NEW LEGACIES: EXAMINING THE IMPACTS OF INCREASING TEMPERATURES AND ENERGY BURDEN IN AMERICA'S LEGACY CITIES

by

Maggie Cooney, Shwetha Govindan, & Renee Magyar

A project submitted

in partial fulfillment of the requirements

for the degree of

Master of Science

(Environment and Sustainability)

at the University of Michigan

April 2025

Project Advisor: Professor Larissa Larsen

TABLE OF CONTENTS

CHAPTER 1: LITERATURE REVIEW....1

Introduction....1

Defining Extreme Heat....2

Heat Risk and the Urban Heat Island Effect....3

Urban Heat Islands....3

Urban Heat Island Effect on Climate Change....4

Urban Heat Island Effect in Legacy Cities....4

Urban Forest Canopy and Indoor Temperatures....5

Climate Change Effects on Summer Temperatures in Midwest Cities....5

Housing Effect on Extreme Temperatures....6

Health Impacts of Heat Exposure in Legacy City Residents....7

Energy Poverty and Exacerbation of Heat Vulnerability....9

Utility Poverty and Energy Burden....9

Assessing Vulnerability and Coping Mechanisms....10

Power Outages and Grid Vulnerability....10

Overview of the U.S. Electricity System....10

Impact of Extreme Weather on Electricity Systems....11

Impact of Grid Failure on Indoor Temperatures....11

Implications of Long-Duration Power Outages....12

CHAPTER 2: METHODOLOGY....13

LEGACY CITY PROFILES....14

Cincinnati....15

Cleveland....17

Detroit....19

Milwaukee....21

Summary of Key Demographics....23

Comparison of Legacy Cities to MSAs....25

RESEARCH QUESTIONS....29

STATISTICAL METHODS....32

CHAPTER 3: RESULTS I....33

AHS Research Results....36

CHAPTER 4: DISCUSSION....40

Limitation: Level of Geographic Analysis....40

Implication: Skewed Results....40

Limitation: Small Data Set....40

Interpretation of Results....42

CHAPTER 5: CONCLUSION....43

ABSTRACT

Extreme heat is increasingly plaguing urban environments, placing vulnerable urban populations at disproportionate risk of heat illness and energy burden. This study investigated differences in heat risk and discomfort due to extreme heat and cooling problems, and related consequences of power outages across four legacy cities: Cincinnati, Ohio, Cleveland, Ohio, Detroit, Michigan, and Milwaukee, Wisconsin. Our overarching research questions were: 1) How many people have access to air conditioning (AC)?; 2) How many people are experiencing heat burden (thermal discomfort)?; 3) To what degree is AC used as a coping mechanism?; 4) How is cooling ability impacted by grid failure?; and 5) What are reported health impacts due to loss of AC, such as visits to the ER? For each city, we examined Public Use File microdata available at the metropolitan statistical area (MSA) level from modules newly added to the 2023 American Housing Survey on heat risk, cooling problems, and power outages. We used contingency tables to correlate presence and functional status of AC with reported discomfort due to indoor heat or power outage, household behaviors of limiting use of AC due to cost, and visits to the emergency room due to indoor heat. The results showed that 87.87 to 96.5% of households had access to AC. Cleveland and Detroit had the highest proportion of residents lacking access, at 10.28% and 12.13% respectively. Between 6.24% and 8.26% of the MSAs experienced heat burden, with Cleveland (7.49%) and Detroit (8.26%) at the upper range. Coping-related results showed that access to AC did not guarantee protection from extreme indoor temperatures, energy costs did not greatly impact the use of AC, and effectiveness of AC was contingent on the home's energy efficiency. 21.55% of Detroit households experienced power outages compared to 14.56% to 15.13% of residents in the other three MSAs. Power outages caused spoiled food, loss of refrigerated medicine, disruption to electric medical devices, displacement, and lost work. Cleveland reported the highest percentage of respondents requiring hospitalization due to heat (1.09%), followed by Cincinnati (0.98%), Milwaukee (0.94%), and Detroit (0.76%).

ACKNOWLEDGEMENTS

Our team would like to acknowledge the effort, commitment, and guidance our advisor, Professor Larissa Larsen, has given to our team. Without her grace and expertise, especially on the topic of exposure risks of extreme heat, this project would not have been possible.

We also wish to acknowledge the SEAS Detroit Sustainability Clinic for their enduring support of our research into extreme heat and energy burden, and other symptoms of climate change affecting Detroit residents.

Thank you

CHAPTER 1: LITERATURE REVIEW

Introduction

The purpose of this research is to explore the experienced heat burden in four of America's legacy cities, paying particular attention to how cooling problems, power outages, and the socio-economic conditions of the legacy cities compound heat risk. As climate change causes temperatures in the Midwest United States to increase and occurrences of heat waves to increase, the importance of understanding the impacts of increased heat on human health is also increasing.

Legacy cities are of particular concern due to their history of economic decline, their subsequent disinvestment in urban centers, their aging housing stock, and their relatively high percentage of vulnerable communities facing known impacts of the urban heat island effect.

The data used from the 2023 American Housing Survey was chosen for its inclusion of heat risk, cooling problems, and power outages, which ideally would allow for a more detailed perception of experienced heat burden as it relates to indoor temperatures and the use of AC as a coping mechanism. While the study was able to discern initial patterns of importance, the available data was collected at the metropolitan statistical area level, rather than at the legal city level, and therefore reflects households' experiences across a larger area, including wealthier suburbs. In this study, legacy city geography and legal city boundaries are used interchangeably.

In the first section of the literature review, we summarize challenges inherent with defining extreme heat events. Extreme heat lacks one standard definition and is complicated by the differing input used to calculate heat indices (Kent et al., 2014). In the second, third, and fourth sections we summarize the impacts of the urban heat island, paying particular attention to legacy cities. The urban heat island refers to the temperature difference experienced between urban and rural areas, and there are a great number of ways to mitigate this effect (Stone, 2012; Stone & Rodgers, 2001). The fourth section summarizes the impacts of tree canopy on indoor air temperatures. The fifth section summarizes the predicted increase in temperature for the Midwest region of the United States where the four legacy cities chosen for this study are located. Temperatures in the Midwest are expected to increase over the next century, as are the frequency of heat waves (Anderson & Bell, 2011; Kunkel et al., n.d.). The sixth section identifies how differing housing characteristics can impact experienced heat burden. Presence of AC, regular building maintenance, and degree of housing quality all contribute to extreme indoor heat (Gronlund & Berrocal, 2020). The seventh section looks at the health impacts associated with extreme heat, identifying children, seniors, pregnant women, and those with pre-existing health conditions as the most vulnerable to heat-related illnesses (Lin et al., 2009; Lavigne et al., 2014). In the eighth section, we summarize the potential of energy burden to exacerbate heat burden. Energy burden is apparent when households are forced to choose between basic necessities as a result of the high cost of utilities, such as heating and cooling, which has the potential to reduce

the effectiveness of AC as a coping mechanism for extreme heat (Reames, 2016). The ninth section summarizes different coping mechanisms used by energy-insecure homes to maintain comfortable temperatures. Energy-insecure households engage in a multitude of behaviors to manage indoor temperature, some of which are riskier than others (Carley et al., 2022). The tenth and eleventh sections summarize the U.S. electrical grid and how extreme heat impacts the system. Extreme heat decreases the efficiency of the electrical system, leading to grid disruption during times of increased demand (Zamuda et al., 2023; Bartos et al., 2016). The twelfth section summarizes the impacts of power outages on indoor air temperature, citing how the loss of other power can disrupt the ability of individuals to utilize AC as a coping mechanism (Stone et al., 2021). The final section summarizes health concerns associated with the concurrence of a heat wave and electrical grid outage. Such an event would increase risk of exacerbating heat-related illnesses, specifically in populations with increased levels of pre-existing conditions (Vaidyanathan, 2020).

