EXTREME HEAT: PREPARING FOR AN UNCERTAIN FUTURE

Background Information

Arizona State University

Museum of Science

ECAST
EXPERT AND CITIZEN ASSESSMENT OF SCIENCE AND TECHNOLOGY

Northeastern

Section 1: Vulnerabilities to Extreme Heat

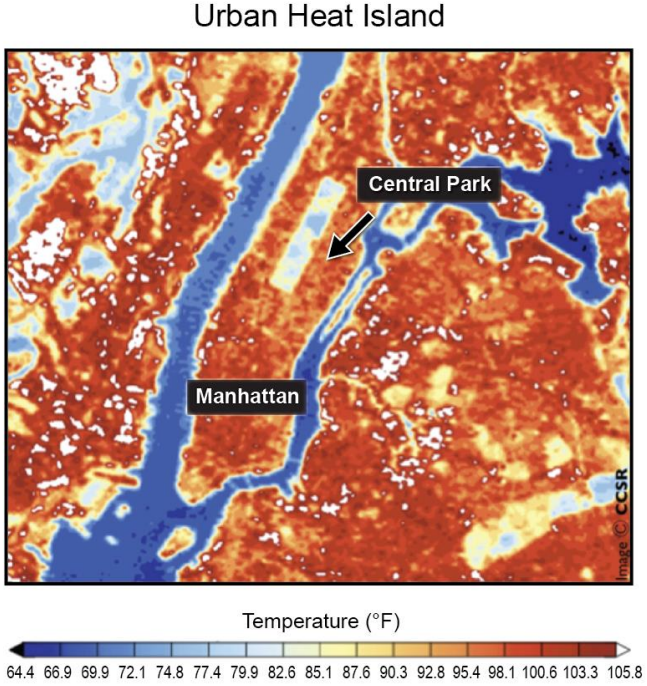
Extreme Heat Overview

An extreme heat event or heat wave describes a time of abnormally warm temperatures lasting days or even weeks. In the U.S., the number of extreme heat events has increased in recent years and these events have become hotter and longer[1]. More high temperature records are being broken than low temperature records, indicating that extreme heat events are on the rise[2]. Scientists predict that heat waves will become more common and more intense in the coming decades. Extreme heat creates many hazards to communities across the country. Extreme heat threatens human health, electricity and transportation infrastructure, and can affect ecosystems important to humans. Resilience planners are thinking about how to protect communities from the worst impacts.

Why is extreme heat becoming more common and intense?

Extreme heat is becoming more common and intense for two reasons. The first is changes in global and regional climate patterns. Many scientists link extreme heat events with the increase in average global surface temperature and increased variability in temperature. In other words, as average temperatures and variability increase so do the chances that a place might experience an extreme heat event.

In cities, the urban heat island (UHI) effect makes extreme heat worse. The urban heat island effect is when warmer temperatures are found in cities compared to their surrounding, non-urban environments. The intensity of the UHI effect varies by city but is more pronounced at night. Two factors contribute to the UHI effect: human-made heat and the physical landscape of cities. Human-made heat includes the heat generated by burning fuel for transportation or heat generated by air conditioning units. Cities contain a lot of asphalt, concrete, and



This image of New York City shows surface temperatures are about 10 degrees higher in the city than in tree-covered Central Park. source: Center for Climate Systems Research, Columbia University.

[1] National Climate Assessment, 2014. http://nca2014.globalchange.gov/; Habeeb, 2005. https://dx.doi.org/10.1007/s11069-014-1563-z

[2] https://www.epa.gov/climate-indicators/climate-change-indicators-high-and-low-temperatures

buildings. These surfaces absorb heat from the sun during the day and release that heat back into the air at night, preventing the city from cooling down.

The following section outlines the social, economic, and environmental impacts extreme heat could have on cities, rural areas, and people. This will introduce you the problems officials face when considering resilience plans.

