Resiliency and Heat in Sacramento: How climate change is affecting the city's response to extreme heat events.

Thesis

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Abstract

This thesis examines the ways in which extreme heat and anthropogenic climate change are expected to affect the residents of Sacramento, California. As the effects of climate change continue to worsen, it is imperative that the city's leaders realize the importance of heat resiliency and ways in which to adapt or mitigate the effects on both the public and our natural environment. Through synthesizing peer-reviewed literature and technical reports, this thesis aims at identifying what heat-related problems the city can expect to face as climate change increases the frequency and intensity of extreme heat events, as well as to provide recommendations on heat mitigation or adaptation methods based on studies conducted across the United States and globally.

Table of Contents

Introduction

The City of Sacramento saw a record breaking high of 109°F on Sunday July 16th, 2023. Surpassing the previous record by 1°F, this was the highest temperature recorded on this day since 1935 and overall, was the hottest day of the summer that the city experienced in 2023. Capital Public Radio, an affiliate station of NPR, interviewed a member of the mutual aid group Bay Area Superheroes (BASH) who chose to travel to Sacramento when heat predictions began to lean toward the extreme range. That Sunday, BASH had preemptively sent out a call for help via social media in purchasing and distributing bottled water to the city's community of unhoused individuals as a way to combat the high temperatures. Around eleven o'clock that morning, the aid group ran out of bottles to give after going through over thirty cases in a little over two hours. With most unhoused individuals unable to access the local cooling centers, the efforts of this group was one of the only ways that this disadvantaged community were able to stay somewhat hydrated (Secaira, 2023).

The article goes on to describe how deadly the effects of extreme heat can be for these individuals experiencing homelessness and other vulnerable populations, and ultimately concluded with an interview of scientists at the Lawrence Livermore Berkeley Labs. The pair of interviewed scientists go on to explain that the one of the best ways to combat extreme heat is to use alternative methods of household cooling to mitigate and adapt to the heat (Secaira, 2023). And while this method is scientifically proven to work, it remains to be seen how efficient household cooling methods are in providing direct help to those unhoused folks unable to find shelter.

Unfortunately, situations such as this are not uncommon across the United States, and the rest of the world, as humans are experiencing increasingly dire conditions directly stemming from climate change. The effects of this anthropogenic induced climate change are changing the world at an unprecedented rate. Worsening natural disasters, dwindling natural resources availability, and a warming planet are just the tip of the proverbial iceberg when it comes to measuring the effects of climate change. With little time or hope to reverse the current rate of warming, the question then becomes by which methods do we adapt to our changing planet in an equitable way, especially when the effects are becoming increasingly more severe across the board (Bedsworth et al., 2018). Governments are tasked with finding the answers to these difficult questions to protect the public, environmental, and economic health of its citizens. In California, the effects of climate change are felt deeply as the state has a seen a staggering amount of severe weather events in the last several years (Ebi et al., 2021). Wildfire, flood, land subsidence, rising ocean levels, drought, and many other natural disasters have plagued the state but one of the most pervasive and devastating among them is extreme heat events.

Extreme heat events are not uncommon in California and have been recorded since the founding of the state in 1850. The difference between the extreme heat events of the past and those occurring in modern times is that the heat waves of today last much longer and are much worse in terms of intensity (Tamrazian et al., 2008). In addition to public health, extreme heat can have a huge effect on the state's environmental health. Habitat and biodiversity loss are very real concerns of ecologists and in some cases can lead to species extinction (Bedsworth et al., 2018). Even in urban environments, extreme heat has a detrimental effect on the ecosystems in place and disrupt much of the native flora and

fauna. However, with an increased focus on limiting the effects of extreme heat, Californian cities have an opportunity to build resilience to the dangers associated with extreme heat.