Defining Extreme Heat

As global temperatures rise in the changing climate, extreme heat events, or heat waves, are increasingly plaguing urban environments, with disastrous results. Heat waves are the leading weather-related cause of human mortality in the U.S., responsible for more deaths annually than hurricanes, lightning, tornadoes, floods, and earthquakes combined (Luber & McGeehin, 2008; CDC, 2004; CDC, 2020; NOAA, 2023).

Heat waves can be caused by stagnant moist air being trapped on the Earth's surface by high atmospheric pressure, which is a natural phenomenon referred to as a heat dome. Such conditions exacerbate discomfort and are increasingly common in urban areas (CDC, 2004; NOAA, 2023).

Despite the pervasiveness of extreme heat, there is no universally accepted or used definition to identify a heat wave. The lack of a distinct definition has been attributed to the variety of different stakeholders who engage with the study of heat waves, each of whom has their respective purposes (Smith et al., 2013). One notable difference exists between climate scientists who generally focus on historical mean temperature data in comparison to health researchers who have a greater interest in aspects of human well-being as it pertains to heat waves (Smith et al., 2013).

Differing interests have led to the inclusion of differing variables used to establish heat indices, which are defined using temperatures alone or temperatures in addition to other meteorological factors such as humidity and wind speed (Kent et al., 2014). In addition to stakeholder interests, the difference in climate patterns, housing characteristics, urban and rural land uses, vegetation patterns, and acclimation of a population greatly determine the applicability of a particular heat index (Kent et al., 2014).

Within the complexity of defining particular heat indexes and subsequently heat waves, there are characteristics common to most definitions. Such characteristics include still, hot air and consecutive nights with high minimum temperatures (Luber & McGeehin, 2008). According to the United States Center for Disease Control (CDC), "...most definitions refer to an extended period of time—several days up to several weeks—with unusually hot weather conditions—temperatures that hover 10 degrees or more above the average high temperature for the region (*CDC Extreme Heat | A Prevention Guide to Promote Your Personal Health and Safety*, n.d.). Additionally, such conditions can potentially harm human health". The CDC previously published the following definition:

> "Extreme heat or heat waves occur when the temperature reaches extremely high levels or when the combination of heat and humidity causes the air to become oppressive" (*Beat The Heat: Extreme Heat*, n.d., p.1).

By contrast, the National Weather Service defines a heat wave as, "...a period of abnormally hot weather generally lasting more than two days" (US Department of Commerce, n.d.).

Heat Risk and the Urban Heat Island Effect

Urban Heat Islands

Urban development and deforestation contribute significantly to the accumulation of excess heat energy in urban and suburban areas, elevating the average temperature of cities several degrees above that of surrounding non-urbanized regions (Oke, 1982; Larsen, 2023; Phelan, 2015; Stone, 2012). This phenomenon, known as the urban heat island (UHI) effect, has profound environmental and societal implications, influencing air quality, energy consumption, and overall climate trends.

UHI occurs due to 1) loss of vegetation and pervious surfaces; 2) abundance of man-made materials and impervious surfaces that attract, store, and re-emit heat; 3) restricted air flow between buildings; and 4) waste heat from vehicles, industrial processes, and mechanical cooling systems (Stone, 2012; Phelan et al., 2015).

Phelan et al. (2015) found direct impacts of UHI on daytime and night-time temperatures, and indirect impacts including increased air conditioning (AC) loads, deteriorated air and water quality, and exacerbated heat waves.

The design of cities plays a critical role in exacerbating or mitigating UHI effects, as urban form directly affects thermal efficiency (Stone & Rodgers, 2001). One of the most concerning consequences of UHI is its impact on air quality. The elevated temperatures accelerate the formation of ground-level ozone, a toxic pollutant that poses significant health risks. Additionally, the increased demand for AC in response to higher urban temperatures leads

to greater energy consumption, resulting in higher carbon emissions and financial costs associated with electricity production.

Urban Heat Island Effect on Climate Change

Measuring the contribution of urban heat islands to global climate change presents a complex challenge. Urban warming trends are highly localized, varying between cities and their adjacent rural areas, making it difficult to quantify their overall impact on global temperature rise. Parker (2010) examined the effect of UHI on land surface air temperature (LSAT) and found that its contribution to global warming is relatively small, accounting for less than 0.74°C of the observed temperature increase between 1906 and 2005. While this suggests that UHI alone is not a primary driver of global climate change, its localized effects remain significant, necessitating targeted mitigation strategies.

Recent research has further explored the relationship between UHI intensity, air temperature, and precipitation in large cities worldwide. Li et al. (2020) found that the correlation between UHI and air temperature varies depending on local climate conditions and the vegetation differences between urban and rural areas. However, a more stable relationship exists between UHI and precipitation. Higher precipitation levels tend to amplify the UHI effect, particularly at night, likely due to increased soil moisture differences between urban and rural environments. This highlights the critical role of precipitation in shaping UHI intensity, especially in urban areas with limited vegetation cover. Understanding these complex interactions is essential for developing climate-responsive urban planning strategies that incorporate green infrastructure and other mitigation measures to counteract the adverse effects of UHI.

Together, these findings emphasize the need for comprehensive urban design and policy interventions to address the growing challenges posed by the UHI effect. Incorporating vegetation, improving thermal efficiency in building materials, and optimizing city layouts can help reduce heat accumulation and mitigate its negative consequences on air quality, energy demand, and climate resilience. By acknowledging the localized nature of urban heat islands while also considering their broader implications, cities can implement more effective strategies to promote sustainable and livable urban environments.

Urban Heat Island Effect in Legacy Cities

Legacy post-industrial cities, including Cincinnati, OH, Cleveland, OH, Detroit, MI, and Milwaukee, WI face unique heat risk challenges due to their urban form, infrastructure, and socioeconomic conditions.

Urban form was shaped in part by redlining practices of the 1930s through 1960s, followed by disinvestment in poor neighborhoods. Lasting effects include highways constructed through poor and minority communities. These communities are also more likely to live in areas

with fewer trees and more impervious surface, both of which lead to higher temperatures (Wilson, 2020).

Between 1950 and 2010, Detroit lost about 61% of its population along with lost job opportunities leading up to an economic crash and bankruptcy in 2013 (Merry, 2014). “White flight” to the suburbs in the early 1950s greatly impacted Detroit and other Midwest industrial cities where it was happening rapidly, such as Cleveland and St. Louis, MO (Dilworth, 2019). Dilworth (2019) also notes in the 1970s, many Black families with financial means moved to the suburbs, although in smaller numbers. The majority of residents remaining in disinvested neighborhoods were close to or below the poverty threshold (Dilworth, 2019; Wilson, 2020).

Wilson (2020) found “thermal inequity” in disinvested areas of Baltimore, MD, Dallas, TX, and Kansas City, KS. Areas of these cities that suffered from disinvestment showed higher mean surface temperatures.

Urban Forest Canopy and Indoor Temperatures

Between 1950 and 1980, Detroit experienced significant street tree canopy loss due to Dutch elm disease, followed by emerald ash borer infestations (Merry, 2014). As many as 500,000 trees were lost during that time (American Forests, 2012).

In the early 2000s, Buffalo, NY had a 12% tree canopy coverage (Groundwork Buffalo, 2009; Magavern, 2007).

Trees affect microclimates surrounding structures by providing shade, shielding wind, and emitting moisture (Larsen et al., 2023). In a study comparing houses in Los Angeles, CA with more or fewer trees, de Guzman (2023) found homes with more trees experienced lower indoor daytime temperatures. However, night time temperatures were not equally affected. Stone et al. (2023) found that street trees reduced heat-related mortality by an average of 20% across the cities in their study, Phoenix, AZ, Atlanta, GA, and Detroit. Urban trees have been found to help reduce the demand for cooling energy which could reduce energy burden for homes running AC while also reducing carbon dioxide emissions from power plants (Akbari et al., 2001).

