

Research Article

An Analysis of Heat Waves in Disaster Management

Benjamin Rundbaken * 

Independent Scholar, Fort Myers, The United States

Abstract

This paper examines the current state of disaster management for heat waves in the United States. The paper begins by providing the status of heat waves in the U. S. A. and the detrimental effects they can have on society, such as human and animal health concerns, damage to infrastructure, and strained power grids. The paper then provides a synopsis of the disaster management framework provided by the U. S. government. This entails a description of the five stages of disaster management: Prevention, Protection, Mitigation, Response, and Recovery. Next, the current public health measures taken to address extreme heat are organized within this framework, described, and assessed based on a review of existing literature. These public health measures include protection of the power grid, incorporating green and cool spaces into city design, cooling centers, and heat warning systems. The results of the literature review show that actions taken prior to an extreme heat event are more effective than actions taken in response to the event or during the recovery from it. Measures taken in the Protection and Mitigation stages have a more reliable and documentable benefit to human health than measures in the Response and Recovery stages. Additionally, these actions, such as safeguarding power grids and installing green infrastructure in urban environments, generally provide financial benefits that exceed their costs, making them good investments for both public and private entities. It is therefore recommended to focus programs and investment on measures in the Protection and Mitigation phases.

Keywords

Heat, Heat Waves, Urban Heat Island, Disaster Management, Disaster Response, National Preparedness Goal, Literature Review

1. Introduction

1.1. Heat Waves

The rationale behind a focus on heat waves is simple- heat waves kill more people in the United States than all other weather-related disasters combined [1]. A heat wave is defined as an unusually hot period of weather that lasts at least two days, with the specific temperature levels defined by that area's typical averages [1]. Not only can these extreme heat events have significant health impacts for humans, but they

can also damage agriculture and livestock increase wildfires, and strain power grids [2]. Although heat waves already pose a significant threat, they are becoming more dangerous as the climate warms [2]. Heat wave frequency, duration, and intensity have all been rising in the U. S. since the 1960's- the average heat wave is now 2.3 degrees F over local thresholds compared to 2.0 degrees F in the 60's, and the average heat wave season is now 49 days longer than it was in the 60's [2]. Heat wave season, the time between the day of the first heat wave of the year and the last, is significant as people tend to

*Corresponding author: brundbaken21@gmail.com (Benjamin Rundbaken)

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have their guard down for heat waves outside of the typical time of year that they expect extreme heat [2]. This has a direct impact on public health. A study of Louisiana temperature and hospital data found that as temperatures rise, so do heat-related hospitalizations and work-related emergency department visits [3].

Not only are heat waves appearing earlier and later due to climate change, but these effects are appearing in areas that ordinarily do not struggle with heat [4]. An Environmental Protection Agency (EPA) study of cities in the U. S. found that the cities with the highest increase in heat wave intensity were, in order, Philadelphia, Pittsburgh, Salt Lake City, and Boston [4]. Additionally, cities as far north as Portland, Seattle, and Milwaukee have seen an increase in heat wave season between 30 and 60 days [4]. Northern cities such as these are generally not as accustomed as traditionally hot cities to dealing with extreme heat- only 44% of households in Seattle have air conditioning compared with the 91% American average, as well as 47% in San Francisco and 79% in Portland, respectively [5]. However, 99% of households in traditionally hot cities such as Houston, Miami, and Atlanta had air conditioning at the time of this study, showing the disparity in preparedness between northern and southern cities in the U. S. [5].

Particularly susceptible to heat waves are urban areas that trap and absorb heat due to their abundance of concrete and asphalt, known as urban heat islands [6]. These environments can have daytime temperature averages between 1-7 degrees F hotter than “outlying areas”, as well as nighttime temperatures between 2-5 degrees F warmer [6]. Currently, 56% of the world’s population lives in urban areas, and that number is expected to grow to nearly 70% by 2050 [7]. Therefore, proper public health initiatives to address heat waves in urban heat islands are essential today and will continue to be in the future.