Across the world, many cities are finding ways of mitigating or adapting to the effects of climate change and are paving the way to protect citizens as the frequency and intensity of these events worsens. California is leading the way in innovative solutions and policies to address the danger extreme heat poses to the state but, simultaneously, policymakers have a long way to go to combat the effects (California Natural Resources Agency, 2022). With intentional policymaking and innovative solutions, local governments within the state must ensure that communities increase equitable heat resilience strategies for the betterment of current and future residents.

Purpose and Methods

By utilizing peer-reviewed articles and government reports, this body of work will examine alternative ways in which to adapt or mitigate extreme heat related impacts that the City of Sacramento has yet to adequately address. This thesis ultimately aims at providing a thorough and comprehensive analysis of the methods the City of Sacramento has put into place to mitigate the effects of extreme heat as well as to provide several key recommendations that the city may use to further address policy shortcomings and increase disaster resilience.

Impacts of Extreme Heat

Extreme heat events have the ability to disrupt everyday operations and plunge a city into emergency depending on the severity of the heat event. With this in mind, there are several noteworthy areas that must be identified as having the biggest impact on a city's

residents – social, environmental, and infrastructural impacts. All three of these areas can have significant effects on both an individual and organizational level.

Social Impacts

Of all the social impacts attributed to extreme heat events, public health is one of, if not, the most affected. Extreme heat has been proven to be the deadliest weather-related risk in the United States with an average of 1,300 deaths per year (Environmental Protection Agency, 2021). Collectively, this accounts for the largest health burden than any other natural disaster including hurricanes, wildfires, and earthquakes. Older populations are especially affected by extreme heat, accounting for the majority of all heat-related fatalities in the U.S. (Gabbe et al, 2021). Because of its regularity, extreme heat events are consistently affecting the public, especially those in vulnerable communities with less access to heat mitigating methods like shaded areas or cooling centers. Other risks include heat exhaustion, heat stroke, dehydration and in some cases, death. Additionally, people with pre-existing conditions such as hypertension, heart diseases, or respiratory diseases are at a higher risk of complication when exposed to extreme heat (Berberian et al., 2022).

This risk of heat-related health complications can be especially harmful in disadvantaged communities where residents are disproportionately affected by these types of events. Access to air conditioners and cooling centers can be extremely limited in these areas and with less access to resources, this can be a deadly combination. Areas with low-income residents are often less likely to use or have an air conditioning unit due to a lack of income, and oftentimes do not have access to transportation in order to move to a cooling center (Jay et al., 2023). Many times, extreme heat events hit these areas the hardest in terms of temperature because there is a well-researched disparity in access to shade trees,

green spaces, and other cooling techniques (Gabbe et al., 2021). This disparity is of concern to environmental justice advocates and must be addressed by local governments in order to ensure that all residents are able to have their basic needs met.

Another public health issue related to extreme heat is the toll on mental health that heatwaves and extended extreme temperatures can have on humans. During a heatwave, it has been found that hospitalizations due to mental illness episodes increase tremendously and that suicide rates nearly triple (Gilbert et al., 2019). Studies have also shown that thermal comfort is paramount to an individual's choices during an extreme heat event. Thermal comfort is the perceived feeling of contentment with ambient air temperatures and highly influences a person's choices such as air conditioning unit use, method of transportation, and level of outdoor activity. Accounting for thermal comfort, many urban dwellers have a much higher sense of heat stress than those in lesser populated areas. In the Philippines, a study was conducted to survey residents about perceived heat stress in highly populated areas and results showed that 91% of citizens were negatively affected by heat stress. Many city residents found that densely populated areas negatively affected both their perceived feeling of heat and had detrimental impacts on their mental health (Cadag et al. 2018).

