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

An Interactive Qualifying Project Proposal
Submitted to

The Faculty of the
WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

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Abstract

Chelsea, Massachusetts is facing problems from extreme heat. If our research on vulnerable populations during extreme heat is correct, then it leads us to believe that Chelsea's residents may also be vulnerable to extreme heat. The goal of this project is to assess the effects of excess heat in Chelsea, identify the populations and geographic areas that would be particularly impacted, and develop an inventory of best practices applicable to Chelsea to help the City mitigate the impacts on the vulnerable populations. We are going to accomplish this goal by researching what other communities have already done to protect their vulnerable populations from extreme heat. We are also going to interview residents to find out what factors affect their vulnerability to heat and how they can be helped. We will produce a report with the best management practices to be implemented in Chelsea, which will be delivered to our sponsor, John DePriest, of the Department of Planning and Development.

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Introduction

At one point, climate change used to be a fear that scientists viewed would affect the future, but it has now become a reality that affects us today. Average temperatures have risen by almost 2 degrees Fahrenheit since 1895 in most parts of the United States. Temperatures are continuing to rise at such a rate that by the middle of the 21st century parts of the Northeast are expected to see temperatures above 90 °F for two additional months each year (Melillo, et al., 2014). A contributor to nearly half of this rise in temperature is the greenhouse gas effect (Melillo, et al., 2014). These additional hot days are classified as extreme heat, which is when the temperature of an area rises above the average for that specific place for an extended period of time. Some of the risks extreme heat poses to people are: cardiovascular problems, heat stroke, respiratory problems, and many other health issues (Melillo, et al., 2014). As a result, extreme heat is one of the leading weather-related causes of death in the U.S. despite being preventable (City of Cambridge, 2015). Furthermore, though extreme heat poses risks to the entire population of affected areas, there exist groups of people who are more susceptible to these dangers 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.

As temperatures rise, so do the risks that are imposed on vulnerable populations, which are even more severe for people in urban areas (Melillo, et al., 2014). Across the Mystic River from Boston lies Chelsea, a small city facing the dangers of increasing heat. Within its 2.2 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 municipality 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 interest to take measures to ensure their safety.

While everyone is susceptible to the 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 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). To mitigate these problems, many organizations, 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; Wisconsin, 2016; Kansas, 2014). This advice is fairly universal, repeating the same few pieces of advice across multiple organizations, making it fairly accessible, and is mostly focused towards vulnerable populations,

such as the elderly and infants. Cities must then take the universal knowledge and tailor it to their own city's 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., 2009). This speaks to how adaptation methods such as these could be of interest to Chelsea.

Though 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, there has yet to be any preparation specifically regarding the risks from rising temperatures. 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 people from heat. With temperatures increasing and its citizens potentially being at risk, the City is in need of plan to keep them safe.

The goal of this project is to help Chelsea better prepare for the risks of rising temperatures on its residents. To do this, we will work with the DPD to identify the demographics of Chelsea that are vulnerable to extreme heat. We will analyze the strategies that other places have used to lessen the risks and vulnerabilities imposed on their citizens by extreme heat. Lastly, our project team will synthesize all information that is gathered to identify the best management practices applicable to Chelsea, MA. Through this project, the City of Chelsea will become better prepared and more knowledgeable about the effects of rising heat.

2.0 Background

In this chapter we start by discuss the main issue, rising temperatures. We then analyze what extreme temperatures are, as well as the predictions for the Northeast region of the United States. We also focus on cities and how the urban heat island effect increases the risk of extreme heat in urban areas. We then discuss what populations in United States' cities have been found to be vulnerable to extreme heat under three categories of vulnerability: exposure, sensitivity, and capacity to cope. This chapter also discusses methods that other cities in the United States have taken to adjust to extreme heat events.

2.1 Rising Temperatures in the Northeast

Temperatures are rising in the world, which poses a threat to the Northeast. Greenhouse gas (GHG) emissions from industry and transportation trap heat in our atmosphere, which is causing a trend of increasing global temperatures (Environmental Protection Agency, 2014). One of the effects rising temperatures will have on the Northeast is an increase in the number of extreme heat days (Melillo et al., 2014). An extreme heat event is defined as when the temperature of an area stays above the average for a specific place for a few weeks. For reference, figure 1 depicts the projected increase in number of days per year with temperatures above 90 °F in the Northeast (Melillo et al., 2014). These are averaged projections for years 2041-2070. The portion of the figure labeled "Historical Climate" depicts the average number of above 90 °F days per year from 1971-2000. The bottom-left portion of the image (scenario B1) predicts that even if there is substantial lowering of global emissions, parts of the Northeast will experience nearly 30 days per year with temperatures exceeding 90 °F. The bottom-right part of the image (scenario A2) shows that if global emission trends remain high, parts of the Northeast will experience above 90 °F temperatures for nearly two months per year (Melillo et al., 2014).