Climate Change Effects on Summer Temperatures in Midwest Cities

The Midwest region is generally used to refer to the states of Illinois, Iowa, Indiana, Michigan, Minnesota, Missouri, Ohio, and Wisconsin. However, some sources may include different combinations of states in their definitions of the “Midwest.”

Over the last century, the average Midwest air temperature has been increasing at an accelerated pace (Anderson & Bell, 2011). From 1900 to 2010, the average Midwest air temperature increased by more than 1.5℉ (Anderson & Bell, 2011). However, given the geographic variations of Midwestern states, differences arise in particular predicted trends for specific areas of the Midwest (Anderson & Bell, 2011). As a result, the greatest temperature

difference is predicted to occur in the northern latitudes of the Midwest, while the highest temperatures will be felt in the lower latitudes of the Midwest (Anderson & Bell, 2011).

Predicted middle-of-the-century and end-of-the-century temperatures for the Midwest are dependent on future carbon dioxide emissions reductions (Anderson & Bell, 2011). By the middle of the century, the predicted increase in average temperature is 3.8℉ if there is substantial emissions reduction, or 4.9℉ if there is a continued growth in global emissions (Anderson & Bell, 2011). By the end of century, the predicted increase in average temperature is 5.6℉ if there is substantial emissions reductions, or 8.5℉ if there is continued growth in global emissions (Anderson & Bell, 2011).

The predictions for summer temperatures also depend on differing geographical locations within the Midwest (Wuebbles & Hayhoe, 2004). Overall, the greatest increase in regional warming has occurred during the summer and fall months in the past three decades (Wuebbles & Hayhoe, 2004). This is in contrast to the previous years where winter and spring experienced the greatest increase in regional warming (Wuebbles & Hayhoe, 2004). The Great Lakes region in particular is expected to experience an increase of 3℃–6℃ in daily average maximum temperature by the end of the century (Wuebbles & Hayhoe, 2004). However, the greatest change in temperature is expected to occur over the southern and western parts of the Midwest (Wuebbles & Hayhoe, 2004). Additionally, researchers expect there to be 5 to 30 more days per year with a maximum temperature exceeding 95℉ by the middle of the century, with southern states accounting for the higher end of the range (Kunkel et al., 2013). Lastly, researchers predict there will be more occurrences of consecutive periods of 95℉ temperature or greater (Kunkel et al., 2013).

Housing Effect on Extreme Temperatures

Housing can play an important role in mediating extreme temperatures. Presence of AC, regular building maintenance, and degree of housing quality have a significant impact on indoor thermal comfort and health outcomes in extreme heat events. Central and room AC can effectively lower indoor temperatures during heat waves, enhancing thermal comfort and reducing health risks. However, effectiveness varies depending on the type and availability of the system, with central AC typically offering more consistent cooling than room units (Gronlund & Berrocal, 2020). AC units are often underutilized in low income households due to high utility costs and other economic constraints leading to higher indoor temperatures and health risks (Williams et al., 2019).

Proper insulation and design has the potential to mitigate the effects of extreme temperatures. Loughnan and Tapper (2015) find significant differences in indoor temperatures related to the age of the house, air conditioning units, pitch of the roof and home insulation. Poor housing quality plays a significant role in the risk of heat exposure during extreme weather. A study by Ahrentzen, Erickson, & Fonseca (2016) found that energy retrofits in affordable

housing units showed a significant stabilization of unit temperatures and improvement in occupants' health.

Routine maintenance and the use of passive cooling strategies, such as night ventilation, shading, and improved roofing, can strengthen a building's resilience to heat. These approaches help decrease dependence on air conditioning and reduce energy costs. Community-driven programs aimed at enhancing housing quality and maintenance can help reduce the negative impacts of extreme temperatures, particularly for children and the elderly (Howden-Chapman et al., 2023).

Health Impacts of Heat Exposure in Legacy City Residents

Temperature extremes, especially extreme heat, have a direct impact on health by disrupting the body's ability to regulate internal temperature. When this regulatory system fails, it can trigger various conditions including heat cramps, heat exhaustion, heatstroke, and hyperthermia during extreme heat events. These temperature extremes also exacerbate existing chronic conditions like cardiovascular, respiratory, and cerebrovascular diseases, as well as diabetes-related conditions (Lin et al., 2009; Lavigne et al., 2014). Research shows that extended exposure to high temperatures correlates with increased hospital admissions for cardiovascular, kidney, and respiratory disorders. Additionally, high minimum temperatures can impair the body's ability to recover from daily maximum temperature exposures (Anderson & Bell, 2011).

Direct attribution studies that examine the health effects of heat often tend to underestimate the actual number of deaths due to extreme temperatures. This is often due to the fact that medical records do not need to include information on weather conditions and the lack of diagnostic criteria to determine whether heat had an impact on a pre-existing condition such as cardiovascular disease (Sarofim et al., 2016). Statistical studies on the other hand, help establish associations between temperature extremes and increase in premature deaths and illnesses. Different methodologies have made comparison of mortality estimates difficult due to varying criteria, time periods examined, and variation in analytical approaches. An important caveat to note is that in both direct attribution and statistical methods, temperature data is based on weather station data, which may not accurately reflect individuals' exposure to heat in their houses or neighborhoods (Sarofim et al., 2016).

Heat-related mortality has been documented in cities such as Philadelphia, PA in 1993 and 1994, Chicago, IL in 1995, and in California as recently as 2006 (CDC, 1994; CDC, 1995). Most regional and national studies conclude that extreme heat results in premature deaths; some statistical studies estimate that more than 1300 deaths per year are heat-related in the U.S. (Kalkstein et al., 2011). The 1995 Chicago heat wave had a deadly combination of high humidity, and high daily maximum and nighttime temperatures, which resulted in 736 attributable deaths. In their study in the American Journal of Public Health, Kaiser et al. (2014), argue that while 26 percent of the deaths were attributed to mortality displacement—deaths that

would have occurred shortly thereafter regardless of the heat wave—the most vulnerable and high risk community, Black residents, had substantially lower mortality displacement levels. This suggests that many of these deaths were not simply accelerated deaths of already vulnerable individuals and can be directly attributed to extreme heat. The figure below illustrates excess deaths reported during the 1995 Chicago Heat Wave.