Social impacts

Extreme heat directly threatens human health. From 2006-2015, 1,130 people died from heat in the U.S., more than any other natural disaster, including tornadoes, floods, extreme cold, and hurricanes[3]. Heat directly and indirectly leads to health problems. Direct impacts include various forms of heat-related illness, including heat cramps, heat exhaustion, and heat stroke. Symptoms of heat-related illnesses include light-headedness and fainting, nausea, fatigue, and confusion. The most severe type of heat-related illness is heat stroke, which occurs when a person's body can no longer maintain its internal temperature, and it begins to rise dramatically[4]. Heat stroke can damage internal organs and quickly lead to death. Indirect health impacts can include increasing the risk of other health problems, such as heart attacks.

The impact of extreme heat on people varies across communities. Some people, such as elderly residents, people who live alone, and people who have trouble getting around or are ill, are more susceptible to the health impacts of heat[5]. These groups were at a higher risk of dying due to heat in the Chicago heat waves of July 1995, which killed over 700 people. Other people disproportionately impacted by heat include people who work outdoors, such as construction workers or landscapers. People who use public transportation face prolonged exposure to extreme heat while they walk to and wait for busses and trains[6]. The homeless are disproportionately affected by extreme heat because they lack a cool space to go on hot days and cannot cool off at night due to the urban heat island effect.

Within cities, some neighborhoods bear the brunt of heat because their neighborhoods are hotter than others. These neighborhoods usually lack vegetation, have more buildings and manmade surfaces, and are often poorer than cooler neighborhoods within the same city. In Phoenix, AZ, for example, poorer residents and ethnic minority residents were more likely to live in warmer neighborhoods with less vegetation[7]. These residents often lack the social networks and resources necessary to cope with heat, and lack a cool place to go during extreme heat and do not have, or cannot afford to run, air conditioning in their homes.

[3] Center for Disease Control, 2016. https://www.cdc.gov/climateandhealth/pubs/extreme-heat-guidebook.pdf
[4] Center for Disease Control, 2012. https://www.cdc.gov/disasters/extremeheat/heat_guide-page-3.html
[5] Semenza, 1996. http://www.nejm.org/doi/full/10.1056/nejm199607113350203,
Zhang, 2015. https://ehjournal.biomedcentral.com/articles/10.1186/1476-069X-14-11
[6] Fraser and Chester, 2016. http://dx.doi.org/10.1016/j.jth.2016.07.005
[7] Harlan, 2006. http://dx.doi.org/10.1016/j.socscimed.2006.07.030

Some researchers argue that social considerations, such as providing cool spaces for those who lack access to them, are more important than planting trees or creating shade[8]. Access to air-conditioning, however, varies across cities. In Portland, OR, 30 percent of homes lack air conditioning while in Tucson, AZ 12 percent of homes lack air conditioning[9]. Researchers found that portions of residents in Los Angeles and Phoenix lack adequate access to cooling centers, public libraries or suitable commercial spaces, such as malls[10]. This problem is more severe for people with limited mobility.

Economic impacts

Extreme heat affects infrastructure and people's livelihoods, leading to substantial economic impacts. Electricity demand is highest during heat waves because so many homes and businesses need to run their air conditioners for longer periods of time, and these machines are less efficient in high temperatures, meaning more power is required to cool a building. Not only does this high demand put the electricity grid at risk, it also increases electricity costs, which can strain budgets.

Concrete road 'buckling' due to heat. Image from: http://www.accuweather.com/en/weather-news/roads-buckle-shatter-in-central-us-amid-june-heat-waves/58223451