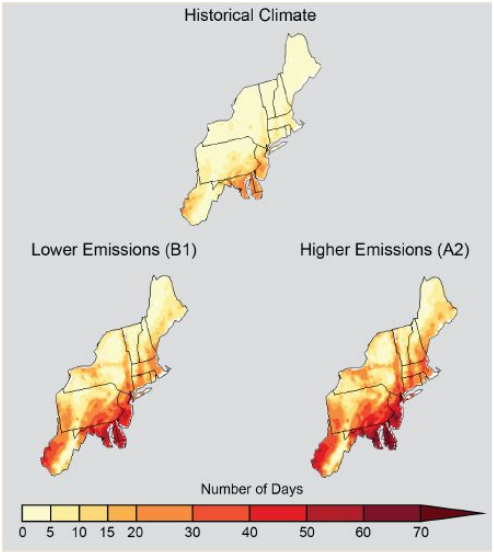

Figure 1: Northeast Heat Predictions. A prediction of the trajectory of extreme heat days in the Northeast over the next sixty years. Preventing this trajectory can be found in section 2.2.3.

These projected increases in frequency and severity of extreme heat pose 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

During heat waves, there are several forces at play that cause cities to be even hotter than their non-urban surroundings, increasing the risks to its populace. This phenomenon is known as the urban heat island effect (UHI). According to Michael Alder 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). Lack of vegetation refers to a common lack of shade-providing trees in cities. Dark colored infrastructure is common in urban areas in the form of asphalt and roofs, which trap heat due to two factors: solar reflectance and heat emittance. Solar reflectance (albedo) and heat emittance are measures of how much of the sun's energy a surface absorbs and how quickly a surface releases heat. Surfaces with low albedo and heat-emittance levels (e.g., dark roofs) are undesirable because they absorb a lot of energy from the sun and slowly release that energy at night as heat into the atmosphere and the buildings below (Environmental Protection Agency, 2017). In addition to these effects, heat adaptation methods that use energy actually increase total atmospheric temperature. For example, though an air conditioning unit helps cool down the inside of a building, it releases hot air outside, contributing to increased heat within the surrounding city (Alder et al., 2010). 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 buildings 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 (Alder, et al., 2010). The dangers of increasing temperatures in cities are evident and pose serious risks to vulnerable populations.

2.2 Effects of Heat

Extreme heat can cause health, social, and economic impacts on everyone in a city. The health risks of exposure to summer heat waves are a significant problem in many areas of the world, including the Northeast. Heat waves affect the lives of thousands of people annually, primarily those who are more vulnerable to the risks that come with it. Figure 3 below, shows that for every million people, in the United States, approximately three people die annually from heat related incidents (Environmental Protection Agency, 2016). That translates to around a thousand deaths per year.

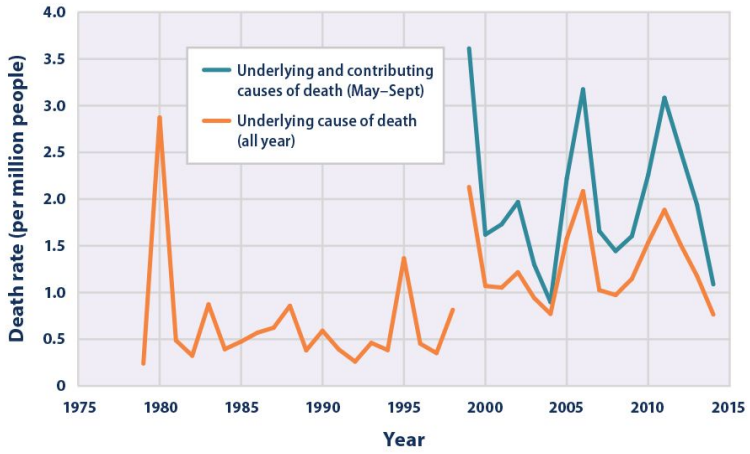

Figure 2: Heat Related Deaths in the United States. The Environmental Protection Agency's graph representing the number of deaths per million in the United States since the 1970s.

