofs on these buildings could help maintain a low indoor temperature, lessening the energy expenses of the buildings and helping reduce the load on the power grid. The two main types of cool roofs are: reflective roofs (painted) and green roofs.

4.4.1 Reflective Roofs (Painted)

A roof can be painted with a reflective coating that is usually white or another light color, which allows it to reflect away a greater amount of sunlight.

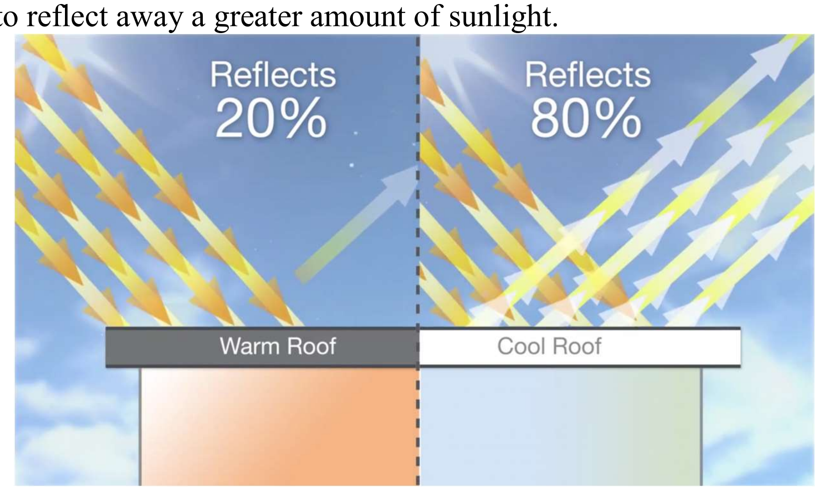

Figure 20: Warm Roofs vs. Cool Roofs. This figure illustrates the difference in solar energy reflected from a standard black roof versus a cool roof.

This reflective property is known as ***albedo***. These cool roofs can reduce air conditioning expenses anywhere from 10% to 30% and help keep the temperature low in buildings during the hot days of summer (de Blasio, 2017). Even though the cool roof plan has been a success in other areas such as New York City, the City of Chelsea should consider the challenges of using this approach. Renters would have to consult their landlords as well as any other tenants in the building in order to carry out this modification, though it would be an easier case to make than requesting a cool roof that requires a full roof replacement. On the other hand, painted cool roof installation on owner-occupied residences carries risks as well. Chelsea residents who are not able to afford the cost of both the paint and installation required for a cool roof may attempt to cut costs by performing the installation themselves or hiring a handyman instead of a professional. The NYC Cool Roofs plan addresses this issue by eliminating the installation cost for affordable/low-income housing (de Blasio, 2017). In addition, however, one of the conditions for the installation is that the roof must be flat, which is not the case for many buildings in Chelsea. Another problem that might arise is the reluctance or even the disapproval of the residents and the owner of the building due to the inconvenience this expense might cause.

We recommend this method mainly for residential buildings since it is low budget and relatively easy to implement in Chelsea. We recommend the city to take further action by:

- Contacting local painting companies and try to come up with an agreement for more affordable service.
- Creating a plan to financially help the low-income population of Chelsea.
- Advertising and promoting cool roofs in order to familiarize the residents of Chelsea with this new idea.

4.4.2 Green Roofs

An alternative method to changing the color or material of a roof is installing a ***green roof***, like a roof garden. Green roofs have additional benefits to cooling, like noise and pollution reduction (Green Building Alliance Staff, n.d.; Sproul, 2014). Green roofs being made of plants are highly recommended, because they absorb carbon dioxide, decreasing the greenhouse gas effect, and helping fight the UHI effect. Though green roofs do reflect more sunlight than black roofs do, white roofs reflect three times more light away from the building than green roofs (Sproul, 2014). Furthermore, white roofs are better economic value because they have lower installation and maintenance costs (Chao, 2015).

Figure 21: Green Roof. This apartment building has turned its roof into a large green space

While we see some types of cool roofs to be viable recommendations for Chelsea, we have reason to believe that green roofs would not suit the city. Green roof installation cost ranges between $10-$25 (EPA, 2017) per square foot, while cool roof installation cost ranges usually between $0.75-$3 (EPA, 2016) per square foot, including the labor cost. Having a green roof also requires a yearly maintenance of approximately $0.75 to $1.50 per square foot (EPA, 2017). With our research showing that a significant portion of Chelsea's population is low-income, we think it would be more suitable for the city to implement a more economically friendly solution, like the painted reflective roofs method. Additionally, installing a green roof is a more complicated process compared to the other ones, as seen in Figure 22 below, which might be discouraging for the renters and the home owners. We believe that the method of green roofs would best be implemented in public or commercial buildings rather than private residences.

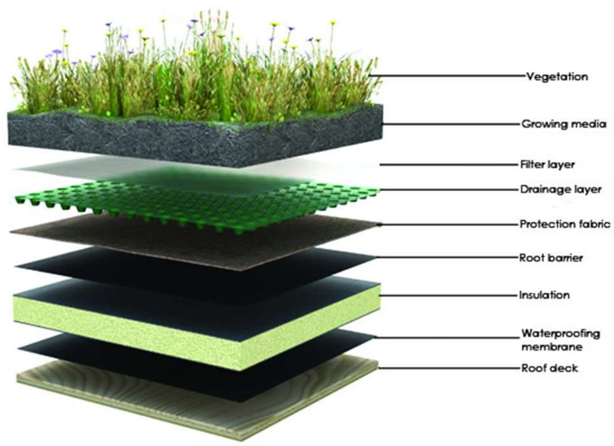

Figure 22: Steps to install a green roof. The steps to install a green roof outnumber the few steps to install a white roof.

Our recommendation for the city concerning the green roofs is to:

- Conduct further research on what type of green roofs are appropriate for Chelsea

The City of Chelsea should conduct further research for both methods as our group is not fully aware of the types of roofs each building has in order to give more specific recommendations concerning the implementation of cool or green roofs.