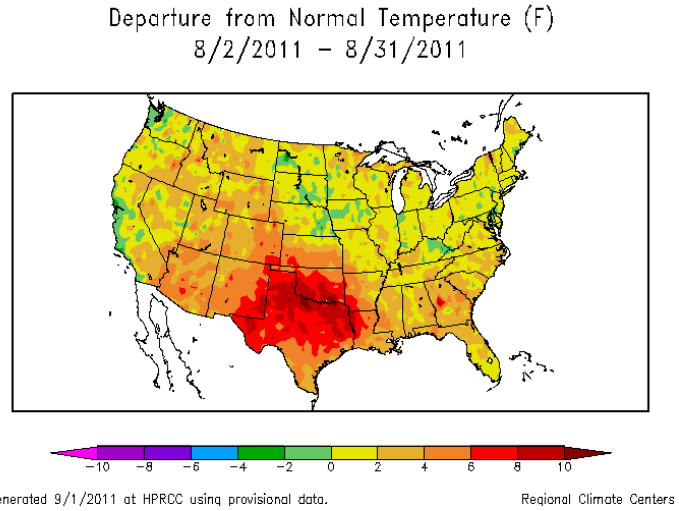
Heat also stresses important infrastructure, like power plants. Power plants are less efficient in hotter temperatures and sometimes must be shut down if the water source they use for cooling becomes too warm. In 2003, a heat wave in France caused river water temperatures to rise to the point that, the equivalent of four nuclear power plants had to shut down [11]. Cables and transformers can fail at high temperatures due to high demand and the stress of heat on grid infrastructure. This can lead to brownouts or blackouts. Blackouts force businesses and industries to shut down, affecting the economy. Blackouts leave residents without air conditioning with potentially disastrous health implications. In 2006, parts of New York City experienced blackouts during a heat wave. High electricity demand and temperatures caused aging underground cables to fail[12]. The heat wave lasted a few days but the resulting power outages lasted a week. Over 100,000 people lost power, affecting businesses and residents. Fortunately, no deaths occurred in areas lacking power[13].

Extreme heat can disrupt transportation infrastructure. Hotter temperatures cause road materials like concrete to expand, causing road surfaces to buckle, and leaving pieces of

[8] Harlan, 2013. https://dx.doi.org/10.1289%2Fehp.1104625
[9] https://www.census.gov/programs-surveys/ahs/data/interactive/ahstablecreator.html
[10] Fraser, 2016. https://dx.doi.org/10.1177/0265813516657342
[11] https://www.theguardian.com/world/2003/aug/12/france.nuclear
[12] http://www.nytimes.com/2006/07/26/nyregion/26network.html
[13] http://www.nytimes.com/2006/11/16/nyregion/16heat.html, http://www.nytimes.com/2006/07/21/nyregion/21cnd-power.html

roadways damaged and unusable. Buckled roads create unsafe driving conditions, slow traffic, and require costly and sometimes lengthy repairs[14]. Heat also affects airports when extremely high temperatures can ground flights because some types of airplanes are not certified to fly above certain temperatures[15].

Agriculture is also affected by extreme heat. Extreme heat can damage crops[16], reduce milk production in cows, and result in the death of livestock and poultry. Heat forces ranchers to provide extra water, shade, and food to their livestock, often at a considerable price, or risk losing livestock to heat stroke. One group of researchers estimated that heat causes billions of dollars in losses every year in the livestock sector alone[17]. Other crops, like wine grapes, nuts, and citrus, are particularly sensitive to extreme heat. In June 2017, walnut farmers in California were forced to use white mineral-based sprays that prevented heat damage to walnut trees[18].



Record heat across Texas and Oklahoma in 2011 contributed to failing crops and livestock losses. From: https://www.ncdc.noaa.gov/monitoring-content/sotc/hazards/2011/08/us-temp-anom-08-2011.png

Record high temperatures dried out soils across Texas in 2011, making an ongoing drought worse and contributing to widespread economic impacts on agricultural and livestock production [19]. Texas' high temperatures and drought reduced cotton yields, contributing to high cotton prices throughout the world. Corn yields also fell by about 20 percent costing Texas corn producers about $327 million[20]. While it's difficult to untangle extreme heat and drought in this case, extreme heat was a major component of Texas's and other states' extreme weather in 2011, which lead to substantial consequences for many people's livelihoods.