There is only so much the human body can do to adapt to high temperatures. The human body's natural cooling mechanism is to release sweat from the skin. When sweat evaporates, it cools the body, preventing its internal temperature from rising (Biology, Adamantiadou, et al., 2010). 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. Furthermore, the act of sweating is only effective in cooling the body to a certain extent, meaning that it cannot prevent some of the negative effects of high temperatures, especially in extreme heat (Kahn, 2016). This can cause people to suffer from several health risks.

Heatstroke is one of the most severe threats excess heat poses to heat-vulnerable populations (Mayo Clinic Staff, 2014). A heatstroke is the overheating of the body, resulting in the rise of its temperature to a high and dangerous level (usually above 104 degrees F or 40 degrees C). Heatstroke is a serious condition which requires emergency treatment and usually appears during heat waves. If not treated properly, there is an increased chance of death. The symptoms of a heat stroke are similar to the ones of a heart attack or a stroke and include intense headaches, difficulty in breathing, altered behavior, even nausea and vomiting (Mayo Clinic Staff, 2014). If the patient does not get treated on time, it can result in complications like a heart attack, kidney or breathing failure, convulsion, vital organ damage due to dehydration, even death.

Heat exhaustion is another health impact the exposure to extreme heat can have on the human body (Mayo Clinic Staff, 2014). Intense heat and exercising in a hot and humid environment can cause heavy sweating and a rapid pulse, which means the body is overheating. Symptoms of heat exhaustion may include dizziness, faintness, low blood pressure, nausea and headache.

Heat cramps are defined as muscle spasms, usually expressed as intense muscle pain caused by heavy exercise in hot environments. Specialists believe that their main cause is the dehydration coming from excess sweating. Heat cramps occur mostly on legs, arms and

abdominal muscles, although they may include any muscle group involved in exercise (Mayo Clinic Staff, 2015). Other risks may include heat rash, heat edema and sun burns.

2.2.1 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 varies greatly. 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 level of exposure, sensitivity, and capacity to cope to extreme heat (Manangan et al., 2014). High exposure, high sensitivity, and low adaptive capacity are undesirable traits because people with these characteristics are more likely and more strongly impacted by the effects of extreme heat while having less ability to help themselves (City of Cambridge, 2015). Groups of people characterized by certain traits share similar degrees and manners of vulnerability.

First, renters and low-income residents represent vulnerable populations with high exposure and low adaptive capacities. The relationship between renter and landlord directly affects the vulnerability of a renter because the lease to a rental agreement determines whether or not a tenant may make major alterations to the premises (Lynn, 2016). Furthermore, lower income neighborhoods tend to be warmer than middle or upper-class areas because poorer neighborhoods often have characteristics (e.g., infrastructure materials having low albedo levels and high heat retention) that facilitate the UHI effect (Worland, 2014; Alder, 2011). As such, a tenant whose apartment lacks air conditioning in a low-income neighborhood, may be left to the mercy of a heat wave without the legal means to cool their apartment down (Lynn, 2016). Furthermore, absentee landlords are less likely to provide adequate updates to their rental properties if the issues at the location do not directly affect their lives, which speaks to the difficulties of a tenant in a low-income neighborhood (Rephann, 2009). Even in the event that a tenant can come to an agreement with their landlord regarding installations, they may not be able to afford the alterations (Schweitzer, 2016).

Second, the elderly are vulnerable. People of older ages are generally more susceptible to heat-related illnesses than the younger portion of the population because of "dysfunctional thermoregulatory mechanisms, chronic dehydration, medications, and diseases involving the systems that regulate body temperature" (Worfolk, 2000). They are also more sensitive to the sudden changes of the climate due to "impairment of temperature control mechanisms" (Worfolk, 2000). Their sweat system can be impaired because of low fluid intake, due to a reduced sense of thirst. To prevent this, older people should be watched during heat waves, remain in a cool environment and increase their fluid intake. The risks do not begin at the end of life—in fact, they are also very prominent in the early stages.

Third, infants and young children are also a portion of the population that is vulnerable to the effects that extreme heat has on the human body. They produce more heat energy but do not sweat enough in order to keep their body temperature steady, which can have a negative effect on them ("Young children and babies", 2014). Babies are also not able to communicate that they are thirsty. Therefore, it is easy for them to become dehydrated in hot weather if not monitored closely by an adult ("Babies in Hot Weather", 2017). Another thing that makes babies vulnerable is their inability to get themselves to a cooler place when they become hot. The largest issues for babies during extreme heat is having to rely on others to keep them safe.