4.5 Public Risk Education

As the number of extreme heat events in New England increases, so does the number of emergency calls. During extreme heat events in Chelsea, emergency calls increase, since people do not know how to cope (Prado, 2017). These calls are generally about the health of the elderly, people with special needs/disabilities, and those who live on the top floor of a building. Fire calls also occur as a result of misuse of air conditioners, resulting in the destruction of property. Calls like these could be avoided if the public knew what actions to take during an extreme heat event and how to properly use cooling utilities, such as air conditioners.

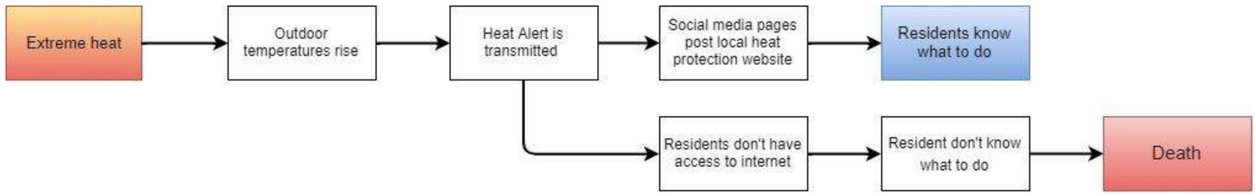

Figure 23: Causal Model of Public Education. This model shows a positive resolution in blue where residents are informed on what to do in extreme heat events. There is also a negative resolution in red that ends in death due to the resident's lack of knowledge.

This chapter will discuss different methods on how to educate the public and how it may work in Chelsea. Many different locations have successfully implemented this method in a variety of formats, such as websites, applications, and seminars. Educational methods can be proactive, reactive, or both depending on the information provided and how it is distributed.

4.5.1 Extreme Heat Information Website

Public risk education in the form of ***websites*** is typically run by local government agencies or organizations and provide information related to extreme heat. This information may include the effects and risks of extreme heat, how to prepare for or react to extreme heat events, and live updates regarding current weather conditions.

The State of Arizona maintains a website by the name of the Arizona Emergency Information Network, otherwise known as AzEIN (AzEIN Staff, 2017). AzEIN has regular updates about the weather and the expected forecast. The website also explains what a heat wave is as well as what the health implications are. The website is translatable into multiple languages, improving its accessibility to Arizona residents. The website has three parts:

- **Be Prepared**: The Be Prepared section speaks to how to get oneself ready for an extreme heat event. This includes instructions on how to build an emergency kit, what to check within the house to make sure it is ready to face a heat event, and advice to keep relatives and neighbors safe.
- **Take Action**: The Take Action section describes what actions should or should not be taken during an extreme heat event. This includes keeping hydrated, staying indoors with cool temperatures, avoiding sudden temperature changes, and where to go for assistance if needed.
- **Be Informed**: Be Informed gives links to information about extreme heat events as well as where to find updates on the current heat event (AzEIN Staff, 2017).

Together, these sections help keep Arizonans safe by providing them with information on how to stay safe both before and during extreme heat events. A website with features similar to AzEIN's could be both beneficial to and feasible in Chelsea.

4.5.2 Application

Another strategy to keep people safe is the use of a smartphone, tablet, or computer ***application***, to make information easily accessible to those who have internet access. One application already in use in the Boston area is the Keep Cool app created by the Metropolitan Area Planning Council (MAPC).

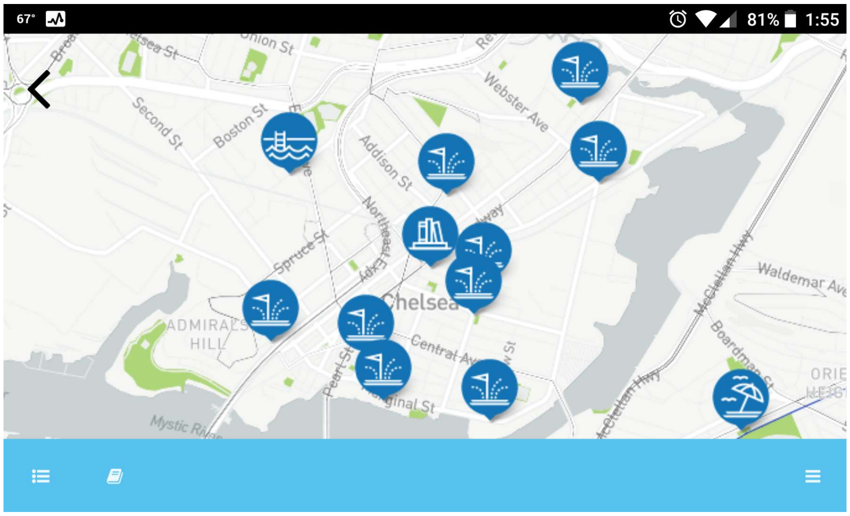

Figure 24: Keep Cool app's map of Chelsea. This app maps out all the parks with water features, libraries, pools, and beaches as places for people to go to cool off (MAPC, 2016).

The app also has links to resources on how to stay safe in the heat, how to keep cool, and the science behind extreme heat. Additionally the app has a feature where once a heat alert is issued it maps out emergency cooling shelters which are otherwise not visible. While it is already available for use in Chelsea, many people are not aware of its existence. The app is also only available in English, making it inaccessible to non-English speakers as well as those who lack internet access.

4.5.3 Public Seminars

One other strategy to focus on is ***public seminars***, which can be implemented in multiple ways. The first of which could be in the form of heat preparation workshops. This would educate people in what extreme heat events are, how to prepare for them, identify the signs of heat-related illnesses and what to do if symptoms occur. In New York City they have started to do something similar. The city has partnered with three major home health aide employers and integrated heat health education as part of the aides' training who will then be able to identify who is vulnerable, how to prevent heat-related illness, and identify what barriers their clients may have from keeping cool (de Blasio, 2017). From this, heat health education can reach those who live alone and have medical conditions, two of the vulnerable populations we have found in Chelsea, and educate them on what to do during an extreme heat event.