Environmental impacts

[14] http://www.accuweather.com/en/weather-news/roads-buckle-shatter-in-central-us-amid-june-heat-waves/58223451 http://wisconsindot.gov/Pages/about-wisdot/newsroom/news-rel/082a-co-dtsd.aspx
[15] http://www.azcentral.com/story/travel/airlines/2017/06/19/heat-cancels-phoenix-flights/409634001/
[16] Lobell and Asner, 2003. http://science.sciencemag.org/content/299/5609/1032
[17] St-Pierre, 2003. http://dx.doi.org/10.3168/jds.S0022-0302(03)74040-5
[18] https://www.cnbc.com/2017/06/27/californias-triple-digit-heat-slows-milk-production-threatens-crops.html
[19] http://www.nytimes.com/2011/10/31/business/energy-environment/catastrophic-drought-in-texas-causes-global-economic-ripples.html
[20] http://today.agrilife.org/2011/08/17/texas-agricultural-drought-losses-reach-record-5-2-billion/

Ecosystems change in response to extreme heat. Extreme heat can stress trees, causing a reduction in leaf area and declines in overall forest health. Extreme heat can cause plants to lose more water to the atmosphere, which can reduce moisture levels in soils and compound the effects of drought[21]. Heat stress can also make trees more susceptible to pests. Pests, dry conditions, and stress on trees, increase the chance of catastrophic wildfires. Wildfires can devastate ecosystems and threaten humans. In the summer of 2017, wildfires brought on by continued heat waves spread throughout western North America and southern Europe, even killing 60 people in Portugal [22].

Rivers and lakes are also affected by extreme heat. Extreme heat can raise water temperatures, stressing fish populations and harming water quality. In the Columbia River Basin, for example, researchers expect a longer season of warm water temperatures in the future. Even slight warming stresses salmon populations. Pockets of warm waters along the Columbia River are lethal to some types of salmon, forcing fish to wait for cooler temperatures in deeper parts of the stream, negatively impacting their breeding patterns[23]. Changes to salmon populations affect people too, as salmon fishermen might have fewer fish to catch. Warmer water in lakes also contributes to water quality problems. As water warms, algae and toxic cyanobacteria can grow more rapidly. Algae blooms can threaten municipal water sources, and kill fish and other aquatic plants and animals.

Plant and animal habitats are also affected by extreme heat. Most directly, some plants and animals can die during heat waves. Thousands of bats died due to record temperatures in Australia in 2017[24]. More indirectly, heat waves and increases in average temperature can push some plants and animals from their current habitat towards cooler areas. This means those plants and animals will be found at higher elevation or farther north.

Section 5: Potential Resilience Strategies for Extreme Heat

Cities will need to plan for extreme heat in the coming decades, and must consider the tradeoffs of various strategies for resilience without complete certainty as to what will occur. Resilience planners around the world are considering a range of strategies that can help to protect cities from the impacts of heat waves on people, infrastructure, and ecosystems.

The following section outlines a select number of possible strategies that can be used to help prepare cities for heat waves. While there are many ways for cities to prepare, this section will give you an overview of some of these options and the social, economic and environmental impacts of each. This information will prepare you to make your own resilience plan for the city

[21] Teskey, 2015. http://dx.doi.org/10.1111/pce.12417
[22] http://www.latimes.com/local/lanow/la-me-ln-red-flag-conditions-california-20170621-story.html, https://www.climate.gov/news-features/event-tracker/early-summer-heat-wave-europe
[23] https://www.climate.gov/news-features/featured-images/warming-climate-will-add-habitat-woes-pacific-nw-salmon
[24] http://www.smh.com.au/environment/animals/thousands-of-bats-drop-dead-from-trees-in-nsw-heatwave-20170213-guc8la.html

that you and your fellow participants will be considering, based on the discussion you will have with your table on the day of the event about the range of possible resilience strategies and their tradeoffs.

COOL THE CITY - Change the built and natural environment to lower temperatures and create shade

COOL THE CITY

COOL THE CITY involves various actions to reduce outdoor temperatures or create shade, such as planting trees and other vegetation to provide shade and cooling, changing hard surfaces to be more reflective, and building shade structures.