Environmental Impacts

In addition to the social impacts of extreme heat, the surrounding urban environment is hugely affected by the prolonged heat experienced in recent years. These heat events are especially brutal on urban vegetation and wildlife within cities. With a changing climate, much of the natural landscape of a city is affected by higher temperatures and in some cases, can cause native vegetation to be increasingly heat stressed and unable

to survive. In addition, the urban landscape's biodiversity is increasingly challenged by severe weather and possibly unable to adapt to rising temperatures (Hibbard et al. 2017). This could potentially mean that more invasive species adapted for heat could find their way into an urban environment and take over or ruin the exiting ecosystems.

Infrastructure Impacts

Extreme heat can cause numerous disruptions to a city's infrastructure. Public utilities have a long history in California of being unable to meet the needs of residents during extreme heat events and have come under scrutiny in recent years as the frequency of natural disasters has increased. Infrastructure systems in general must find ways to adapt to the changing climate while keeping in mind that sustainable methods must be utilized in order to reach the California's climate goals in the near future (Houlton and Lund, 2018).

Water use during extreme heat events is especially important to examine due to the necessity of its use. Communities depend on water systems for a variety of reasons during an extreme heat event as oftentimes increased watering is needed to keep vegetation alive or used as a cooling measure. However, with an increase of just 1°F, it is estimated that a single-family residence can increase their water use by 290 gallons (Houlton and Lund, 2018). This is significant for a variety of reasons, especially in areas often experiencing drought or scarce water resources. Limited water availability can affect local farmers crops and livestock, decrease the amount of urban vegetation and green spaces, and have an adverse effect on perceived heat stress in residents (Houlton and Lund, 2018).

Energy systems and extreme heat have long been inextricably linked to one another for many years. While energy generation has improved in efficiency and sustainability,

extreme heat events seem to continuously put energy grids to the test. Energy infrastructure reliability is a huge area of concern for many cities and have caused local governments increased stress in recent times due to the increased intensity and frequency of extreme heat events (Han et al. 2021). For example, with increased usage of air conditioning units, the need for reliable energy sources is paramount in emergency situations in order to mitigate the effects of the event. Oftentimes a working air conditioning unit is all that stands in the way of managing extreme heat in urban areas. Alternatively, this increased use of air conditioning units can have an adverse effect if used as the sole method of heat mitigation. More units providing cool air to residents also results in increased GHG emissions and ultimately exacerbating the problem long term (Han et al., 2021).

In addition to energy, transportation infrastructure can also be highly affected by extreme heat events. With hotter days and nights, many residents turn away from alternative transportation and instead choose to use personal automobiles as the primary mode of travel. Heat waves further feelings of heat stress and dissuade residents from using other forms of travel like walking, biking, or public transportation like buses and railways (Burillo et al. 2018). This is again worsening the problem of GHG emissions as more gas-powered vehicles on the road means more emissions being released and affecting the climate.

Driving Factors of Extreme Heat

As mentioned previously, extreme heat has been linked to many detrimental effects on the populace. Ranging from public health concerns to impacts on city infrastructure, extreme heat is pervasive, especially in the urban environment. However, extreme heat can

and is driven by two notoriously common phenomenon, climate change and the Urban Heat Island Effect. Both of these identified elements influence extreme heat events and greatly contribute to the need to improve upon Sacramento's heat and disaster resilience.

Climate Change

Climate change is raising the global temperature average at an alarming rate and can be directly linked to humans in the form of greenhouse gas (GHG) emissions. Since the late 1800's, the average global temperature has increased by 2°F and is expected to rise even further in the coming decades (Bedsworth et al., 2018). Due to this continuous warming, extreme heat events have shown to be longer in duration, more frequent in occurrence, and increasingly intense in severity. From 1986 to 2016, the state of California saw temperatures increase by 2.5° on average with future mid-century projections increasing temperatures up to 5.8°F. While the definition of what constitutes as an extreme heat event varies by region, many of these projections continue to indicate that climate change will cause heat events to exceed current frequency levels and temperature in the coming decades and will continue to detrimentally affect California at staggering rates (Bedsworth et al., 2018).