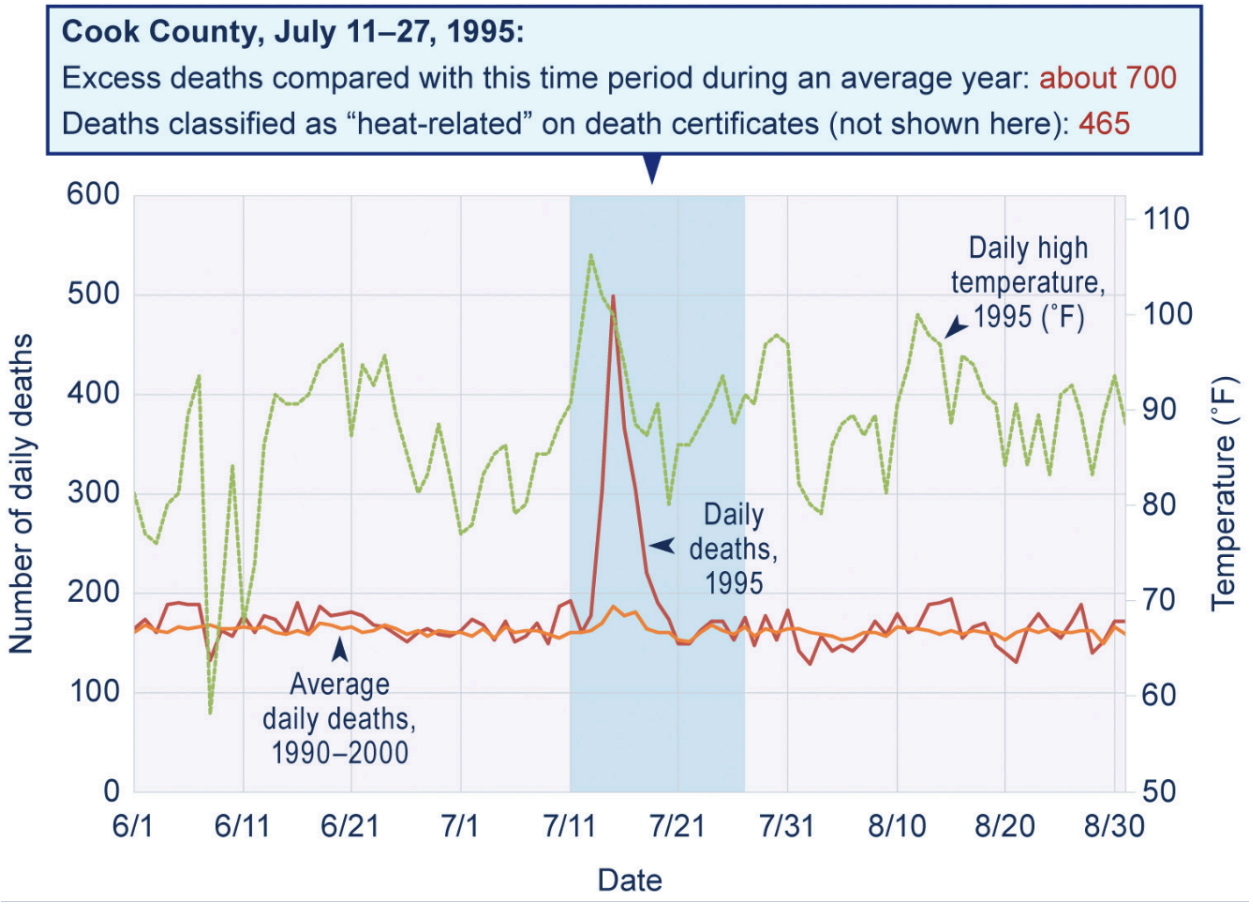


Figure 1. Source: EPA, 2014: Climate Change Indicators in the United States, 2014. 3rd edition. EPA 430-R-14-04, 107 pp. U.S. Environmental Protection Agency, Washington, D.C.

Extreme heat has a disproportionate effect on certain vulnerable populations, with the main populations of concern being children and the elderly. Older adults face higher mortality risks during extreme temperatures and are particularly vulnerable when they have preexisting conditions, take medications affecting thermoregulation (beta-blockers, major tranquilizers, diuretics), live alone, or have limited mobility (Madrigano et al., 2013). Children on the other hand are susceptible to dehydration, electrolyte imbalance, fever, renal disease, heat stress, and hyperthermia during extreme heat, (Xu et al., 2012) especially due to physiological factors such as inefficient thermoregulation, reduced cardiovascular output, heightened metabolism. Another

population of concern is pregnant women; studies show that heat events were associated with adverse birth outcomes including low birth weight and infant mortality (Basu et. al, 2010).

Urban environments pose particular challenges during temperature extremes due to the urban heat island effect which intensifies temperature extremes and limits nighttime cooling relief (Stone et al., 2010). This effect, combined with urban land cover characteristics and poor air quality, further amplifies temperature impacts on city residents (Anderson & Bell, 2011; Harlan et al., 2013). Socioeconomic factors also significantly influence vulnerability, with homeless populations experiencing increased exposure to temperature extremes (Cusack et al., 2013), while race, ethnicity, and socioeconomic status affect overall vulnerability to heat and cold events (Gronlund, 2014). Studies have consistently shown Non-Hispanic Black individuals face heightened risks during extreme temperature events (Kaiser et al., 2007; Basu, 2009). These vulnerabilities are further compounded by social isolation, underlying health conditions, and limited access to protective resources like air conditioning or adequate healthcare (Klinenberg, 2015; Sampson et al., 2013).

Energy Poverty and Exacerbation of Heat Vulnerability

Utility Poverty and Energy Burden

Fuel poverty (energy poverty or energy insecurity), refers to the "inability of households to afford energy services for adequate heating and cooling resulting in uncomfortable indoor temperatures, material deprivation, and accumulated utility debt" (Reames, 2016, p. 549). The consequences of fuel poverty result in afflicted households making trade-offs between adequate cooling or heating of their homes and other basic necessities such as food, medicine, and childcare ("Energy Burden," 2020). Furthermore, not paying utility bills on time can result in high financial penalties, eviction, and utility shut-offs (Finnigan, 2018).

Fuel poverty is measured by the proportion of household gross income that is spent on home energy costs, a metric referred to as energy burden (Reames, 2016). However, Reames (2016) acknowledged that an accurate measure of fuel poverty should take a "relational approach," where energy policy, housing infrastructures, and lived experience of the fuel poor are taken into account, in addition to income. A heating energy burden over 2% is considered unaffordable (Reames, 2016). Additionally, it is widely accepted and studied that low-income households experience a disproportionate energy burden. The national average energy burden for low-income households is 8.6%, which is three times higher than the energy burden for non-low-income households (Energy Burden, 2020). African American communities experience an energy burden 64% greater than white communities, and Latino communities experience an energy burden 24% greater than white communities (Energy Burden, 2020).

It is important to note that "...all else being equal, low-income households consume less energy than non-low-income households" (Reames, 2016, p.550). Therefore, a higher energy

burden should not be used as an indication of a household's behavioral tendencies regarding electricity. Instead, poor energy efficiency has been used as not only an intervention, but also a reason for disproportionate energy burdens (Reames, 2016).

Assessing Vulnerability and Coping Mechanisms

Energy-insecure households engage in four main types of coping strategies including behavioral, financial, assistance, and bill strategies (Carley et al., 2022). The most common coping strategy utilized by 32% of energy-insecure households is financial strategies, wherein households partake in "carrying debt across utility bills," skipping payments until the consequences become severe, or sacrificing the payment of other bills (Carley et al., 2022, p.3). The second most common coping strategies, behavioral strategies, vary in their level of health risk (Carley et al., 2022). Overall about 26% of energy-insecure households engage in risky behaviors including use of space heaters, fireplaces, ovens, dryer vents, or trash burning to generate heat (Carley et al., 2022). While these behavioral coping strategies refer only to heating problems, they suggest individuals would engage in similarly risky behaviors in order to reduce temperature. The third most common coping strategy, used by 11% of energy-insecure households, is to seek government assistance (Carley et al., 2022). Interestingly, seeking government assistance can be considered one of the least risky strategies, but yet is only the third most commonly utilized strategy (Carley et al., 2022).

Power Outages and Grid Vulnerability

Overview of the U.S. Electricity System

The current electric infrastructure in the United States is vulnerable to instances of extreme heat that are likely to occur with increasing frequency in the coming years as a result of climate change (Zamuda et al., 2023). In the United States, there are two major electric grids, the Western Interconnect and the Eastern Interconnect; the state of Texas has its own electrical grid (US EPA, 2022). Within this system, over 7,300 centralized power plants generate electricity that is delivered to end-users via substations, transformers, and millions of miles of transmission and distribution lines (US EPA, 2022). The interconnected nature of the U.S. electric grid allows for the exchange of electricity, helping to achieve affordable and reliable electricity access to end users (US EPA, 2022).

However, U.S. electric grids are outdated. The majority of grid infrastructure was built in the 1960s and 1970s, leaving over 70% of current transmission lines at the end of their expected lifespan (U.S. Department of Energy Grid Deployment Office, 2023). In addition to aging infrastructure, recent developments in data centers and projected mass electrification are expected to cause a nearly 20% increase in demand for electricity in the United States over the next decade, with peak demand growing by 5% in the next four years (Walton, 2024). Increased demand on electricity systems, in addition to increasing occurrences of extreme weather and changes in average weather conditions, are all likely factors contributing to increased

occurrences of grid blackout events. Citing the U.S. Energy Information Administration, Stone et al. (2023) report the incidence of blackout events and electrical grid failure, defined by power outages lasting more than one hour and impacting more than 50,000 customers, with major events having more than doubled since 2015 (Stone et al., 2023).