1.2. Disaster Response: National Preparedness Goal

The goal behind this project is to assess current disaster response to heat waves in the context of the disaster management framework established by the U. S. National Preparedness Goal. The National Preparedness Goal outlines five key stages of disaster management: Prevention, Protection, Mitigation, Response, and Recovery [8]. The goals of each of the stages are as follows:

Prevention: Actions taken to “avoid, prevent, or stop” an act of terrorism- examples of prevention core capabilities are Forensics/Attribution and Intelligence/Information Sharing [8].

Protection: Actions taken to shield against disasters of all forms, specifically to protect “our people, our vital interests, and our way of life”- examples of protection core capabilities are Planning, Physical Protective Measures, and Risk Management [8].

Mitigation: Actions taken to reduce the negative impacts of disasters before they occur- examples of mitigation core capabilities are Community Resilience, Long-Term Vulnerability Reduction, and Threats and Hazards Identification [8].

Response: Actions taken to “to save lives, protect property and the environment, and meet basic human needs” immediately following a disaster- examples of response core capabilities include Public Information/Warning, Critical Transportation, and Mass Care Service [8].

Recovery: Actions taken to aid communities in their efforts to recover from an incident- recovery core capabilities include Economic Recover, Housing, and Infrastructure Systems [8].

2. Methods

This paper will focus on actions taken before, during, and after heat waves and examine which stages of the Natural Disaster Recovery Framework are the most effective at protecting public health during extreme heat. A literature review will be conducted consisting of relevant journal entries, newspaper articles, and publicly available government information on heat and heat action plans. This analysis will first require understanding of measures taken to address heat waves, followed by an assessment of their effectiveness and benefits relative to the costs. Once these steps are completed, it will be possible to draw conclusions as to public health recommendations for heat waves within the National Preparedness Goal framework.

3. Results

A review of the existing literature found a multitude of different approaches taken by governments to address the health effects of extreme heat waves. In order to properly examine the results, this paper will present them sorted by the stages of disaster management to which they belong. As the Prevention stage applies exclusively to terrorist attacks, it will be excluded in this paper.

3.1. Protection

There are both short-term and long-term protection measures that can address heat waves. The primary short-term measure that falls under the protection stage is securing critical infrastructure against heat waves; specifically, the power grid [9]. Extreme weather patterns are the biggest factor in blackouts and heat waves are predicted to become more extreme as climate change progresses [10]. Blackouts during heat events are of particular concern because they prevent the public from accessing air-conditioning (AC) systems during hot weather, driving higher mortality numbers [10]. A study of a two-day New York City blackout in August of 2003 found that it “caused a 122% increase in mortality from accidental deaths and a 25% increase in mortality from dis-

ease-related deaths” [10]. Another study found that a potential summer blackout in Phoenix could expose seven million Phoenix residents to hazardous heat conditions [9]. These are not unexpected phenomena- studies have found that heat waves increase all-cause mortality, and these effects would be amplified during a blackout when the public is no longer able to access many cooling systems [11]. The primary protection measures to avoid heat-related blackouts are diversification of energy sources, preparedness measures at power plants, and programs offering consumers rebates if they reduce their energy usage during peak hours [12]. According to energy experts in Texas, these measures prevented any major blackouts in the summer of 2023, despite it being the hottest summer on record [12].

A long-term heat wave protection measure would be to address climate change, as climate change is the driving force behind the increasing intensity of heat waves seen across the country [2]. Reducing greenhouse gas emissions and preventing the increase in these extreme weather events would have an enormously protective impact on public health. However, as reducing climate change requires global policy changes in public health, energy consumption, and culture, these protection measures are outside the scope of this paper.

3.2. Mitigation

The heat wave actions taken in the mitigation stage largely focus on reducing ambient temperatures to lessen the effects of heat waves, particularly in cities to control the urban heat island effect [6]. These mitigation techniques were found on the EPA’s website, which provides a guide for cities looking to manage heat.

The first method provided by the EPA is to plant trees and vegetation throughout the city [13]. These green spaces lower heat through two routes. They provide shade for the streets, protecting them from the sun and allowing them to remain cool during summer [13]. This shading effect also reduces pavement deterioration due to heat, making the roads safer for passenger cars and emergency vehicles [13]. The second route through which greenery cools ambient air is evapotranspiration, in which plants release water to the atmosphere and the evaporation process removes heat from the air [13]. Trees and vegetation are very effective at cooling urban areas, with green spaces in cities having been shown to be an average of 2.9 degrees F cooler than urban areas without green spaces [13]. Additionally, trees and vegetation have the positive side benefits of improving air quality and holding stormwater during flooding events [13]. This heat mitigation method is extremely cost-effective. A study of five U. S. cities showed that cities made between \$1.50 and \$3.00 for every \$1.00 invested in trees [13].