To encourage involvement in these types of workshops incentives could be given by employers, particularly those who interact with the general population. They could also be integrated into the employee's training. It would also be more effective if, instead of just English, they were offered in the major languages spoken in Chelsea such as Spanish, French Creole, African, Vietnamese, and Portuguese, making it more accessible to those who want to learn more on their own (Statistical Atlas Staff, 2015).

Another form could be teaching heat safety to young children in schools. Much like they do with recycling or fire safety, there could be a unit about heat safety, what it is, how to take care of yourself, and what to do during an extreme heat event. They could also be taught how to properly use an air conditioner; where it can be plugged into, what type of extension cord can be used with it, where to keep cords, etc. Along with that they could learn about what brownouts are, why they happen, and what to do if a brownout occurs. This would introduce the idea of going to a cooling shelter to an impressionable population who in turn will tell their parents about what they learned. This could be supplemented with a handout for children to bring home for parents to read and in turn learn about heat safety themselves. In order for this to work it would need to go through the superintendent before it can be brought to schools. This in itself is hard to do as many schools have a very tight curriculum and don't have the time or resources to divert from their lesson plan. While something like this would be useful in the long run, it would take some time for it to be fully implemented. It would also only help the population who has small children at home.

4.5.4 Implementing Heat Risk Education in Chelsea

When looking to inform Chelsea residents about extreme heat and its risks, the city should consider these different forms of education **in conjunction with each other** rather than separately. We recommend that the city implement a website as a main source of information that would be promoted together with the Keep Cool app via workshops and social media during extreme heat events. The breakdown of how this website could be implemented in Chelsea is as follows.

Content

A website should provide all information regarding extreme heat to help Chelsea residents stay safe. The content should consist of:

- What an extreme heat event is
- What the effects of extreme heat are
- How to prepare for extreme heat events
- How to react when extreme heat events occur
- Live updates on current weather conditions

This would enable residents to identify when they are experiencing such an event as well as to take actions to keep themselves safe. This would also help address the issue of residents in Chelsea seeking emergency help during extreme heat events by calling 911 or going to the hospital simply because they do not know what else to do. A reduction in these incidences would free up emergency resources. The information on how to act during an extreme heat event should include: where to go (e.g., locations of cooling shelters in the city), how to care for one's health, and what actions to take regarding the safety of others (e.g., checking in on elderly family and neighbors who live alone, tending to one's children, etc.).

Accessibility

In order to maximize the dissemination of information, the city should strive to make the website as accessible as possible. Due to the fact that Chelsea has a significant non-English speaking population, ensuring that the website be available in at least both English and Spanish is necessary. With regard to how to encourage residents to use the website, the city should take advantage of **pre-existing local groups**.

A few residents maintain a **Facebook page** called "**Chelsea, Ma What's Happening**" that has nearly eight thousand members and would be a great asset in promoting the website (Chelsea, Ma What's Happening, n.d.). We encourage the city to reach out to the administrators of this Facebook page to determine whether they would be willing to establish a sort of protocol during extreme heat events. This would entail posting the website on the page and one of the administrators pinning the post so that it would always be at the top of the feed. With this, people who visit the page would see the post immediately, helping them learn about what is going on and what actions they should take to protect themselves. We recommend that when contacting the administrators of the page, the city should consult them on who should be the one to make the post, as it could be posted by the group page itself, one of the administrators, the Chelsea PD Facebook page, or even a designated local resident. The most important aspect is ensuring that the designated poster would be well received by residents.

In the same vein, we recommend that the **Chelsea Police Twitter account** (@CityofChelseaPD) share the website by tweet (Chelsea Police, n.d.). The account is the largest Chelsea government Twitter account with over six thousand followers. Similar to the What's Happening Facebook page, the Twitter account would be able to pin the tweet so that it would be at the top of the page for as long as needed. We believe that the Facebook group would have a wider outreach than the Twitter page because the former is a community hub, while the latter is a government agency page. Nonetheless, we believe that they would both be worthwhile accounts to rely on during extreme heat events, and we encourage the city to look into any other local social media groups that could be of use.

We also recommend that the city seeks to establish a similar relationship with local organizations and agencies that work closely with city residents, particularly those who are vulnerable to extreme heat. A few groups we have identified are the Massachusetts General Hospital (MGH) **Chelsea Healthcare Center** and **Chelsea Collaborative**. The Chelsea Healthcare Center has contact with sick, injured, or otherwise disabled residents, who represent higher sensitivity and lower adaptive capacity to extreme heat. Chelsea Collaborative is a local organization whose mission is "to enhance the social, environmental and economic health of the community and its people," which they strive to achieve by "community education and organization," (Chelsea Collaborative Staff, n.d.). We believe that the city's initiative of spreading heat safety information aligns with Chelsea Collaborative's mission and that they would likely agree to cooperating. A group like Chelsea Collaborative could potentially proactively host workshops as well as reactively assist in coordinating community members during extreme heat events. The city should seek to establish relationships with local groups such as these so that they would educate their clients of proper practices against extreme heat as well as inform them of the website and application for easy reference.

Addressing Technological and Social Challenges of Implementation

We believe certain aspects of the Keep Cool app and the information website provide challenges that the city should keep in mind and address when pursuing these medium as means of education. First and foremost, a device with internet connection is needed to access these, so it may be difficult to ensure that the information reaches certain Chelsea populations such as the elderly, the socially isolated, and those who have neither computers nor smartphones. Additionally, sharing the website via social media would likely reach primarily the younger, technologically literate population of Chelsea. These concerns are thankfully abated by Chelsea's large Hispanic population, as their strong social network facilitates the spread of information that concerns the safety of one's friends and family (Klinenberg, 2002). As such, we recommend that the city places an emphasis on the section of the website that informs one on whom to check up on and how to take care of them during extreme heat events. Furthermore, to help counter the aspect of the website only being accessible via internet, the city should ensure that the information is laid out in a format that is conducive to printing. This would enable people to print it out to either keep somewhere, such as taped on the refrigerator, or to carry with them if they do not have mobile internet access. Additionally, printing the pages out would allow for the city and other groups to distribute the information to passersby and clients.