Impact of Extreme Weather on Electricity Systems

Extreme weather, such as wind, ice, flooding, and wildfire, causes electrical transmission lines to be more vulnerable. Specifically, extreme heat decreases the transmission capacity of the electrical grid (Zamuda et al., 2023). Higher ambient air temperatures in combination with increased resistance from conductors contribute to increased transmission line temperatures (Gupta et al., 2012). As a result of increased line temperature, the conductive material of transmission lines experiences thermal expansion and begins to sag (Gupta et al., 2012). Transmission lines that are sagging decrease the efficiency of electrical transmission by effectively lengthening the distance the electricity must travel (Gupta et al., 2012). In addition to decreased efficiency, extreme heat accelerates the deterioration of electrical grid infrastructure, including transformers and transmission lines (Zamuda et al., n.d.). Lastly, higher ambient air temperatures are also likely to decrease the ability of electricity production as generators will have greater difficulty in performing necessary cooling operations (Zamuda et al., 2023).

Beyond decreasing electrical grid capacity, efficiency, and lifespan, higher ambient air temperatures are expected to cause increased demand for electricity that further stresses the electrical system (Bartos et al., 2016). In particular, peak demand is expected to have the greatest growth during the summer months, which may contribute to increased electrical grid failures (Bartos et al., 2016). Increases in peak demand and decreases in electricity system capacity are expected to be the greatest in the Federal Energy Regulatory Commission, Midcontinent Independent System Operator (MISO) electricity market, which comprises the majority of midwestern states (Bartos et al., 2016). In addition to increased demand associated with predicted rising temperatures as a result of climate change, trends toward electrification and increasing numbers of data centers may exacerbate issues of electricity demand in the future (Walton, 2024).

Thus, increased peak demand for electricity is occurring at the same time that grid infrastructure is vulnerable to decreased capacity. In combination with predicted increases in the frequency of extreme heat events and aging electrical infrastructure, it is clear there is potential for increasing grid failures. Understanding the impacts of grid failures during periods of extreme weather is imperative in preparing for the possible consequences for human health.

Impact of Grid Failure on Indoor Temperatures

Indoor environments are used as a way to protect individuals from harsh environmental conditions, and most people spend the majority of their time indoors (Sailor, 2014). Most indoor

environments are controlled at a temperature of 63℉ to 87℉, with indoor temperatures outside of this range being uncomfortable living conditions (Kovats & Hajat, 2008).

In most cases, health impacts are predicted using outdoor temperatures that are sourced from a singular location, however, in the instance of high heat or extreme heat, indoor temperatures will likely be more affected (Stone et al., 2023). Stone et al. (2023), using individually experienced temperature (IET) as a metric to measure human heat exposure as a result of moving from outdoor to indoor environments, found that IET tends to be underestimated unless the metric is inclusive of both indoor and outdoor heat burden (Stone et al., 2023). Another study found that estimated indoor air temperatures surpassed national hazard thresholds for heat-related illness as a result of modeling a concurrent heat wave and grid failure in Phoenix, Arizona (Stone et al., 2021).

An important tool for combating uncomfortable temperatures in indoor environments has been the introduction and increased usage of air conditioning (Stone et al., 2021). During grid failures, IET was shown to increase for individuals who normally had access to air conditioning, suggesting that air conditioning may unintentionally exacerbate heat vulnerability (Stone et al., 2021). Moreover, another study found that the predicted percentage of people dissatisfied with indoor temperature increases from 5–6% to 71.4% in Houston, TX and from 6.2–7.9% to 39.2% in Chicago, IL given future climate predictions under a scenario where air conditioning is lost (Sailor, 2014). Although the positive effect of air conditioning on thermal indoor comfort is well accepted, it is important to note that the degree to which air conditioning contributes to thermal comfort is hard to discern given the great number of variables involved (Davis et al., 2003).

Implications of Long-Duration Power Outages

Power outages during heat waves or other extreme weather events pose a greater risk to low-income households and minority populations experiencing greater heat exposure and sensitivity and higher likelihood of underlying chronic health issues (Vaidyanathan, 2020). These populations are not only more likely to experience longer duration outages following disaster than wealthier, white populations (Dugan et al., 2023), they are at greater risk of experiencing interrupted cooling, food and refrigerated medicine spoilage, and lost access to medical devices (Dugan, 2023; American Housing Survey, 2025).

CHAPTER 2: METHODOLOGY

Our study was inspired by past research on extreme heat in vulnerable communities in Detroit, and an interest in residents' access to cooling at home. A launching point for our research was the paper by the Genter et al. 2022 report, "Cognitive Pretesting of 2023 American Housing Survey Modules" in which the authors "present findings from cognitive testing of select questions and modules from the 2023 American Housing Survey" on heat risk, cooling problems, and power outage (Genter, 2022). Currently, data about U.S. residents' access to air conditioning are not collected in the American Community Survey (ACS).

The ACS is a national survey conducted by the Census Bureau to gather data about the U.S. and its residents. Information from this survey helps inform how "trillions of dollars in federal funds are distributed each year" (About the American Community Survey, n.d.). Planners, businesses, and public officials use the information to "plan for hospitals and schools, support school lunch programs, improve emergency services, build bridges, and inform businesses looking to add jobs and expand to new markets, and more" (About the American Community Survey, n.d.). The ACS is conducted annually to the city level (legal boundary), and every five years to the census block level. The sample size is between 3 million to 3.5 million households.

The American Housing Survey (AHS), sponsored by the U.S. Department of Housing and Urban Development (HUD), and conducted by the Census Bureau, is "the most comprehensive national housing survey in the United States" (American Housing Survey (AHS), 2025). This survey was launched in 1973 to collect information about housing quality and cost. The AHS is conducted biennially in odd-numbered years in major metropolitan areas. It collects data at a coarser grain, with the smallest unit being the metropolitan statistical area (MSA). The survey uses a longitudinal sample of around 2000 households.

Since 1985, the AHS has collected information on air conditioning (AC), however until 2023, data was limited to prevalence of AC in homes (American Housing Survey for the Cleveland Metropolitan Area in 1988, 1990, p.4). With the introduction of new Heat Risk, Cooling Problems, and Power Outage topical modules, the 2023 survey is the first year in which data was collected on householders' experiences with discomfort from heat due to lack of any cooling system in the home, lack of working air conditioning, or lack of air conditioning due to power outage, among other cooling problems (Genter et al., 2022).

The introduction of these test questions is useful in better understanding householders' experiences with extreme heat and energy burden. The data help illuminate vulnerability to heat stress or heat stroke due to lack or loss of AC, risk of illness or mortality due to power outage, such as loss of food and medicine refrigeration and inability to power medical devices, and other complications such as missed work, and displacement from home.

LEGACY CITY PROFILES

To understand heat risk and energy burden in legacy cities, we compared 2023 AHS data from the MSAs of Cincinnati, Ohio, Cleveland, Ohio, Detroit, Michigan, and Milwaukee, Wisconsin. We used data from newly added modules from the 2023 American Housing Survey on heat risk, cooling problems, and power outage. We followed the American Council for an Energy-Efficient Economy definition of energy burden, which is the percentage of household income spent on energy bills; over 6% qualifies as a high energy burden, and over 10% qualifies as a severe energy burden (ACEEE, 2024). To the best of our knowledge, this is the first study that compares these new data across our study areas.

Our decision to investigate the four cities of Cincinnati, Cleveland, Detroit, and Milwaukee is based on their similar definitions as legacy cities and being part of the American "Rust Belt" (James chen, 2025). As such, these four cities have similar economic histories that have resulted in similar auto-dependent urban development patterns with predominantly single-family housing stock and large areas of industrial facilities (American Housing Survey, 2023). Three of the four cities are located on the Great Lakes, and through their ports, they exchanged raw materials and finished products (Francomb, 2024; Case Western Reserve, 2018; Costello, n.d.; Orum, n.d).