The next method given by the EPA is to replace traditional pavements, such as asphalt and concrete, with cool pavements made of materials that can remain cool during heat waves [14]. These pavements maintain lower temperatures through properties such as an improved ability to reflect sunlight, enhance

water evaporation, and more [14]. Conventional pavements can reach between 120- and 150-degrees F in the summer and cover between 30-45% of cities, so replacing them would make a significant impact on a city’s heat [14]. Preliminary studies show that increasing the solar reflectance of a city’s pavement from 10% to 35% would cause a temperature drop in the city of 1-degree F [15]. However, due to the varieties of cool pavements, as well as the fact that they are rarely implemented without accompanying mitigation measures, a cost-benefit analysis does not exist for this technique [14].

A third mitigation method provided by the EPA is to replace conventional roofs with green ones, which are rooftops covered in trees/vegetation [16]. Conventional rooftop surface temperatures can exceed ambient air temperatures by up to 90 degrees F in the summer [16]. Green roofs, however, can reduce surface temperatures from 20-45 degrees F, with the added benefit of improving air quality and managing stormwater [16]. A study in Toronto predicted that adding green roofs to 50% of available downtown surfaces would cool the entire city by 0.2-1.4 degrees F [16]. Green roofs also provide a high cost/benefit ratio [16]. Chicago estimates that its green roof on City Hall will save the building \$3,600 annually on energy costs [16]. Additionally, a University of Michigan study found that while green roof installation costs an extra \$129,000 over a traditional one, it will save over \$200,000 in its lifetime through energy costs [16]. Installation of intensive green roofs, which are fully accessible rooftop parks, can also raise property values as they are an attraction for residents [16]. Lower summer energy usage could also allow buildings to take advantage of consumer programs offered by power companies, in which energy users are compensated for lower power usage during peak demand hours [17]. After Los Angeles implemented a combination of green spaces, green roofs, and cool pavements, research found that it had improved the overall city’s temperature by 1.5 degrees F, which resulted in \$90 million savings in energy consumption and smog mitigation [15].

There are numerous other heat mitigation techniques available to cities, such as education on heat health effects and city planning designed to reduce direct sun exposure to buildings [18]. However, significant data was not available as to the results or the cost/benefit of these methods, so they were not included in the results of this study [18].

3.3. Response

A major part of heat wave response is the use of cooling centers, which are air-conditioned, or cool locations that are designated as sites to “provide respite and safety during extreme heat” [19]. These can be an effective way to mitigate health effects of heat- spending even a few hours in a cool environment reduces heat risk, and one study found that using a cooling center reduced mortality by 66% [19]. Additionally, cooling centers are extremely cost-effective as they generally take advantage of areas that are already cool or air-conditioned, meaning the only costs to run them are

staffing, services at the centers, and transportation to them [19]. The use of cooling centers as part of larger heat action plans has been shown to be effective in practice [19]. After the implementation of cooling centers and warning systems, a 1999 Chicago heat wave had 80% lower mortality rates than a similar Chicago heat wave in 1995 [19]. A final benefit of cooling centers is that proper AC use can improve indoor air quality by trapping particles such as dust, smog, and mold [20]. However, this effect is only seen when AC filters are properly used and replaced. If filters are used incorrectly or for too long, bacteria and other pathogens can build up in the AC system and potentially cause illness [20]. Therefore, it is imperative that cooling centers properly maintain their AC system.