The city should also take a number of steps that we believe would go a long way in improving the effectiveness of these methods. These are:

- **Memorable URL:** Make sure that the information website's URL is short, easy to remember, and perhaps even catchy. This makes it so that residents may be able to access the website even without needing the link written down or otherwise given to them.
- **Single-source info:** Keep all extreme heat-related information that is intended for residents centralized on the one website because directing people to several different locations would likely make it more difficult for them to keep track of where they found which information.

Aspects such as these are important because the city should attempt to prevent any barriers that would otherwise make it more challenging for the city's inhabitants to utilize these resources. Furthermore, the city should not limit itself to these considerations, as it should strive to ensure that every resource for Chelsea residents is as accessible as possible.

4.6 Community Action Plan

While the previous approaches are important to consider, municipalities should also produce a community action plan to prepare for extreme heat events. A community action plan is a checklist of actions to be taken by stakeholders during an extreme heat event to keep as many people as safe as possible.

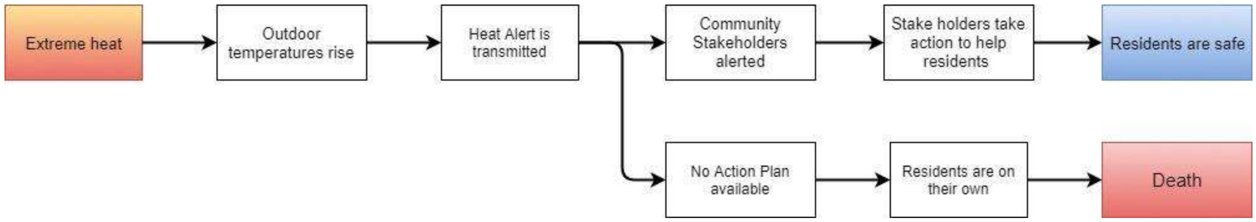

Figure 25: Causal Model of a Community Action Plan. Having a Community Action Plan in place would potentially keep many people safe.

A three-tier system classifies heat conditions into low, medium, and high risk, which then defines the actions stakeholders within the community are expected to take (e.g., during low risk conditions, the health department is expected to issue heat health updates).

One place in particular that has implemented this type of system is Milwaukee. In 2014, they released their Excessive Heat Coordination Plan that defines different levels of heat alerts and what actions stakeholders should take within the community. In Table 6 below is a recreation of Milwaukee's alert system, outlining criteria for each alert to be activated as well as the level of activation for the plan. This system is used in conjunction with NOAA's Heat Vulnerability Index (Figure 3), where HI stands for the Heat Index, which is the effective temperature for a human when comparing current temperature and humidity levels.

Update **Readiness Alert**	**Advisory** **Limited Activation**	**Warning** **Full Activation**
1. HI values are expected to be 95 or higher during the daytime hours in the next 1-7 days	1. A single daytime period in which HI values are expected to be 100 or higher -OR- 2. Daytime HI values are expected to be 95 to 99 for 4 consecutive days or more	1. A period in which daytime HI values are expected to equal or exceed 105 while nighttime HI minimums are 75 or higher, for at least a 48-hour period -OR- 2. Heat Health Advisory criteria of daytime HI values ranging from 100-104 are expected for 4 or more consecutive days

Table 6: Tiered Alerts. This three step, color coordinated system has initiation requirements which can be seen in the boxes.

Milwaukee then identified key stakeholders (i.e., first responders and authority figures) in the community to have key roles under each of the three tiers of the system. Similar stakeholders local to Chelsea, such as the American Red Cross of Massachusetts, Chelsea Health & Human Services, Elder Services, the Chelsea Police and Fire Departments, the Department of Public Works, the Department of Public Safety, local EMS, and Mass General Hospital Chelsea, could fulfill similar roles if such a plan were implemented in Chelsea. These stakeholders would have their contact information in a master list at City Hall, which should be updated at least yearly to ensure the Community Action Plan is continually reliable and successful.

This type of system has already been implemented in places such as Milwaukee, California, and New York and could work in Chelsea as well if the priority is preventative action. A plan such as this would require stakeholders in the community to check on residences and give the residents resources to help themselves and others during an extreme heat event. This, however, would require significant planning and cooperation between multiple stakeholders making it hard to implement in the near future. It would also require the use of other strategies, such as cooling shelters, which would be difficult to effectively utilize if Chelsea does not have an organized strategy in place. As such, we recommend the city look into how to coordinate these actions among multiple stakeholders as well as how to divide up responsibility and locations. Furthermore, the city should determine its own classifications for the different tiers of heat alerts, as Chelsea's climate is likely different from Milwaukee's. We recommend the city look into how Boston classifies tiers of extreme heat, as they are very close in proximity and have similar average temperatures. Boston's breakdown of heat events is as follows:

- **Excessive Heat Warning:** Daytime HI ≥ 105° F for at least 2 hours
- **Heat Advisory:** Daytime HI 95–99° F for at least 2 hours over 2 consecutive days, or 100–104° F for at least 2 hours over 1 day
- **Heat Wave:** Issued for non-criteria warning/advisory heat. A heat wave is defined as 3 or more days of ≥ 90°F temperatures (NWS Boston, n.d.)

Though the effects of urban heat islands may vary between Boston and Chelsea, we believe that Boston's criteria for heat events serve as an appropriate starting point for the City of Chelsea.