2.3 What Others Have Done to Combat Extreme Heat

While the focus of our project is in Chelsea, populations in many cities across the United States are vulnerable to the effects of the 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, as seen in figure 3, and to what extent they benefit different vulnerable populations is necessary to assess what would be possible to implement in Chelsea.

Method	Locations Applied	Type
Cooling Shelter	Boston Chicago Arizona	Construction Cooling
Rain Barrels	Chicago	Utility Water conservation
Shade Trees	Chicago	Construction Cooling
Website	Arizona	Electronic Informational

Figure 3: What Others Have Done. Table of strategies employed by other locations

2.3.1 Public Cooling Strategies

Some places have found that the use of public cooling areas lessens the impacts of extreme heat on the entire community. A cooling center is, by definition, “An air-conditioned public facility where people may go for relief during periods of extreme heat” (Oxford Dictionaries). Many municipalities across the United States have utilized these in an attempt to mitigate the effects of extreme heat days. These centers can be public buildings such as libraries or schools that are air conditioned, pools associated with an air conditioned building, or a combination of the two.

The City of Boston created a detailed and thought out heat protection plan. Its main focus during extreme heat days is to identify who is vulnerable, alert them as quickly as possible, and intervene if needed. Boston implements this through the “Heat Wave Annex” and “Heat Alert Plans” which allow the city to make announcements via phone call to warn the residents how severe the temperatures are and what they should do to keep themselves safe (Alder, et al., 2010). To physically help those in need, Boston has established multiple cooling centers, which

are public buildings that are either air conditioned or have swimming pools, around the city (Alder, et al. 2010). However, Boston's plan has some criticisms. When the Heat Alert goes out to the city, they only do so on the third day of extreme heat, which could be deadly to more vulnerable portions of the population as most heat related deaths occur within the first two days ("Heat Wave Plan for England: Protecting Health and Reducing Harm from Extreme Heat and Heat waves", 2011). There have also been several criticisms on how Boston alerts its' citizens. EPA regulations state that information should be readily available to all citizens, but the Heat Alert reaches people via phone call and only in English, rendering it useless to all non-English speakers (Alder et. al, 2010). This lack of communication doesn't allow for the citizens to easily locate the cooling centers, rendering them useless to them.

In Arizona, the Maricopa County Department of Public Health evaluated the effectiveness of their cooling centers "based on the services provided, daily operations, demographics of visitors, and potential for expansion" (Maricopa Department of Public Health, 2015). From this evaluation, they found that while 90 percent of the cooling centers were easily accessible, only 33 percent had visible signs stating that they were cooling centers, and of those signs only 41 percent had it in both English and Spanish (Maricopa Department of Public Health, 2015). While the centers are physically accessible to the public, if there is nothing stating that it is a cooling center or not having it in the major languages of the area, then a portion of the population will not know about them and are rendered vulnerable.

2.3.2 Water Conservation Strategies

Another strategy to adapt to extreme heat that has been implemented in other areas are rain barrels, which collect water year round and can then be used to keep people safe during extreme heat events. Rain barrels are a means of taking a renewable and environmentally friendly approach to adapting to excess heat. By placing barrels around the city, in both public and private settings, rain can be collected year round for a number of uses. Some applications of the rain water may require sanitation methods, like use in public swimming pools, so that people can cool off, lowering their body temperature. Meanwhile, others may not, like when used to water public parks and plants, during extremely warm days. The barrels also serve the dual purpose of keeping rainwater from overflowing the sewers, helping to decrease flood potentials (Metropolitan Water Reclamation, n.d., "Rain Barrels,"). The water can also be used to cool the body. Cold water is the leading cure to heat stroke. (Casa, et al., 2007). Therefore, water captured in rain barrels can serve multiple purposes, but most importantly it will keep people safe from extreme health risks and relieve the rest of the population from the heat.

2.3.3 Vegetative Cover Strategies

Another natural adaptation that we would like to highlight is the use of shade trees to cool infrastructure. Shade trees are an increased vegetation plan throughout a city in order to reduce the urban heat island effect and the greenhouse gasses emissions (City of Chicago, 2009). 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.

Currently Chicago has identified areas within the city that are susceptible to extreme heat, and in response they have planted over 500,000 trees along with mandating that all new private buildings to meet the city's reflective roof standard. The standard keeps houses cooler since they are not absorbing as much direct heat from the sun (Chicago Climate Action, 2009).