Despite the benefits, there are significant issues with the use of cooling centers as disaster response to heat waves. First, to take advantage of a cooling center, people must actually be in them. This means that they do not help people working outdoors, who are an extremely vulnerable population to heat waves. A study in Los Angeles found that an increase in construction workers in a community led to a direct increase in work-related heat hospitalizations [21]. Another study in Louisiana found that there were an average of 320 work-related heat hospitalizations per year in Louisiana from 2010-2020 [3], with 81 of those coming just from New Orleans [22]. This number is likely undercounted since it is based solely on worker's compensation claims, and many workers, particularly the undocumented, may not have taken advantage of worker's compensation [22]. These outdoor workers might not be working near cooling centers and would therefore be unable to access them when they are the most at risk. Additionally, those without transportation are unable to access cooling centers. A 2021 study found that only 10% of Americans in cities lived within walking distance of cooling centers [23] and that only 13% of counties in New York with cooling centers offered transportation to them, compared with 100% of counties in California with cooling centers [19]. Not all cooling centers are publicly run, however. A 2023 study of Los Angeles found that the majority of residents that sought out cooling centers during heat waves opted for informal ones, such as shopping malls and movie theaters [23].

Another issue with cooling centers is that they do not always reach the targeted population. A study from 2006 found that cooling centers were used more by low-risk individuals than by high-risk ones [19]. Data from the CDC also found that vulnerable individuals are not likely to see themselves as such, which likely contributes to the fact that a survey found that 25% of elderly populations would refuse to be sheltered in an extreme heat event [19]. People also continue to view cooling centers as spaces for the elderly and homeless [19]. However, homeless populations are more likely to congregate in cooler green spaces rather than an indoor cooling center [19]. Using a cooling center also requires knowing that they exist, which can be a problem. A 2011 Canadian survey found that over half of the respondents did not know they existed [19].

The other major response strategy to heat waves is to es-

tablish heat warning systems (HWS) which monitor heat waves and trigger public outreach with information about inclement weather and heat safety [18]. The public is informed about the nature of the heat wave, available public resources, and tips for avoiding negative health effects of extreme heat [24]. These warning systems have been shown to be effective. One study in Philadelphia found that implementation of the HWS saved over 2.6 lives per day when it was active during hot weather [24]. This also would theoretically save \$468 million in health care costs, compared to the \$210,000 cost of running the HWS [24]. These HWS's are especially effective when used in conjunction with other response measures such as cooling centers [24]. HWS's were another part of the public health measures employed by Chicago after the 1995 heat wave that led to a reduction in mortality during the 1999 heat wave [19].

However, there are problems with relying on HWS's as well. First, although many studies have shown a correlation between HWS's and lower heat mortality, none have been able to show a causal relationship [24]. There are many confounding factors that prevent public health researchers from making such a determination, such as improved medical care or better functioning air conditioning from one heat wave to the next [24]. HWS's also rely on people making adjustments after receiving proper information- however, two different studies showed that people were not altering their behavior even after receiving heat alerts [24].

Once again, there are other response techniques that can be employed by public health officials, such as increasing access to water, organizing outreach to vulnerable populations, and issuing municipal decrees maintaining electricity and water even for those that do not pay [18]. However, there is no available data on the results of these methods and they "require further study to understand whether or not they are actually effective cooling methods" [18].

3.4. Recovery

The first step after the heat wave has occurred is for public health officials to conduct an After-Action Review (AAR) wherein they examine what happened, what was done, and the effectiveness of their actions [18]. This AAR then guides the next steps for recovery and shows the public health officials where improvements can be made [18]. However, since these recovery steps vary by heat wave and by location, data as to the effectiveness of recovery efforts was not available.

4. Discussion

The literature review demonstrated that among proven techniques to reduce the hazardous impact of heat waves, the most effective are those taken in the protection and mitigation phases of disaster response, or before the heat wave occurs. All three mitigation techniques given have been shown to have a significant impact on a city's temperature- the study of

the combination of them in Los Angeles in particular is significant, as the 1.5-degree F temperature difference would offset some of the temperature rise in the city caused by climate change. This could make a particular difference in cities that experience heat waves outside of their normal season/intensity, such as Seattle and San Francisco. The installation of greenery and cool pavements could ease the transition as residents begin to acclimate to more intense heat waves, particularly as long as lower percentages of households possess air conditioning. Additionally, not only are these measures effective at reducing ambient temperatures, their benefits also outweigh their costs. While there was no cost/benefit analysis for cool pavements, green spaces and green roofs have been shown to provide positive monetary benefits, making them a wise investment even for those that are not interested in the environmental impact. For instance, green roof installation could profit landlords nearly \$100,000 over their lifetime through lower energy costs alone.