ECONOMIC ★★

Trees cost money to plant, maintain, and water but provide other economic benefits, like increasing real estate values. Strategies to modify roofs and other hard surfaces ranges from inexpensive coatings to green roofs that require substantial construction and expense. Shade structures also vary in cost depending on size and materials used.

ENVIRONMENTAL ★★★★★

A cooler landscape benefits plant and animal communities. Some trees and vegetation improve air quality, provide habitat for animals, clean stormwater, and provide a buffer against urban flooding. Replacing roofs and other heat-absorbing surfaces with vegetation can provide similar environmental benefits.

SOCIAL ★★★

Cooling outdoor landscapes allows people to be outside on more days and reduces the risk of heat-related illness. Trees and greenspace are associated with psychological well-being. Some urban greening programs have been linked to the displacement of poor residents. Construction for shade structures and replacing hard surfaces can be disruptive to residents and businesses.

Read through this box to learn more about the Cool the City strategy. You will use this information during your discussions at the forum.

One way to address the impacts of extreme heat is to take actions that make the environment cooler. In cities, this can mean planting more trees, building shade structures, or changing hard surfaces that contribute to the urban heat island effect.

Trees and vegetation cool the urban landscape in two ways[25]. First, trees provide shade, which keeps people cooler and prevents concrete and asphalt from absorbing heat from the sun. Second, trees and vegetation cool the air through evaporation. Much like sweat cools people, water from tree leaves absorbs heat from the air as it evaporates, making the air cooler. Cooling due to evaporation is stronger in dry climates than in more humid climates. Trees provide other services too, like stormwater control, and are often associated with higher property values. Of course, using trees to cool the city requires water and maintenance. Trees can also pose a hazard during other extreme weather events like thunderstorms. Damage to utilities, either from falling branches that take down power lines or from roots that damage water and sewer pipes, is another potential cost associated with planting trees to cool the city.

[25] https://www.epa.gov/sites/production/files/2014-06/documents/treesandvegcompendium.pdf; Nowak, 2002. https://www.nrs.fs.fed.us/units/urban/local-resources/downloads/Tree_Air_Qual.pdf.

Trees aren't the only things that create shade in cities. Awnings, shade structures, and even solar panels can create shade to keep people cool. Built shade structures require less upkeep than trees but do not provide cooling from evaporation. However, large shade structures can be expensive to build up front and may require disruptive construction.

Buildings and roofs, concrete, and asphalt all absorb heat from sunlight and release it back into the air, warming air temperatures. Changing these materials, either through light-colored coatings or by replacing them, can help reduce local temperatures. For example, light-colored roof coatings reduce heat absorbed by a building, helping to keep temperatures a bit lower and lower energy use. Green roofs, which are roofs with plants covering them, also cool the local environment and provide added insulation to a building. Concrete and asphalt used for roadways, parking lots, and sidewalks can be made lighter in color using various additives to combat the urban heat island effect[26]. These changes can range in price from relatively inexpensive roof coatings to more expensive undertakings like replacing road surfaces or parking lots with light-colored materials. One downside of changing hard surfaces is that the impact of changes on how comfortable people feel is low compared to creating shade.

PROTECT INFRASTRUCTURE – Protect key infrastructure from damage due to heat waves

"Protect Infrastructure" strategies involve upgrading transportation, electricity, and communication infrastructure to prevent, or lessen the impact of, damage from heat waves. Electricity, transportation, and communication infrastructure are key to public safety and business.