Legacy cities are characterized as post-industrial cities formerly with strong manufacturing economies (Zehner et al., 2020). Significant population loss between the 1950s and 1980s and local economic downturn created stark demographic and socioeconomic differences between legacy cities and the surrounding metro areas, with lowest income residents living in urban centers (Zehner et al., 2020; American Community Survey, 2023). Housing stocks are typically older with inefficient windows, inadequate insulation, and lack of cooling systems (American Housing Survey, 2023) These conditions lead to increased heat risk and energy burden for vulnerable residents.

Sourced from Toni L. Griffen et al. (2015), common causes of legacy city decline include:

1. Significant loss of the manufacturing sector and jobs in the 1960s and 1970s, resulting in the loss of the city's economic base and lasting industrial infrastructure assets.
2. Rapid regional growth between 1950 and 1990.
3. Access to better housing and more jobs in the surrounding suburbs, in combination with sustained job and business loss in the city center, leads to high percentages of residents in low-wage jobs and below the national poverty level.
4. Loss of downtown retail and other service functions to the surrounding suburbs, leaving high levels of commercial vacancy.

5. Simultaneous trends of out-migration of residents, lack of in-migration, and a large aging-in-place population resulting in sustained population loss over two decades.
6. Rise in inner-city crime rates, with unemployment and concentrated poverty.
7. Persistent segregation due to red-lining practices and disinvestment in inner-city neighborhoods.
8. Declining tax revenues to support reliable, high-quality public services, resulting in excessive amounts of vacant and abandoned properties.
9. Increasing service charges, property and income taxes, and higher insurance at rates relative to the surrounding suburbs (Toni L. Griffin et al., 2015).

Cincinnati

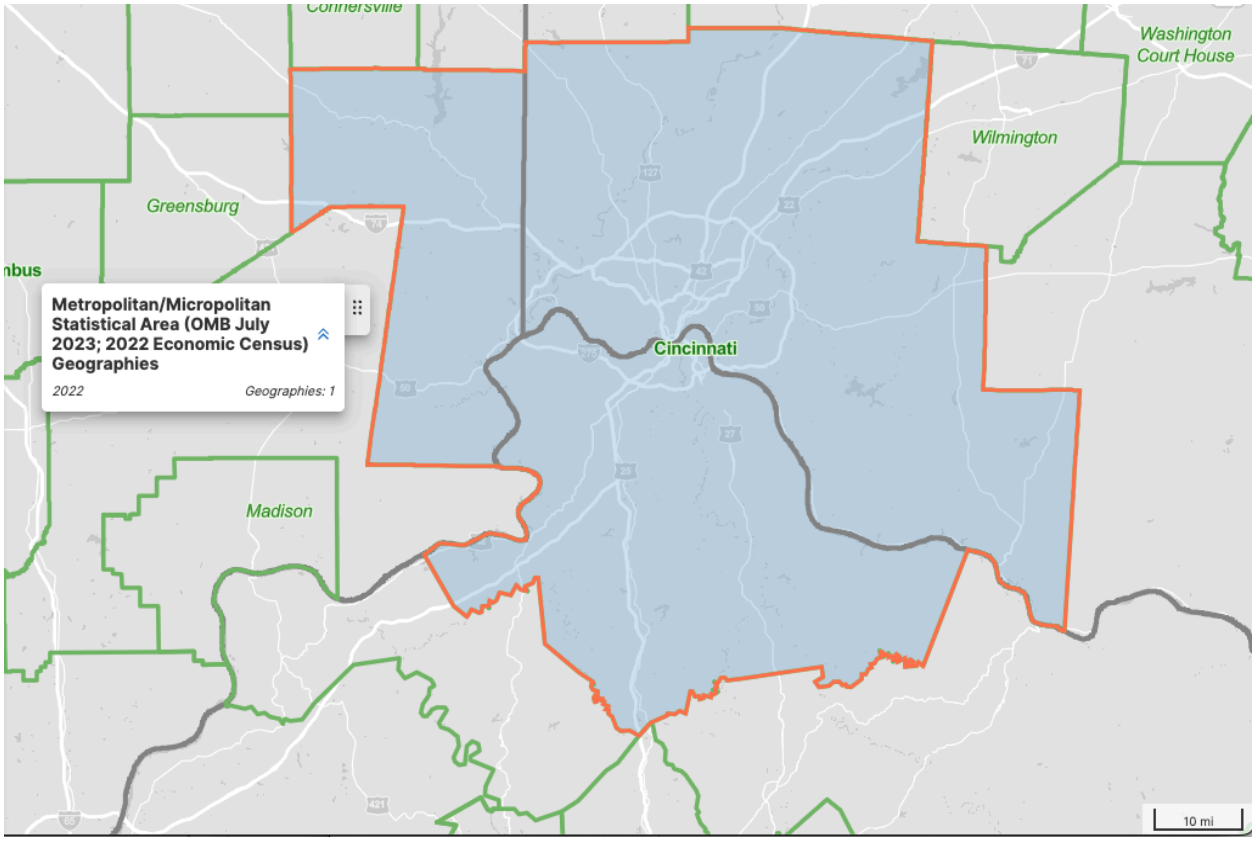


Figure 2. Map of Cincinnati, OH Metropolitan Statistical Area. Source: American Community Survey, U.S. Census Bureau, https://data.census.gov/map/310XX00US17140.

The City of Cincinnati, Ohio, is in the southwest corner of Ohio, just miles from the Kentucky border. The city center is nestled into the bank of the Ohio River, a natural feature that has been

pivotal in shaping the city into an industrial and manufacturing powerhouse for agriculture, pork, and beer (Francomb, 2024).

Industrial production thrived between 1850 with the rise of Cincinnati's pork processing industry, which helped the city grow into the 6th largest city in the country by 1850 (Wagner, 2018). As a result of Cincinnati's capitalization on pork processing, the city was home to the founding of Procter and Gamble, which used pork byproducts in a range of soaps and lotions (Wagner, 2018). With the advent of railroads and westward migrations, Cincinnati took advantage of its railside location to become a center of tool manufacturing for those traveling out west or south. Cincinnati reached its industrial production peak in the 1950s, until the decline of domestic industrial and manufacturing processes in the following decades (Wagner, 2018). Like many cities across the country, Cincinnati has seen a surge in the service industry in recent decades (Wagner, 2018).

With the end of WWII and the National Housing Act of 1934, Cincinnati became one of many cities across the country that would face the systemic consequences of redlining (Overbey, 2020). Consequential disinvestment in housing areas that were "redlined" would lead to the eventual vulnerability of these communities to urban renewal and gentrification (Overbey, 2020). In the meantime, the city of Cincinnati experiences increasing segregation between minority communities in the urban center and white communities in the more expensive suburbs (Overbey, 2020).