Actions taken in the protection mission area are also effective, as shown by the resilience of the power grid in the face of record-breaking temperatures in 2023. The greater diversification of energy sources and preparedness measures prevented major blackouts that could have proven catastrophic, as shown by the Phoenix study. Mitigation measures can also work in tandem with protection measures. If greenery and cool pavement lower ambient temperatures, power use from air conditioning in buildings will be reduced, leading to less stress on the electric grid. Mitigation measures could also reduce morbidity if a blackout occurs. Green spaces could provide relief and shade during a power outage and potentially save lives, especially for vulnerable populations. Green roofs could help lower indoor temperatures for those who may not be able to leave their apartments and prevent overheating during an outage.

The effectiveness of response measures is more complex. Despite the benefits of public cooling centers, they still prevent the challenges of transportation, awareness, and perception. To take advantage of a cooling center, an individual must be aware that he/she is vulnerable, know what a cooling center is and where the nearest one is located, and be able to procure transportation in times of extreme heat. Additionally, the fact that the homeless are more likely to congregate in green spaces means that cooling centers are failing to reach a particularly vulnerable demographic. Cooling centers also rely on continuous and powerful air conditioning, which could contribute to climate change if relied upon as a long-term technique. It could also lead to negative health outcomes if the AC system is not properly maintained, which is entirely possible as there are no indoor widespread air quality regulations. The other major response method, heat warning systems, are likely effective but have only shown improvements when done in tandem with other public health measures. HWS's also rely on the recipients of the information to act accordingly with recommendations, which is not always the case.

Another major flaw with the response measures to heat waves is that their effectiveness would drop drastically during a black-

out. Without an adequate backup generator, a power outage would shut down air conditioning at cooling centers, leaving all of its users stranded in a foreign location in hazardous heat conditions. Additionally, it could be a significant stressor for any mentally ill users of the cooling center, which in turn could be a threat to both the individual with the mental illness and the other users of the center. As a significant target demographic of cooling centers is the homeless/unsheltered, this is a point that must be considered. A blackout would also interfere with the functioning of heat warning systems. Wi-fi routers in homes would cease to work, removing a method for the public to receive heat warnings. If phones run out of power as well, then it would be very difficult for heat warnings to reach their intended recipients. Furthermore, the absence of air conditioning would mean that even if the public receives heat warnings, they cannot seek out cooling centers to escape the heat. A power outage could also prove devastating to any hospital or nursing home with a faulty or insufficient backup generator. All these problems with response systems are of particular concern since extreme heat makes power outages increasingly likely.

The recovery measures for heat waves are not as concrete as the measures for the other stages. Aside from potential strain on power grids, heat waves don't cause physical destruction in the manner of other disasters, such as hurricanes and earthquakes. As shown by the Heat Wave Guide for Cities referenced in the results, recovery methods for heat waves are mainly comprised of making the necessary adjustments to infrastructure where needed. However, these measures are essentially mitigation measures for the next heat wave guided by results from the past heat wave.

5. Conclusion

The results of this project point towards the conclusion that the best disaster management for heat waves is conducted prior to the extreme heat event. Protective actions can be taken to safeguard power grids, as maintaining steady power during heat waves is essential. Mitigation efforts, such as the ones discussed in this project, can have a direct effect on a city's temperature and thereby reduce the heat itself. This heat reduction could have a significant impact on public health outcomes during heat waves. Response measures, however, are less certain for heat waves. While cooling centers and heat warning systems have the potential to improve public health during a heat wave, neither have been conclusively proven to reduce morbidity. There are also obstacles to the effectiveness of each measure, such as transportation to cooling centers or an individual's lack of compliance to recommended heat wave measures. Additionally, a blackout would significantly impair the effectiveness of response measures- particularly cooling centers. Recovery actions for heat waves are fairly indistinguishable from mitigation measures, further driving home the point that the most effective heat wave response takes place before the heat wave occurs. Therefore, emphasis and investment should be focused on programs in the Protec-

tion and Mitigation phases, rather than Response or Recovery.

Abbreviations

EPA	Environmental Protection Agency
AC	Air-conditioning
HWS	Heat Warning System

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Conflicts of Interest

The author declares no conflicts of interest.

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