New York has created an extensive climate change action plan in response to hurricane Sandy. While their plan focuses mainly on ways to mitigate the effects of flooding events, they have dedicated a section on the rising temperatures within the city and how they plan to combat it. Their main action plan is to expand and increase the number of Greenstreets, which is a storm water management system using vegetation to slow, filter and clean storm water (USEPA). They believe it will solve multiple problems at once, such as reducing carbon dioxide levels, mitigate flooding, and absorb storm water, while keeping the temperature at a lower level during summer (PLANYC).

2.3.4 Public Information System in Case of Emergency

A final adaptation strategy used to keep people safe during extreme heat is public information systems. Many people use this systems and they come in many forms. Arizona, for example, has produced a website, the Arizona Emergency Information Network, detailing what the public can do in the event of a heat wave. The website is available in multiple languages to make sure the information is available to a wider population. On the website it emphasizes three main points: Be Prepared, Take Action and Be Informed (az.gov, 2017). The first point details what a person needs to know or do to be ready for days with extreme heat, such as having an emergency kit, have air conditioners ready, stay indoors during the day, among other pieces of advice. The second point explains what a person should or should not do during days of extreme heat. This advice includes: drinking water through the day even if [they] are not thirsty, staying inside at the lowest level possible, wear light, loose fitting clothing, and avoiding anything that could dehydrate you, such as alcohol, salt, and exercise. The last point gives links to resources to help better inform the reader. This section points out that a person should be aware of what the forecast is going to be through the week and understand what extreme heat is by linking websites such as the Center for Disease Control and Prevention. This page is also accessible to many people through the use of Google Translate™. At the top of the page there is an option to translate the page to French, German, Italian, Portuguese, and Spanish. While the translations may not be completely accurate, it will give the non-English speaking residents the general gist of what they need to know.

2.4 Summary

Many populations in Chelsea fit the vulnerability profile, see Appendix A. 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 percent 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, we will later see if these populations in Chelsea fit the trends highlighted in other cities.

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 Phoenix, Arizona and Chicago, Illinois have taken steps to institute protective measures in their regions of the United States. Closer cities like Boston, Massachusetts, have also taken their steps right here in the Northeast which will provide the best mirror to the effects that these high temperature days are having right here 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.

3.0 Methodology

The goal of this project is to help Chelsea better prepare for the risks of rising temperatures on its residents. In order to achieve this goal, we will complete the following objectives:

1. Identify the different demographics of Chelsea that are vulnerable to extreme heat.
2. Analyze strategies used by other places to lessen the risks and vulnerability of extreme heat, among the residents.
3. Identify the best management practices applicable to Chelsea, MA.

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

3.1 Identify the different demographics of Chelsea that are vulnerable to extreme heat

In order to understand how we can help prepare Chelsea for increasing temperatures, we should research who comprises Chelsea's vulnerable populations. This requires us to interview different people who may be affected by extreme heat in specific ways. The desired product of the interviews is information of how extreme heat affects certain people as well as finding out how they feel about the prospect of increasing temperatures, what preparations they would like to see being taken prior to the temperature increasing, and what risks that they feel these high temperatures impose on them. One way to achieve these answers is by asking them about prior experiences, what they did, and why it was helpful to them. The people whose vulnerabilities and preferences we would like to assess include: lower income households, non-English speakers, young children, elderly, workers (specifically outdoors), management, homeowners, renters, and landlords. These are all groups that we have identified to be vulnerable in Appendix A. We then plan on using softwares, like Geographic Information Systems (GIS) and other charting techniques to map out the most vulnerable demographics, thus identifying the geographic distribution of the vulnerable populations. We will also be able to make visual connections around the city of who is identified as being at risk and in what places likely adaptation methods can be implemented, so that the entire city can benefit from their presence.

3.1.1 Interview selection

In order to be efficient with our interviews, and receive the most accurate results possible, we must identify profiles of people who may give us insight into the concerns of multiple demographics. One case would be to interview parents in order to obtain information on how extreme heat affects the younger population of the city and potentially also acquire information about the effects of extreme heat on the elderly. Additionally, we would like to be able to assess their vulnerability to increasing temperatures with regard to any other criteria they may meet, such as their occupations, having a low-income, being a non-English speaker, etc. We will also consult with members of the DPD and possibly other personnel familiar with the situation in

Chelsea regarding the assessment of which populations in Chelsea satisfy/meet several criteria. Only after identifying these information-rich profiles would we be able to begin our interviews.