Urban Heat Island Effect

Another driving factor of extreme heat events is the occurrence of the Urban Heat Island Effect (UHI). The built environment of an urban setting, such as a downtown area of a city, has been found to be much hotter than rural areas for a variety of reasons. Low albedo of streets, reflective building surfaces, and lack of shade trees all contribute to this effect and, in most cases, can exacerbate an extreme heat event by disallowing nighttime temperatures to fall. This is important to note because with no significant cooling of

surfaces in the evening hours, shared resources, such as electricity, are being used at an accelerated rate. Energy grids become strained from the overuse of air conditioning units and in some instances, can cause a total blackout of an area (Chakraborty et al. 2021). This increased usage of air conditioning is exacerbated further with the increased urbanization that many cities across the United States are facing. Rapid urbanization has increased the amount of thermal absorption by buildings with the addition of more infrastructure to meet the needs of cities. With this in mind, many cities are experiencing even higher temperatures in their urban areas than that of the last several decades (Gilbert et al., 2019).

Additionally, the way cities and its citizens use and navigate their large urban centers can contribute to this UHI effect. Both buildings and transportation emit large amounts of waste heat, or the extra or unused heat emitted by buildings into the surrounding areas, that contribute to both GHG emissions and add unnecessary heat during extreme heat events. Buildings emitting this extra heat are often pumping out increased emissions during extreme heat events because of the increased use of air conditioning units, furthering the effects of UHI (Chakraborty et al., 2021). Temperatures in areas experiencing UHI averages to 5.2°F more than the surrounding rural areas, but in some places this difference has been measured up to a 14.4°F. The built environment of an urban center contributes heavily to the UHI effect and can most often be traced back to a lack of shaded green areas combined with built materials that often absorb the heat into surface material and then gradually released overnight (Zittis et al., 2023).

Sacramento and Extreme Heat

The City of Sacramento is facing a host of issues surrounding the topic of extreme heat. With local temperature expected to rise by 10°F by 2100, the city has identified

extreme heat as one of its biggest threats in the coming years (Alvarez et al. 2020). By examining the specific areas of improvement that must be addressed, city officials will be able to begin a strategy of strengthening resilience through both heat management strategies and heat mitigation strategies in order to meet the needs of the city residents.