4.7 Prioritization of Recommendations

Several approaches to mitigating extreme heat should be prioritized based on if they are proactive or reactive. The causal model below (Figure 26) illustrates a high level overview of how heat vulnerability propagates in Chelsea, showing negative outcomes in red and positive outcomes from proper heat countermeasures in blue.

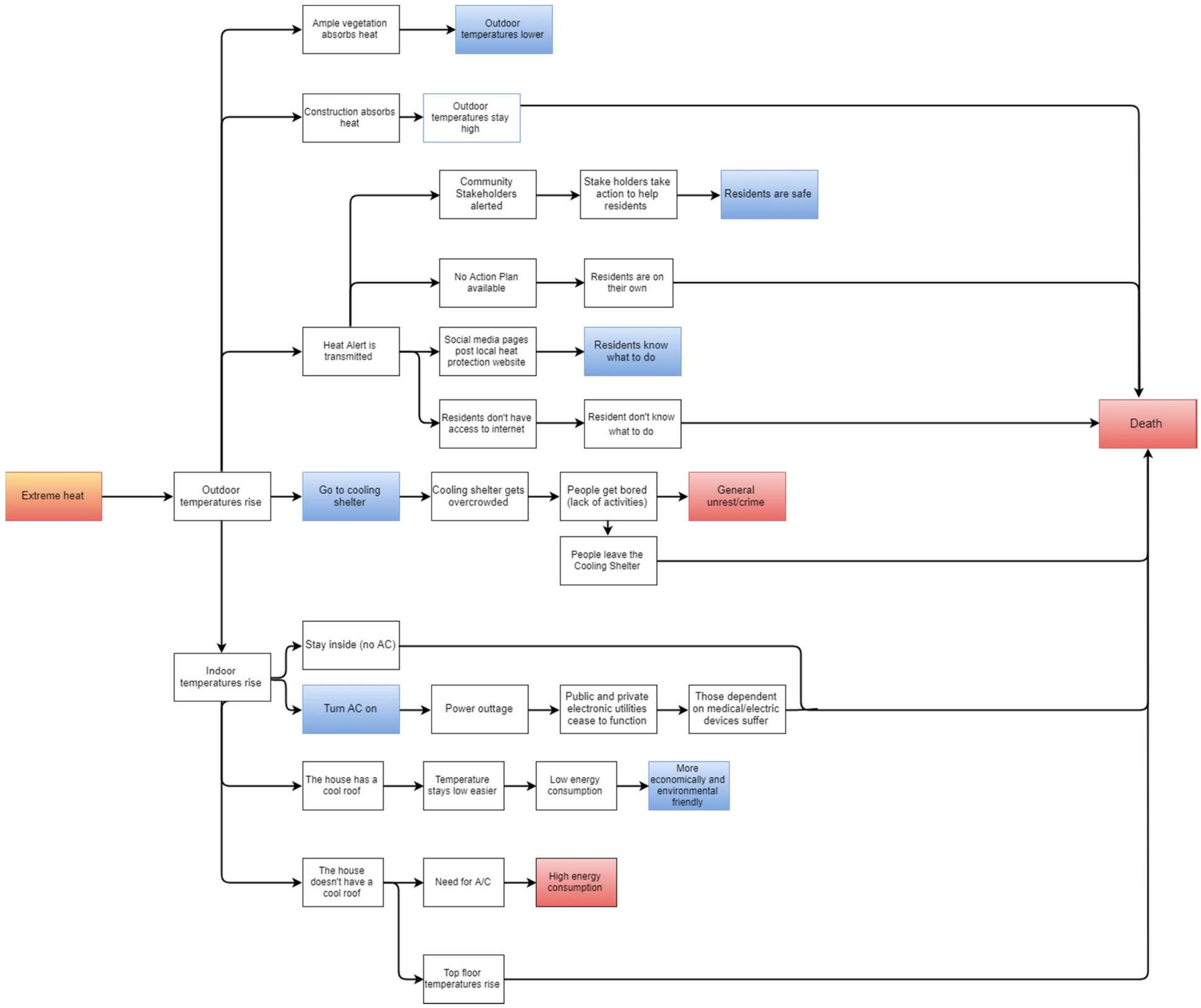

Figure 26: Full Heat Vulnerability Causal Model. This model is a culmination of all previous models, showing how if no steps are taken will lead to one end, death.

This diagram is a useful tool for visualizing how our recommendations fit into the system of vulnerability, which may assist the city in comparing and organizing the different strategies. Creating and establishing a cooling center takes a lot of time and work, which means that the City of Chelsea should consider implementing them in advance, before summer, so its residents can have a "shelter" during the hot period of summer. Likewise, to set up and implement cool roofs proactively informing the residents of the city and creating a plan in order to make sure they are up to code, is necessary. The city should also take action into making Chelsea more sustainable. The "Plan and Plant" method requires extensive research and planning, which makes it a project of priority. Similarly, organizing a plan like New York's HEAP requires time to advocate to the state to include cooling into the program.

Other methods like the different education methods and the community action plan can be developed throughout the year and enhanced with new information even during summer. Table 7 below labels our recommended strategies as being proactive, reactive, or both, which may assist the city in maintaining a balance of which types of methods they would like to implement.

Strategy Type	Strategy	Proactive	Reactive
Cooling centers	Cooling Shelters	x	x
	Parks	x	x
	Impromptu cooling shelters	x	x
"Plan and Plant" methodology	Considerations and guidelines for future efforts	x	
Air conditioning			x
Cool roofs		x	
Information systems	Website		x
	App		x
	Public seminars	x	
	Education plan	x	
Community action plan			x

Table 7: List of Heat Mitigation Strategies. This table organizes strategy types by whether they are proactive, reactive, or both.

Educating the general population will take some time, but should be a priority as they will be more prepared for extreme heat events. Likewise a community action plan will take time to fully form, but having a step by step instruction sheet on who needs to a task during an extreme heat event will make preparations for these events much easier.