To prevent blackouts or brownouts, cities can replace aging transformers and cables, investing in new power sources that are more reliable during extreme heat events, and implement programs to reduce electricity demand during extreme heat events [27]. Replacing transformers and cables can be expensive and require extensive construction, particularly if cables reside underground. Building new power sources can also be very expensive. Depending on the type of power source, there might be additional costs with new power sources. Coal, oil, or gas-fired power plants contribute to air quality problems and use a lot of water for cooling. Solar, wind, or other renewables can lessen environmental impacts of electricity generation but are not always available when needed. There are also ways for residential and commercial properties to make sure they are ready for heat waves. Residents and businesses can increase energy efficiency through weatherization or investing in more efficient air conditioning units and appliances. Weatherization includes replacing insulation, repairing leaky windows and doors, and replacing windows. Improving energy efficiency saves home and business owners money in the long term but weatherization and new air conditioning units can be expensive up front. These measures decrease demand for electricity, helping to keep the grid stable during an extreme heat event.

[26] https://www.epa.gov/heat-islands/heat-island-compendium

[27] http://www.nypa.gov/services/customer-energy-solutions/demand-response, http://www.flexalert.org/what-is-flex-alert, Aivalioti, 2005. http://columbiaclimatelaw.com/files/2016/06/Aivalioti-2015-01-Electricity-Sector-Adaptation-to-Heat-Waves.pdf

To lessen the impact of blackouts and brownouts, cities can prepare key community buildings with back-up generators. Back-up generators allows schools and community centers, to run air conditioning and other vital services during a black out, which creates a cool and safe place for the community. Hospitals and other emergency services can also use back-up generators. While back-up generators provide power in an emergency, they are expensive to purchase and install. Further, a school or community center with a back-up generator can only provide for so many people. A large blackout would still leave some vulnerable to the impacts of a heat wave.

Transportation infrastructure, like roads and bridges, can also be made more resilient to heat waves by making changes to concrete and asphalt that prevent buckling, and by making changes to bridges that prevent excess stress from heat. Protecting transportation infrastructure ensures that people, goods, and emergency services can move around the city. Protecting transportation infrastructure, however, is expensive and requires extensive construction that can cause significant disruptions to traffic.

PROTECT INFRASTRUCTURE

PROTECT INFRASTRUCTURE involves solutions that limit the impact of extreme heat on roads, electricity grids, and buildings. These solutions include replacing transformers and power lines; repairing bridges, roads, and runways; and protecting infrastructure from heat-related threats like wildfires.



ECONOMIC ★★★★

More resilient electricity and transportation infrastructure is critical to economic activity. However, protecting and upgrading electricity grids, roads, and other infrastructure involves expensive construction that can be very disruptive to residents. Building energy efficient buildings can require extensive construction but saves money in the long run.

ENVIRONMENTAL ★★

Construction and upgrades to electrical grids, roads, and other infrastructure have little environmental impaction outside disruptions from construction like removal of trees or dust problems. Building new power plants can be environmentally damaging depending on the type of power plant. Weatherization efforts that reduce electricity demand can reduce local pollution from coal, gas, and oil power plants.

SOCIAL ★★★★

Protecting electricity grids ensures that residents have access to key services, like air conditioning and refrigeration. Safeguarding transportation systems keeps people connected to one another, stores, and key services. Preventing the loss of structures reduces the social toll of wildfires.

Read through this box to learn more about the Protect Infrastructure strategy. You will use this information during your discussions at the forum.

ENSURE SAFETY – Protect vulnerable populations from exposure and health impacts of extreme heat

While the "Cool the City" and "Protect Infrastructure" strategies focus on changes to the landscape, buildings, and infrastructure, the "Ensure Safety" strategy directly keeps people safe during heat waves. A variety of strategies can be employed to ensure safety. These include cooling centers, air conditioning and utility assistance, door-to-door check-in programs, and heat warning systems and hotlines.

Cooling centers provide a safe place for people to go during a heat wave. Libraries, schools, homeless shelters, community centers, and even private businesses can function as cooling centers. Cooling centers can be open to anyone but generally target people who otherwise lack a cool place to go, such as residents without air conditioning or homeless populations. Cooling centers can be run by private or public organizations. Either way, cooling centers require staff and supplies, like cold water and snacks, to operate. Keeping cooling centers open at night requires further resources. Using libraries, schools, or businesses as cooling centers also limits regular functions of those places.