The Cincinnati metropolitan area is the largest of the four cities investigated in this study, covering an area of just over 4,385 square miles in three states. The U.S. Census Bureau defines the Cincinnati, OH-KY-IN MSA as containing the following counties: Brown, Butler, Hamilton, Clermont, and Warren in Ohio; Boone, Bracken, Campbell, Gallatin, Grant, Kenton, and Pendleton in Kentucky; and Dearborn, Grant, Ohio, and Union in Indiana (Overview of the Cincinnati Area (Metro Area), 2018). The population of the metropolitan statistical area grew steadily over the past decade from approximately 2,137,735 in 2011 to 2,272,910 in 2023. Likewise, population density has also been increasing steadily over the past decade from 487 people per square mile to 518 people per square mile in 2023. Additionally, the percentage of racial makeup has been shifting over the past decades with a slight decrease of about 6% in white populations and a slight increase in Hispanic populations of about 2% (although this number is small, it represents a doubling of the total Hispanic population in the past decade). The latest percentage of the population with a bachelor's degree or higher and of age 25 years or older is 3.6% (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

The median income has also steadily increased from $52,373 in 2011 to $77,844 in 2023, averages that more or less follow the pattern of national median income. Cincinnati has seen a powerful decline in the poverty rate of the past decade, with a nearly decrease from 14.3% in 2011 to 10.9% in 2023. The number of housing units has increased from 919,561 in 2011 to 974,115 in 2023, in conjunction with a decrease in the percentage of housing units being rented

from 34.6% in 2015 to 32.6% in 2023. At the same time, median gross rent as a percentage of income peaked in 2011 at 31.2%, then fell to 28.2% and 26.7%, before reaching 29% in 2023. The population of Cincinnati is aging like much of the U.S., with 12.3% of residents in 2011 age 65 and over to 17.1% in 2023 (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

Cleveland

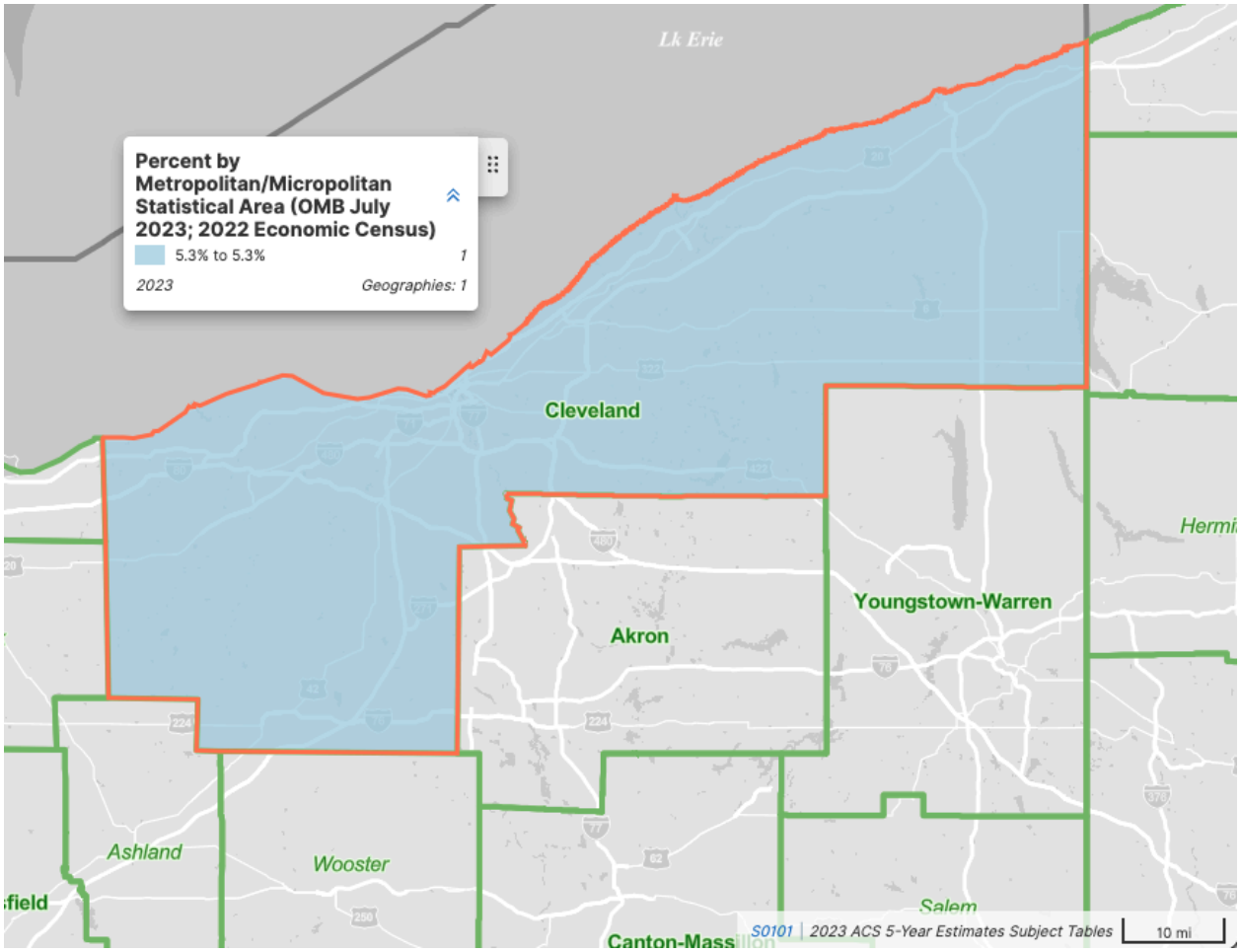


Figure 3. Map of Cleveland, OH Metropolitan Statistical Area. Source: American Community Survey, U.S. Census Bureau, https://data.census.gov/map/310XX00US17410.

Positioned on the south-western end of Lake Erie, Cleveland's first wave of economic development relied on connecting canal systems, including integration into the Erie Canal (Case Western Reserve, 2018). Canals provided cheaper transportation costs, allowing the growth of agricultural trade (Case Western Reserve, 2018). Cleveland's growth mirrored the development of new transportation technologies and the demand for manufactured goods (Case Western Reserve, 2018). Cleveland's economy was diverse as it leveraged its geographic position to be an industrial hub that could provide a number of services efficiently and cheaply (Case Western Reserve, 2018). The city's industries and politics championed free labor and federal support for

domestic industries (Case Western Reserve, 2018). However, in the latter half of the twentieth century, globalization, rising domestic labor costs, and harsher environmental standards in America led to foreign production being able to provide cheaper labor and manufacturing costs for industries (Case Western Reserve, 2018). As a result, the backbone of Cleveland's economy was outsourced (Case Western Reserve, 2018).

Cleveland was seen as one of the most progressive and safe places for African Americans up until the 1910s and 1920s, when the great migration began to make white residents feel threatened (Case Western Reserve, 2022). With a quickly increasing population, waves of African Americans from the south contributed to a housing shortage that worsened resentment between whites and blacks (Case Western Reserve, 2022). Similar to the development of industry, suburbanization in Cleveland mapped onto the development of newer transport systems for workers (Case Western Reserve, 2018). Redlining also contributed to the segregation of Cleveland, which resulted in Cleveland experiencing the phenomenon known as "white-flight," where most white people flocked to the suburbs, leaving the inner city hollow (Case Western Reserve, 2022).

Cleveland is the third smallest of the cities included in the study, with a metropolitan statistical area that covers 2,701 square miles. The U.S. Census Bureau defines the Cleveland-Elyria MSA as containing the following counties: Cuyahoga, Geauga, Lake, Lorain, and Medina ("Overview of the Cleveland Area, Ohio (Metro Area)", 2018) Cleveland's population was decreasing from 2,068,283 in the years following 201, but since 2019 has rebounded with a population of 2,158,932 recorded in 2023. Likewise, population density in Cleveland's MSA decreased between 2011 and 2019, with the lowest recorded density at 758.28 residents per square mile. In 2023, the population density rebounded to 799 residents per square mile. Cleveland's demographic shift over the past decade is similar to that of Detroit's, with the Hispanic/Latino population increasing by 2.1%, the white population decreasing by 3.6%, and the Black/African American population decreasing by 1.3%. As of 2023, the demographic distribution of Cleveland's MSA is 6.9% Hispanic/Latino (of any race), 68% white, and 18.2% black. The percentage of individuals aged 25 years or older with a bachelor's degree has increased from 4.4% in 2011 to 4.9% in 2023, dropping to 4.1% in the years between. Cleveland's MSA's current education level is the highest of all four cities investigated in this study (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