3.1.2 Interview Procedure and Data Collection Methodology

Before making direct contact with those that we plan to interview, we will prepare questions aimed towards obtaining information specific to certain facets of a person's life. We will tailor our initial contact method depending on the type of person and their availability, such as emailing a teacher or personally reaching out to parents. The roles we intend to maintain consist of an interviewer, a secretary, and, whenever possible, a person recording with a voice recorder. Furthermore, all interviews will be similar in having us introduce ourselves, explain the purpose of the interview, and obtain informed consent. How the interviews will differ from one another will depend on the traits of the person being interviewed that distinguish them in the context of heat vulnerability. We will inquire about subjects' current conditions of housing, employment status, issues they face during the summer, and how they try to stay cool. During the interview, the secretary will take note of all the relevant experiences, opinions, and preferences that are shared by the subject. After each interview, we will debrief amongst ourselves and review notes, media, and observations. During this phase, we will record the subject's responses into the table as seen in Appendix B. Appendix B is a table that shows the types of information we are interested in (i.e., the "Topic" column), some example questions for the purpose of obtaining that information, how we'll record their responses, and the type of vulnerability that corresponds with each type of information. By organizing the responses this way, we will be able to evaluate how the subjects' responses reflect their degrees of vulnerability with respect to exposure, sensitivity, and adaptive capacity.

3.1.3 Quantifying Vulnerability and Measuring Risk

After recording the information gathered from the interviews, we must evaluate the degrees to which each demographic population is vulnerable and the degree of their risk. For this purpose, we will develop a method of quantifying single values to represent the exposure, sensitivity, and adaptive capacity of each group of people. By comparing the values of sensitivity and capacity to cope, we will create a table to assess the consequence of a group of people. Consequence in this context is defined as the severity of harm that one would experience when exposed to extreme heat, and an example of a comparison table is shown in Figure 4(a). By establishing a method of evaluating a group's consequence, we will be able to compare this with the probability of that group being exposed to extreme heat in order to determine the overall risk for those people. Risk in this context is a function of a demographics' exposure to extreme heat and the consequence of them being exposed to that heat, with high exposure and high consequence indicating high risk for a population. An example of a comparison table is shown in Figure 4(b). We do not currently know how to calculate the values for the vulnerability criteria nor do we know how to perform the capacity/sensitivity or consequence/probability comparisons. Thus, we will research other vulnerability assessment reports in order to assess objective methods of quantifying vulnerability and risk.

Consequence		Capacity to Cope (Low → High)				
		0	1	2	3	4
Sensitivity (Low ↓ High)	0	1	1	0	0	0
	1	2	2	1	1	1
	2	3	3	2	2	1
	3	4	4	3	2	2
	4	5	5	4	3	3

Risk		Probability (Exposure)				
		0	1	2	3	4
Consequence	0	0	0	0	0	1
	1	0	1	1	1	2
	2	0	1	2	3	3
	3	1	2	3	4	4
	4	1	2	3	4	5
	5	2	3	4	5	5

Figure 4 (a, left) and (b, right): Vulnerability Matrices. These matrices show the vulnerability based on sensitivity vs capacity to cope (a), and consequence vs exposure (b).

3.1.4 Geographic Information System Mapping

Organizing our demographic information enables us to plot the distribution of Chelsea's residents' vulnerability to excess heat. By assessing each individual's heat related experiences, concerns and preferences, and especially the ones that are expressed consistently, we anticipate to create profiles that describe how each person is affected by extreme heat and what their main objectives are. With this method, we would like to combine this data into a map and demonstrate the geographical distribution of these demographics by way of Geographic Information Systems (GIS) in order to assess the distribution of vulnerability in Chelsea. The map can organize people by housing type, work type, as well as other variables found to make people vulnerable. The map can also incorporate our third objective, showing how best management practices will help the spread of vulnerable populations throughout the city, making them safer from extreme heat.

3.2 Analyze strategies used by other places to identify the best possible solutions to lessen the risks and vulnerability of extreme heat

After obtaining and organizing information of the people's vulnerability and objectives, we are planning to look to other cities. Our second objective is to identify successful heat adaptation/mitigation methods in order to gain a thorough understanding of what types of methods have been effective for different municipalities and populations. To this end, we will conduct further research on heat countermeasures and contact officials or specialists who may speak on the process of implementing these strategies.