5.0 Conclusions and Challenges

The main objectives of our project were to define heat vulnerability, to identify the demographics in Chelsea who are vulnerable to extreme heat and their geographic distributions, to analyze strategies implemented in other locations, and to identify the best management practices for Chelsea, MA to further consider. In order to achieve these, we researched vulnerability factors and listed them in matrices, collected data from GIS systems, analyzed mitigation strategies that have been successfully applied to other places, and conducted several interviews with local officials to familiarize ourselves with the vulnerability of the city.

Chelsea will have to confront multiple challenges in order to create a solid mitigation plan. A major issue we have observed is the lack of green space. However, due to the density of the city, expanding green space is a very challenging process that requires careful planning. Additionally, we are aware that there are a lot of people in Chelsea living in overcrowded apartments that surpass the officially recorded number of residents. We believe that the city might face difficulties encouraging those people to seek help in case of a heat-related emergency in the fear of repercussion.

Chelsea needs a plan for how to overcome these challenges. We suggest that the DPD look into each of these recommendations carefully and consider conducting further research to evaluate whether they are appropriate solutions for Chelsea. This is because our project was always intended to be the first steps into providing the city a sense of direction on how it may go about planning for increasing temperatures rather than performing a comprehensive, professional-level climate resilience plan. We concede that our efforts to gain more insight into Chelsea itself from local stakeholders fell short. It is for this reason that we suggest the city next look further into the feasibility and suitability of our recommendations by taking actions such as finding what would be required to make certain policy changes and consulting the groups we recommended to get their feedback. If the city wishes to pursue strategies that involve resident expenses, such as implementing cool roofs or promoting air conditioning units, the city should perform analysis of any and all methods to make these utilities as accessible and inexpensive for residents as possible.

Chelsea has the opportunity to become a leader in heat vulnerability strategies and dense urban planning for other cities. As urbanization continues to cause increasing density in cities around the country, plans such as Chelsea's will be key in providing a reference guide for how these cities may mitigate heat vulnerability and ensure the safety of their residents while working with such conditions.

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Appendices

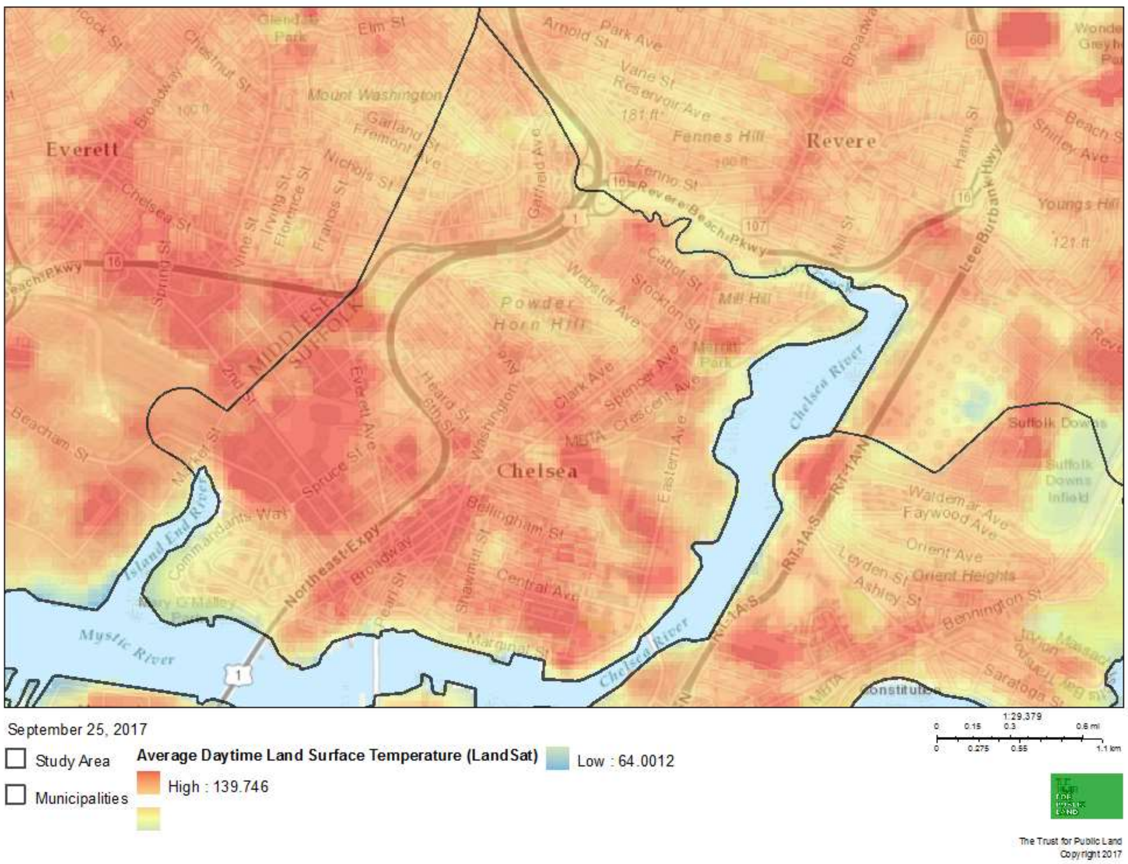
APPENDIX A: Milwaukee's Cooling Shelter Checklist (MMAHTF, 2014).

Essential Recommendations			Additional Recommendations
	Air conditioned		Communication services (internet, translators, etc)
	Publicly Advertised		Transportation services, including wheelchair access
	Accessible to people with disabilities		Adult and Child activities
	Access to potable water		Expanded hours of operation
	Public Restrooms		Back- up generators
	Access to 911 services		Area for Pets
	Parking Access		Facility Security
	Proximity to Public Transit		Medical Staff

This checklist from Milwaukee's Community Action Plan was used as a benchmark for a checklist that was produced for Chelsea, MA.