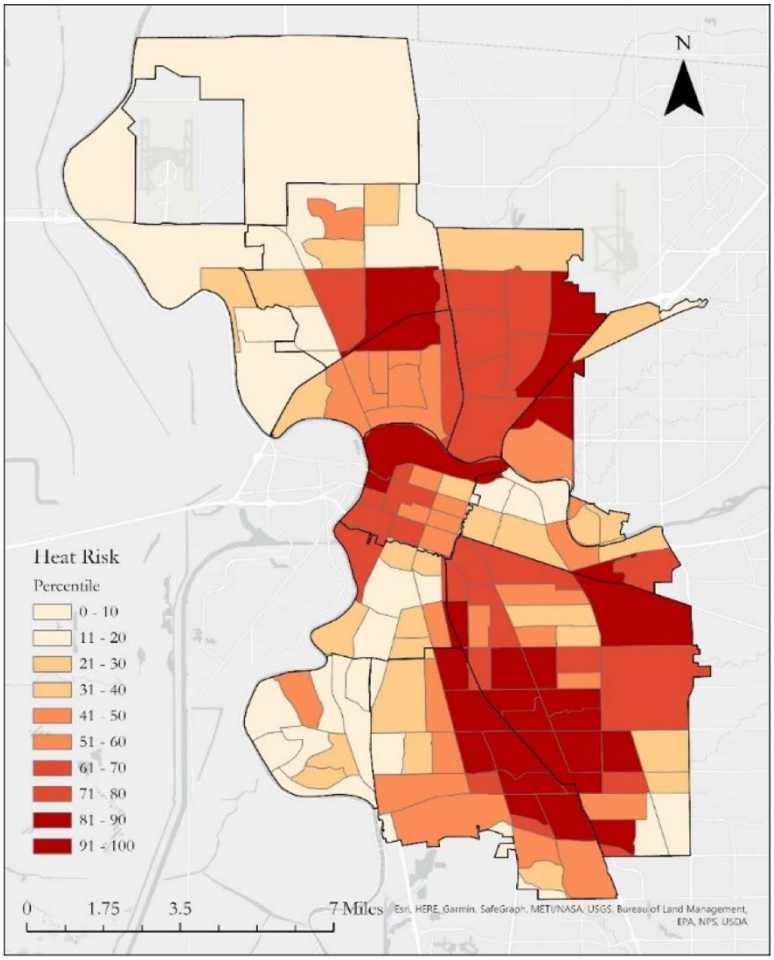

Figure 1: Sacramento Area Heat Risk (Alvarez et al. 2020).

Local Impacts of Extreme Heat

Sacramento policymakers have identified a myriad of impacts when it comes to extreme heat events, chief amongst them is the impact of the UHI effect that plagues several neighborhoods within the city. Officials have identified that within these neighborhoods experiencing increased effects from UHI, there are many underserved and marginalized communities that suffer at a disproportionate rate. In addition, key cooling infrastructure like urban trees and air conditioning units are less likely to be found in these households (Communitywide Climate Action Plan, 2017). In a technical report completed by NASA, researchers were able to map the Sacramento area and detect the heat risk associated (Alvarez et al., 2020). Researchers found that areas like the Stockton Boulevard corridor

and the Del Paso Heights neighborhood as the most at risk for heat and all its complications during extreme heat events (Figure 1, Figure 2).

This is significant due to the thoroughly researched relationship between land surface temperature and income level. In another report focusing on surface urban heat island intensity across 145 U.S. cities, researchers found that urban heat was disproportionately higher in areas with low-income households. Figure 3 illustrates two such cities, Greenville, South Carolina and Baltimore, Maryland. The image compares both race and income in relation