3.2.1 Conduct further research of successful methods in other locations

A major part of our project is to research methods on confronting the extreme heat events that have been successfully applied by other cities around the United States. After we conduct thorough research on what methods other cities follow in order to prepare and adapt to extreme heat, we will try to contact as many delegates as we can in order to determine which of those practices would apply the best in Chelsea, according to what we will have evaluated on what

Chelsea needs. We would need to ask questions related to the success of their adaption/mitigation plan and what difficulties each city faced while applying those plans. Our goal is to be able to identify the best management practices to be applied in the City of Chelsea. We will organize the gathered information into a matrix. An example of this matrix is shown in figure 5 with each specific method grouped by type.

Type	Method	Locations Applied	Individual $ Cost (Low, Med, High)	City $ Cost	Public/Individual	Shared/Personal Use	Ease of Use	Maintenance	Deployment	Efficacy	Accessibility	Other Constraints
Public Cooling	Cooling Shelter	Boston	L	H?	Public	Shared	H	M	Construction		M	Capacity City space
	Misters	Paris	L	L/M	Public	Shared	H	L	Construction		M	Capacity
Water Conservation	Rain Barrels	Chicago	L/M?	L/M	Individual	Personal	M	L	Production Distribution		M	
Vegetative Cover	Shade Trees	Chicago	L	M/H?	Public	Shared	H	M	Construction		H	
	Green Roofs	Chicago	M?	L/M?	Individual	Personal	M	H	Distribution		M?	
Local Temp Mitigation	Albedo Enhancement		L	M?	Public	N/A	N/A	L	Construction		N/A	
Public Information	Information Website	Boston Chicago Arizona	L	L/M?	Public	Personal	H	M	Develop		M	

Figure 5: Matrix of Example Countermeasures. This table organizes other countermeasures that was found during our research. A similar table will be used to organize our ideas as we continue to conduct our research in Chelsea.

3.2.2 Interview officials or specialists in other cities where methods have been implemented

After performing extensive literature review on heat mitigation and adaptation methods in other municipalities, we will look to get the opinions of specialists and officials in areas where these strategies have been adopted. We will first determine which methods we are most interested in learning more about. This will be decided based on which logistics from other strategies are most compatible with Chelsea. We must then determine whom to contact by researching which officials or specialists played major parts in the implementation of the strategies. Next, we will create questions to pose with the goal of obtaining information regarding: what factors facilitated or inhibited implementation of the strategy, the efficacy of the strategy, and the degrees to which different demographics were benefited by the strategy. We will then conduct the interview through conference call. As a group, we will have one person asking the questions, another taking notes, and a third making sure that everything is being recorded. The information gathered in these interviews will allow us to have a more thorough and realistic understanding of the heat countermeasures, better allowing us to make objective recommendations for Chelsea.

3.3 Identify the best management practices applicable to Chelsea, MA

Our third objective is to identify the best management practices that are applicable to Chelsea. We will do this by comparing the information of possible solutions from objective 2 to the information of Chelsea residents' personal objectives from objective 1. Going forth with the most compatible methods, we will consult Chelsea's government officials regarding whether they believe these methods are feasible. After finding the more realistic BMP, we will

consolidate them into an inventory describing their pros and cons, along with a document recommending how they could be implemented.

3.3.1 Cross reference logistics of possible solutions with City logistics and preferences of residents

With knowledge of Chelsea residents' vulnerabilities and personal objectives from objective 1 as well as a thorough understanding of the varying efficacies and logistics of heat countermeasures from objective 2, we will look to cross reference them in order to find the most compatible methods. We will organize the residents' preferences (e.g., accessibility, personal cost, maintenance requirement, etc.) and create a matrix comparing them to the logistics of the methods we identified as being possible. Based on this matrix, we will be able to identify the strategies that are most compatible with the people's objectives and the City's infrastructure.

3.3.2 Consult Chelsea City officials to determine feasibility of methods

Once we know what possible solutions coincide with what will work with Chelsea, we will be able to compile our information into an inventory of best practices. We will take this inventory and give it to Chelsea city officials. After they have gone over our inventory they will give their input on what they think would be most feasible. We are taking this step to make sure that we are abiding by all City laws and following the protocol of the city. We will then ask if there are any additional steps that will need to be taken to make the methods of the inventory work.

3.3.3 Create recommendations based on best practices and residents' preferences

Once we have conducted our research, interviewed the resident's and consulted the city officials to determine the feasibility of our plans, we will finalize our report. Our deliverables will be compiled into a presentation, which we will give to our sponsor and other city officials. The presentation will be the final inventory of best practices and recommendations to the city of what they should do in order to adapt to extreme heat to keep their residents safe.