APPENDIX B: Land Surface Temperatures in Chelsea, Massachusetts (The Trust for Public Land, 2017).

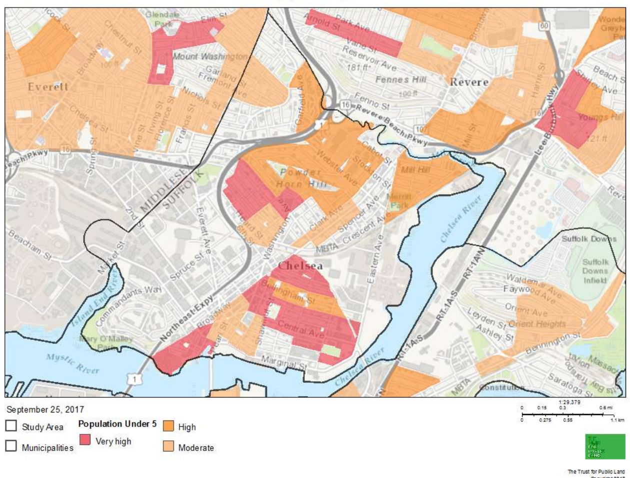
Chelsea, MA Map of Average Daytime Land Surface Temperature (LandSat)



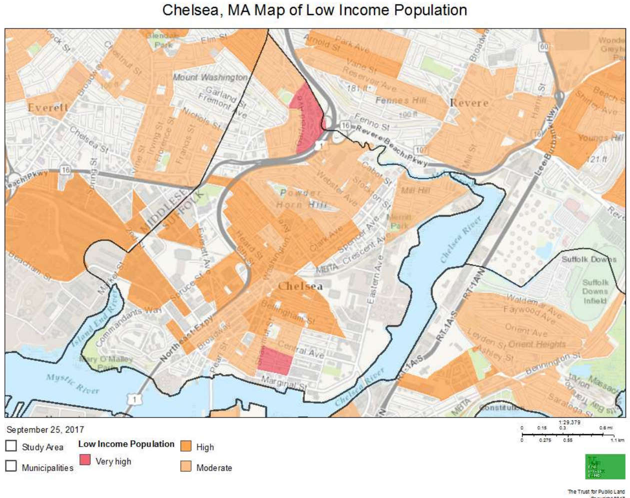
This map, from the Trust for Public Land shows the Average Daytime Land Surface Temperature in Chelsea, MA. We used this to identify the hottest, heat islands, within the city.

APPENDIX C: Vulnerability Maps of Chelsea, Massachusetts (The Trust for Public Land, 2017).

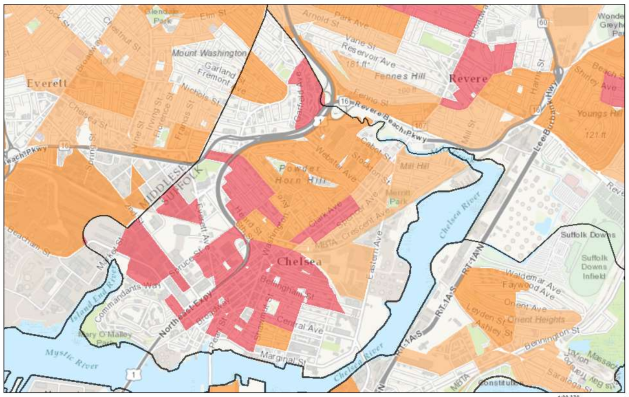
Chelsea, MA Map of Population Under 5



Chelsea, MA Map of Low Income Population



Chelsea, MA Map of Less Than High School Degree



September 25, 2017

Study Area

Municipalities

Less Than High School Degree

Very high

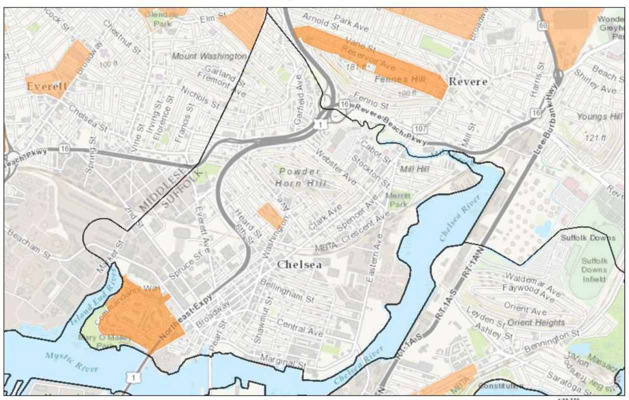
High

Moderate

1:29,379

The Trust for Public Land
Copyright 2017

Chelsea, MA Map of Population Over 64



September 25, 2017

Study Area

Municipalities

Population Over 64

Very high

High

Moderate

1:29,379

The Trust for Public Land
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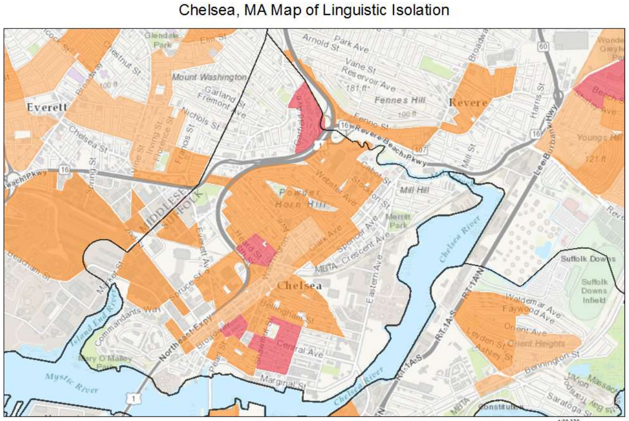
Chelsea, MA Map of Linguistic Isolation