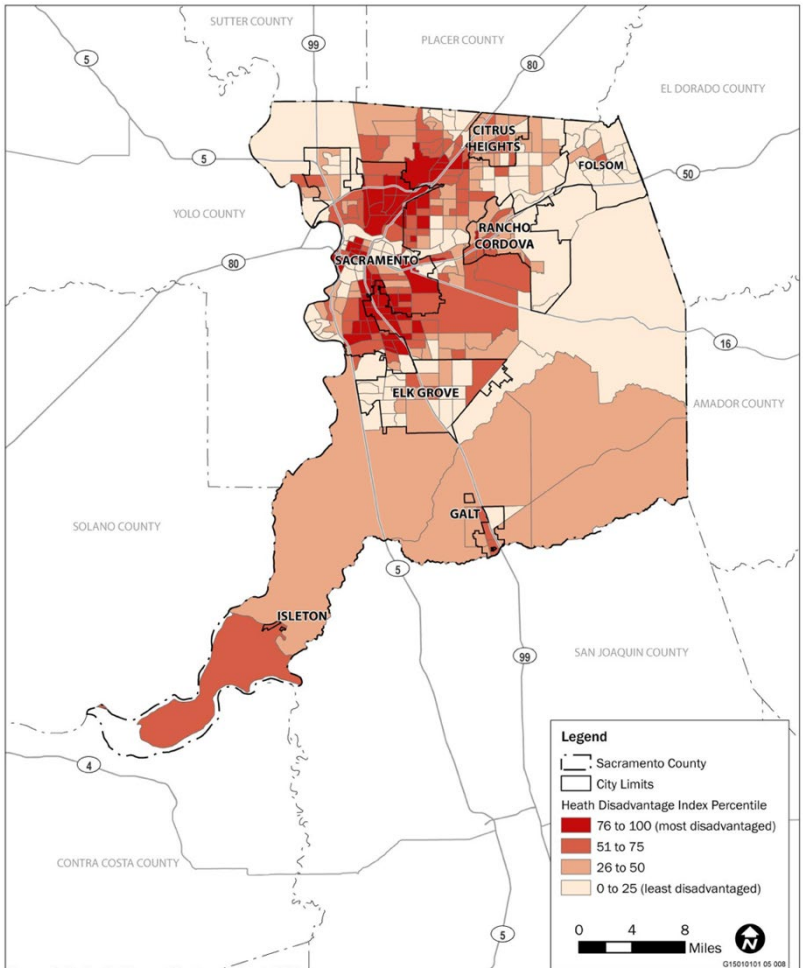

Figure 2: Sacramento County Disadvantaged Communities (Alvarez et al., 2020).

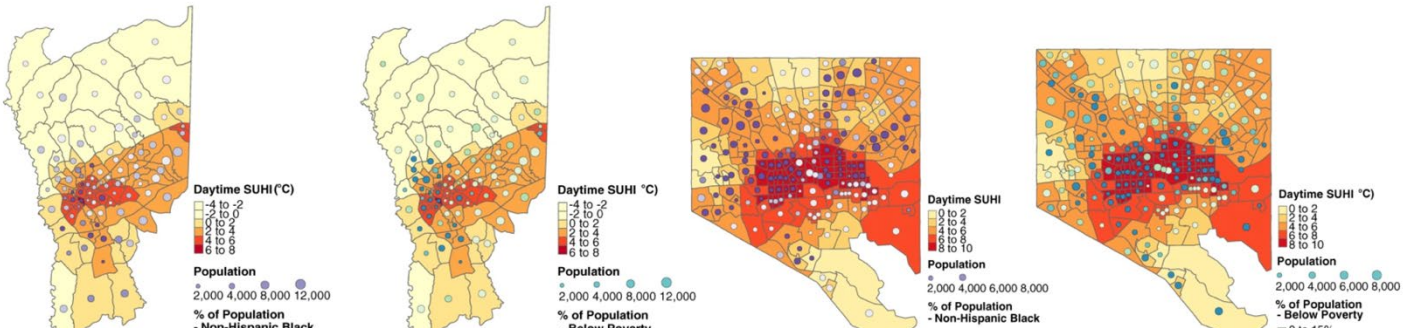

Figure 3: a) Greenville, SC SUHI & race. b) Greenville, SC SUHI & income. c) Baltimore, MD SUHI & race. d) Baltimore, MD SUHI & income. (Chakraborty et al. 2021).

to the surface urban heat island intensity of the respective cities. With these elements in mind, Sacramento is experiencing the same phenomenon of greater heat intensity in predominantly non-white areas or areas with low-income residents. With this problem recognized, the city must address this as an issue of equity and environmental justice.

One of the main drivers of the UHI effect that impacts so many Sacramentans is the effect that the transportation sector has on extreme heat. Albedo, or the amount of reflected light, is a significant driver of the UHI effect as the amount of asphalt and concrete surfaces increases the temperature of many urban areas by absorbing heat throughout the day and emitting it during the night. In Sacramento, residential surface areas are 35% asphalt while commercial districts consist of a surface area that is 68% asphalt. With these low albedo surfaces emitting heat over time, the effect of these roadways and transportation paths are significant to the heat Sacramento experiences (Sacramento Metropolitan Air Quality Management District, 2019).