3.4 Summary

By the end of this project we will produce multiple representations to present to the Department of Planning and Development in Chelsea, Massachusetts. One of those representations will be a GIS Map that will organize different forms of vulnerability as well as any physical best management practices that we aim to produce in the city (i.e. cooling shelters, shade trees, etc.). We are also aiming to create an inventory of Best Management Practices, which will consist of a list of the best methods other cities have been implementing in order to prepare or adapt to heat waves. Finally, we are going to assemble a recommendation document, proposing the best methods that could be applied to Chelsea, and what steps the city should take in order to apply them. In the end we hope that the city has a strong idea of the vulnerabilities that extreme heat poses on its' residents, and that they have a list of strong solutions to implement in their city.

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Appendices

Appendix A: Vulnerability Profile

Traits	Exposure	Sensitivity	Capacity to Cope
Elderly	Home	Health risks (dehydration)	Rely on other human beings
Infants/Children	School Home	Extreme, underdeveloped perspiration system	Rely on other human beings
Language Barrier	Life	Knowledge	Translation/ understanding
Low Income	Life	Average	Minimal
Outdoor Worker	Work	Average	Stuck to employer's decision
Poor Neighborhood	Home	High	Minimal
Renter	Home	High	Must gain approval from landlords to update property

Appendix B: Example Interview Questions and Organization Method of Responses

Exposure	Sensitivity	Capacity	Topic	Responses	Example Questions		
			Name				
			Gender				
x	x	x	Age				
x		x	Occupation		What do you do for work?	What is work like when it's very hot?	
x		x	Residence type		Are you a homeowner, landlord, or renter?		
x			Experiences		Been through a heat wave?	Hottest summer you remember?	
x		x	Home		Does it get hot at home?	How hot?	
x			When worst		Is it bad during night?		
x			Where worst		How is it at work?	How is it at school?	
x	x		Family		Is your family affected?	How are your children affected?	How are your parents affected?
	x		Effects		Have you ever had a heat stroke?		
		x	Cool off		What do you do to cool off?	What do you drink when it's hot?	Do you have air conditioning?
		x	Go where		Where do you go to cool off?	Do you go to the pool?	
		x	Difficulties in staying cool		Does anything get in the way of cooling off?	How hard is it to stay cool?	
		x	Desires		Anything you want to try but can't?	Why not?	

Appendix C: Translated Example Interview Questions

Exposición	Sensibilidad	Capacidad	Tema	Respuestas	Ejemplos de preguntas		
			Nombre				
			Género				
x	x	x	Edad				
x		x	Occupación		Cual es su profesión? En que trabaja?	Que tal es el trabajo cuando hace mucho calor?	
x		x	Tipo de residencia		Es usted un dueño de casa, el propietario, o un inquilino?		
x			Experiencias		Alguna vez ha sido afectado por una onda de calor?	Cual es el verano mas calido que recuerda?	
x		x	Casa		Se pone caliente la casa?	Que tan caliente se pone la casa?	
x			Cuando peor		Que tan malo es el calor durante la noche?		
x			Donde peor		Que tal es el calor en el trabajo?	Que tal es el calor en la escuela/Universidad/colegio?	
x	x		Familia		Es afectada su familia?	Como se ven afectados sus hijos?	How are your parents affected?
	x		Effectos		Alguna vez ha sufrido de una insolación (golpe de calor)?		
		x	Enfriarse		Que hace para refrescarse?	Que bebe/toma cuando hace mucho calor?	Do you have air conditioning?
		x	Ir a donde		A donde va para refrescarse?	Usted va a la piscina?	
		x	Dificultades para mantenerse frío		Does anything get in the way of cooling off?	Que tan dificil es mantenerse refrescado?	
		x	Deseos		Hay algo que quiera tartar de hacer pero no puede?	Por que no?	

Appendix D: Tentative Schedule

What we have to do	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
Interviews (Chelsea)							
Create questions							
Identify subjects							
Find and contact subjects							
Conduct interviews							
Analyze collected data							
GIS Mapping							
Information collection from sponsor and other organizations							
BMP Research							
Conduct further research on heat strategies							
Research how they can be implemented in Chelsea							
Interviews (Other locations)							
Create questions							
Identify subjects							
Find and contact subjects							
Conduct interviews							
Analyze collected data							
Analyze BMP for Chelsea							
Based off interviews with other locations							
Feasibility							
What is needed to make each one work							
Finalize Adaptation methods for Chelsea							
Write the report							