September 25, 2017

Study Area

Municipalities

Linguistic Isolation

Very high

High

Moderate

1:29,379

The Trust for Public Land
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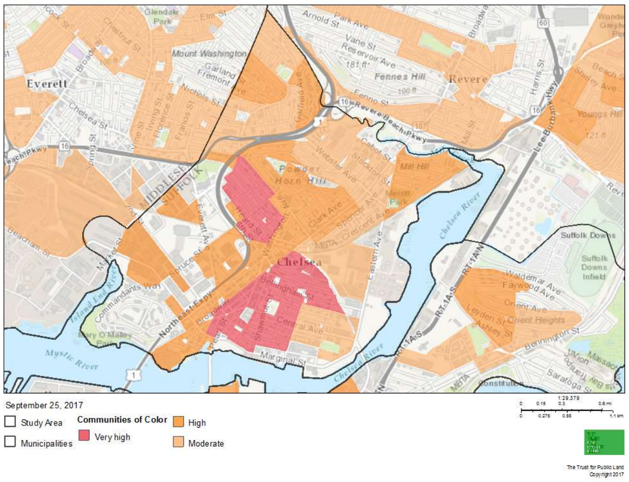
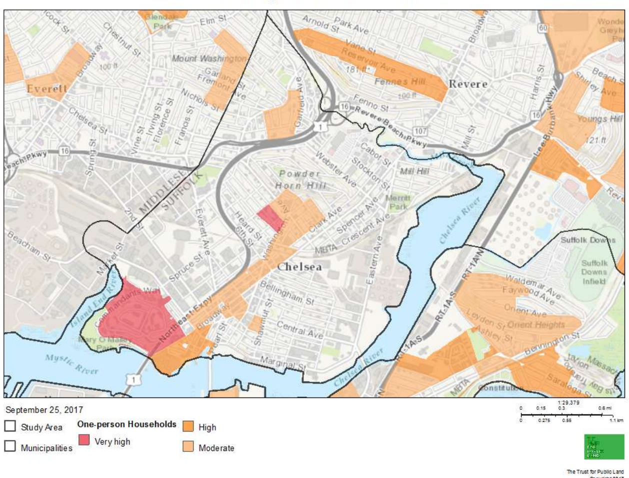
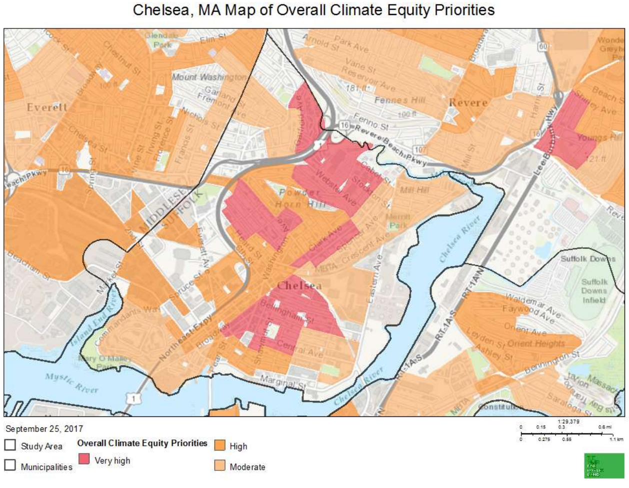
Chelsea, MA Map of Communities of Color



Chelsea, MA Map of One-Person Households



Chelsea, MA Map of Overall Climate Equity Priorities



The maps above, show the geographic layout, in Chelsea, of different vulnerable populations, and how they overlap to form the most vulnerable neighborhoods.

APPENDIX D: Authorship

Abstract- Conrad and Ermina

Executive Summary- Michael and Elizabeth

Acknowledgements- All

1.0 Introduction- All

2.0 An Analysis of Rising Temperatures and the Vulnerabilities of Extreme Heat- All

- 2.1 Rising Temperatures in the World Reflect in the Northeast- Michael
  - 2.1.1 Rising Temperatures in Cities- Elizabeth
- 2.2 The Health, Social, and Economic Impacts of Heat- Ermina
- 2.3 Heat Vulnerability- Conrad
- 2.4 Circumstances in Chelsea Affecting Vulnerability - Conrad
- 2.5 Summary- All

3.0 Methodology- All

- 3.1 Qualitatively Define Heat Vulnerability- Conrad
- 3.2 Identify the geographic distribution of extreme heat vulnerability in Chelsea- Conrad
- 3.3 Analyze strategies implemented in the US to lessen people's risks of and vulnerability to extreme heat- Conrad
- 3.4 Identify the best management practices for Chelsea, MA to further pursue- Conrad

4.0 Recommendations to Chelsea for Mitigating Extreme Heat Vulnerability- Michael

- 4.1 Utilizing Cool Locations- Michael
  - 4.1.1 Cooling Shelters- Michael
  - 4.1.2 Using Parks as a Cool Location- Michael
  - 4.1.3 Providing Relief at Outdoor Events- Michael
- 4.2 Plan and Plant Methodology- Michael
- 4.3 Air Conditioning- Michael
- 4.4 How to Reduce Heat on Higher Levels of Buildings- Ermina
  - 4.4.1 Reflective Roofs (Painted)- Ermina
  - 4.4.2 Green Roofs- Ermina
- 4.5 Public Risk Education- Elizabeth
  - 4.5.1 Extreme Heat Information Website- Elizabeth and Conrad
  - 4.5.2 Application- Elizabeth and Conrad
  - 4.5.3 Public Seminars- Elizabeth and Conrad
  - 4.5.4 Implementing Heat Risk Education in Chelsea- Elizabeth and Conrad
- 4.6 Community Action Plan- Michael
- 4.7 Prioritization of Recommendations- Ermina

5.0 Conclusions and Challenges- Ermina

Appendix A: Milwaukee's Cooling Shelter Checklist- Michael

Appendix B: Land Surface Temperatures in Chelsea, Massachusetts- Michael

Appendix C: Vulnerability Maps of Chelsea, Massachusetts- Michael