Current Heat Resiliency Strategies

With such severe effects stemming from extreme heat, the Sacramento area and its local governments have made some efforts to increase community resilience. The State of California, Sacramento County, and City of Sacramento all have programs and initiatives in place in order to alleviate or mitigate the effects of extreme heat. For example, the Sacramento Municipal Utilities District, or SMUD, has a long-lasting partnership of over thirty years with the local nonprofit Sacramento Tree Foundation to provide a shade tree program to city residents. At no cost, SMUD customers are able to meet with a community arborist to determine what tree species and location to plant a shade tree on their property. This not only cools down the homeowner's property, but also improves Sacramento's tree

canopy by increasing the amount of shade (Sacramento Metropolitan Air Quality Management District, 2019). In addition, the County of Sacramento also provides cooling centers in the event of extreme heat events for residents to utilize. And while the accessibility of the centers must be improved, this provides a service to county residents that will potentially lower heat-related illness or morbidity (Sacramento County, 2023).

Providing services that directly help residents is an important tool in local heat mitigation plans for Sacramento residents but on a larger scale, the State of California has developed the California Heat Assessment Tool, or CHAT, as a way to provide early warnings to local or regional public health departments. The idea behind this tool is to identify extreme heat events most likely to cause heat-related illness and death before the event occurs and provide targeted messaging to the public to reduce public health impacts (Bedsworth et al., 2018). This allows local and regional agencies to prepare ahead of time in order to provide alternative heat relief programs and increase the local community resiliency to harmful heat related effects.

Recommendations for a Heat Resilient Sacramento

There are a variety of additional heat management systems and tactics that the City of Sacramento could implement to lower the impact of extreme heat events even further. Managing extreme heat in an equitable fashion can prove difficult but it is and should be a main priority of the city to address the environmental justice issues identified. By ensuring equity and inclusion, the city is will ensure a lasting and sustainable legacy that is mindful of diversity and inclusion in all areas of government.

Heat Mitigation Strategies

In order to boost the city's resilience to extreme heat, policymakers and leaders should be examining tools and strategies that will mitigate the effects of extreme heat. This can be done by utilizing methods with proven success such as cool surfaces. These surfaces can include wall, sidewalks, and roofs, and is done by installing greenery or high albedo material on surfaces that can reflect the solar rays. Sacramento has identified the benefit that cool roofs can have on the city, but the city can go even further by implementing cool walls and pavements. Both have the ability to lower ambient air temperature by either fixing greenery or high albedo surface material to surface walls, or by installing high albedo surface material on paths and roadways. Both methods have proven results of lowering surface temperatures (Levinson and Rosado, 2019, Ban-Weiss et al. 2019). In addition, increasing the number of cool or green roofs can have significant impact on reducing heatwave related impacts. Lowering the temperature or the absorption of heat on these flat surfaces has been studied and researched in the United Kingdom to have a reduction in heat-related mortality (Heaviside and Macintyre, 2019).

Heat Adaptation Strategies

In addition to heat mitigation methods, which lower the effects of extreme heat, adaptation methods are also a useful tool for the City of Sacramento. Adaptation methods are strategies in which design around the expectation of heat rather than to try and lessen effects. Designing low GHG emission buildings, utilizing natural cooling architecture, and increased access to air conditioning units or cooling centers are all examples of adapting to extreme heat events by designing programs and initiatives around the expectation that extreme heat will become more commonplace and worse in intensity. With this in mind, Sacramento policymakers must increase focus on equitable and sustainable methods to

provide greater accessibility for all residents regardless of location or income (California Natural Resources Agency, 2022, Mayors' Commission on Climate Change, 2022).

Conclusion

Extreme heat events are considered to be an invisible threat of climate change but an increasingly important one to address. Across the U.S. there are continuous reports of increased temperatures for extended periods of time and while they vary in intensity depending on the region, the adverse effects are numerous. Extreme heat permeates into multiple areas of community life and negatively affects the public in significant ways, especially those who are considered to apart of a vulnerable population. By addressing this issue, this paper aims at highlighting what can be done at a local level in order to create change on a larger scale. As the state capitol, Sacramento already serves as a leader in public policy and must reckon with the adverse effects of extreme heat by taking definitive action. By doing so, the city has an opportunity to increase heat resiliency within the communities for the betterment of the city's current residents and those to come.

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