ENSURE SAFETY

ENSURE SAFETY involves solutions that protect people's health and well-being during heat waves by keeping them cool and prepared. These solutions include cooling centers, heat warning systems, community wellness check programs, limits on outdoor activities, and increasing access to air conditioning.



ECONOMIC ★★★

Running cooling centers and wellness check programs across the city requires man power and resources, though volunteers and donations can reduce costs. Reducing heat-related illness can prevent expensive healthcare costs. Air conditioning and utility assistance programs can be quite expensive depending on their size. Outdoor work day limits could impact construction, landscaping, and other outdoor businesses.

ENVIRONMENTAL ★★

Heat warning systems, wellness check programs, and cooling centers have little environmental impact. Air conditioning and utility assistance programs could increase electricity use and the environmental impacts of electricity use.

SOCIAL ★★★★★

Heat warning systems and wellness check programs help people stay safe during dangerous heat. Cooling centers and air conditioning assistance programs help people stay cool, reducing the risk of heat-related illness. Outdoor work limits reduces heat exposure for workers.

Read through this box to learn more about the Ensure Safety strategy. You will use this information during your discussions at the forum.

While cooling centers are very effective in preventing heat-related illness, people first need to get to them. Transportation issues, particularly for the homebound or elderly, sometimes prevent residents from using cooling centers, though some cities hope to partner with taxi, ride share, and other transportation companies to alleviate this problem. The stigma of going to a center can also deter some cooling center visitors. Some people with pets do not go to centers because many cooling centers don't accept them. Finally, many people do not know the location of the nearest cooling center or that they exist at all.

Air conditioning and utility assistance programs help those without air conditioning, or who cannot afford to repair or run it, purchase and run air conditioning. These programs utilize grants for low-income residents to purchase and repair air conditioning units and pay utility bills. Many states have existing utility assistance programs to help low-income residents pay electricity bills but funding is limited and some people who need assistance do not receive it. However, these programs often lack assistance for those who don't have air conditioning, meaning those without air conditioning and who cannot afford it have few ways to get it. Air conditioning and utility assistance programs come with tradeoffs. They tend to increase electricity use, which

could stress electricity grids and these programs fail to address leaky windows and doors that can drive up air conditioning costs.

A community-oriented strategy is door-to-door check-in programs. Check-in programs rely on volunteers and/or public safety officers who go door-to-door to check on residents who might be vulnerable to the impacts of a heat wave, such as the elderly, homebound, or residents without air conditioning. Checks before, during, and after a heat wave ensure that residents are drinking cold water and are using their air conditioning (if available). Volunteers can help residents find a cool place for them to stay if needed, or call for help in case of an emergency. These programs require many people to be effective, though community groups and volunteers can reduce the cost of these programs.

Now that you know how extreme heat affects communities and you're familiar strategies to reduce those impacts, think about which impacts you're concerned about and the strategies you prefer. At your upcoming forum event, you will use this knowledge, along with your values and ideas, to collaborate with peers on creating a resilience plan for extreme heat.

Section 6: Participant Role and Preparation for the Event

The forum you are participating in will be used in eight science museums across the country. Each museum will recruit participants with a wide array of demographics, values, and ideas to create a space that reflects who the people are that live in the region and will be affected by the climate hazards being discussed.

As a participant in this forum, you will be asked to share your opinions, discuss your ideas, and collaborate with your table to make a resilience plan for the city. The first two sessions of the day will involve a fictional city that is grappling with creating a climate resilience plan for one of the hazards you will be discussing. Each fictional city is based on a real place that is currently thinking about ways to become more resilient against the chosen hazard. We chose to use fictional cities in order to create a replicable and unbiased program that can be used in many places around the country and remain relevant to the people who live there. During the last session of the day, you will be able to discuss a topic that is important to city planners who live in your region. This will allow you and your table to think of ideas and options for a resilience planning process that affects your region, and then relay that information to local planners.