Median income in Cleveland's MSA has been steadily increasing from $45,936 in 2011 to $67,586 in 2023. The percentage of people with an income in the past 12 months that is below the poverty line has declined from 16% in 2011 to 13.6% in 2023. During the past decade, the number of housing units in Cleveland's MSA has slowly increased from 956,811 in 2011 to 1,020,814 in 2023, with the percentage of renter-occupied units decreasing from 34.6% in 2011 to 32% in 2023. The decline in the percentage of renter-occupied housing units is recent, as 2015 and 2019 saw increases of up to 35.8%. Median gross rent as a percentage of income has remained relatively constant at around 30%, however, the percentage of individuals with a gross

rent greater than 35% of their income has decreased from its peak at 44% in 2011. Since 2011, the percentage of individuals with a gross rent greater than 35% of their income has decreased to as low as 36.4% in 2019, but saw a recent uptick and now rests at 41.5% as of 2023. Cleveland's MSA has an increasing percentage of its population that is 65 years of age or older, with the most recent estimates at 19% as of 2019 (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

The demographic profile of Cleveland is as follows: 68% of the population is white, 18.2% of the population is black, and 6.9% of the population is Hispanic. 4.9% of the population that is 25 years or older has a bachelor's degree. The median income is $67,586 per year, with 13.6% of the population having an income within the last 12 months that is below the poverty line. Cleveland has 3,899,639 housing units, with 32% being renter occupied. The median gross rent as a percent of income is 30,% with 41.5% of people experiencing a gross rent that is greater than 35% of their income (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

Detroit

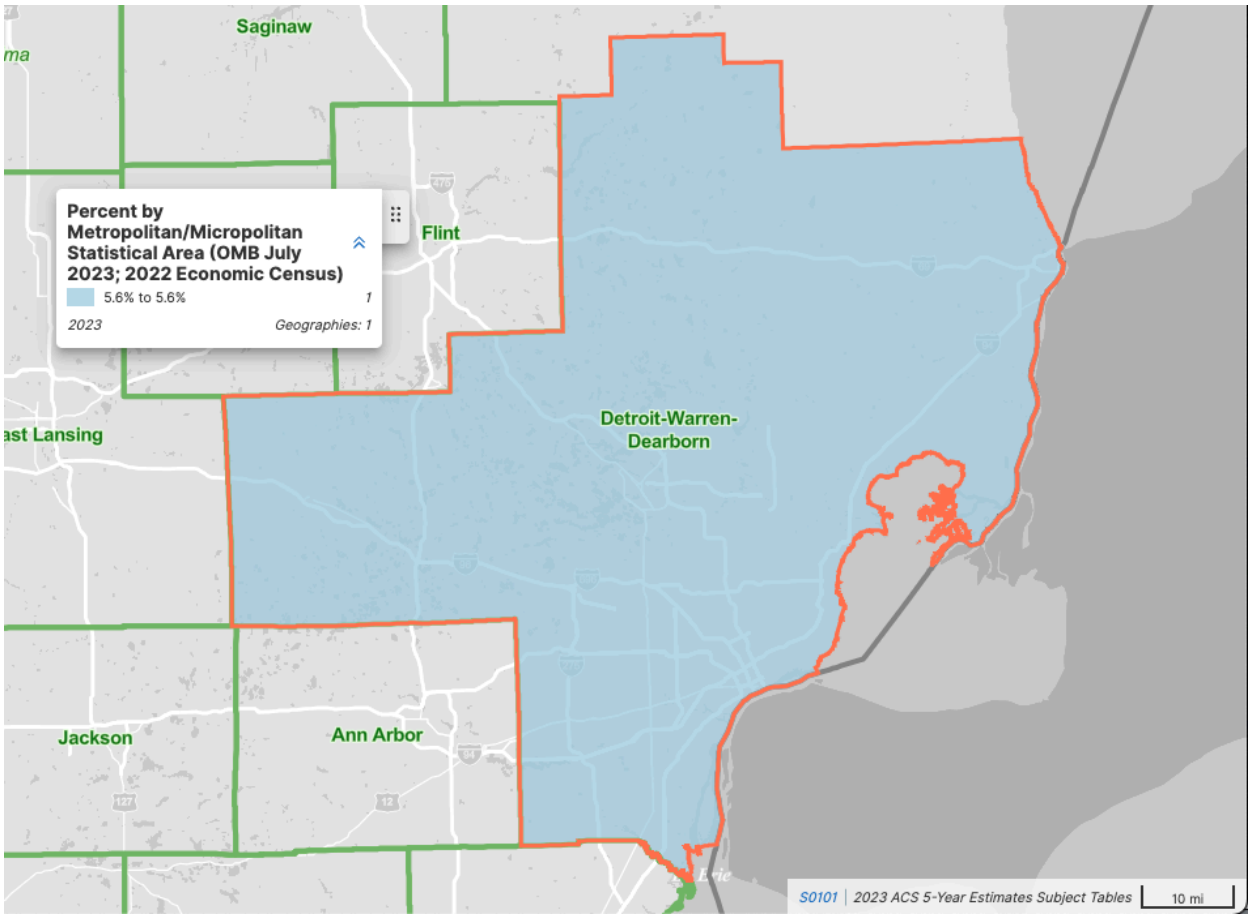


Figure 4. Map of Detroit, MI Metropolitan Statistical Area. Source: American Community Survey, U.S. Census Bureau, https://data.census.gov/map/310XX00US19820.

Located in Southeastern Michigan, the city of Detroit lies on the Detroit River which forms a natural border between the United States and Canada. It is part of the Great Lakes region and situated near the western end of Lake Erie with access to Lake St. Clair. The city's access to the Detroit River's waterways has been crucial for trade, transportation, and industry, particularly due to its entry into the larger St. Lawrence Seaway that allowed for access to the Atlantic Ocean and interior North America.

Known as the epicenter of the global automotive industry, Detroit became a manufacturing powerhouse and served as a base for automakers Ford, Stellantis, and GM, and shaped the region's economy for decades. Beyond the automotive sector, Detroit has a diverse industrial base, including advanced manufacturing, logistics, technology, and health care. The city has a strong presence in defense manufacturing, producing military vehicles and equipment (Hyde, 2013). Additionally, Detroit's location along major waterways and transportation networks makes it a key logistics and trade hub. Detroit saw rapid deindustrialization due to multiple reasons, including automation, globalization, and the outsourcing of manufacturing, and the city experienced significant economic decline, population loss, and urban decay. Several neighborhoods suffered from abandoned buildings and infrastructure decline (Steinmetz, 2009), and together these issues culminated in the city's bankruptcy in 2013, the largest at the time in the United States.

In addition to economic decline, Detroit experienced suburbanization and redlining as a result of the Fair Housing Act. Consequently, white populations were encouraged to move to single-family homes in Detroit's suburbs such as Taylor, Livonia, and Warren. In contrast, Black/African American populations were confined to neighborhoods redlined in the city center, which had lost their tax base and would come to experience significant disinvestment as a result ("Suburbanization and Segregation in Detroit", n.d.).

The city of Detroit is the second largest of the four cities investigated in this study, with a metropolitan statistical area totaling 3892.329 square miles. The U.S. Census Bureau defines the Detroit-Warren-Dearborn MSA as containing the following counties: Clair, Macomb, Livingston, Oakland, St. Lapeer, and Wayne ("Overview of the Detroit Area, Michigan (Metro Area)," 2018) The population of Detroit's MSA has been steadily increasing from 4,285,832 residents in 2011 to 4,342,304 residents in 2023. Population density within Detroit's MSA has also been slowly but steadily increasing from 1,101 people per square foot in 2011 to 1,115 people per square mile in 2023. The racial and ethnic composition of Detroit's MSA has also been shifting over the past decade. There has been growth in the Hispanic/Latino population of 1.4% in the past decade, a 4.1% decrease in the white population, and a 1.4% decrease in the black population. Education in Detroit's MSA saw a recent uptick to 4.3% of individuals 25 years or older having a bachelor's degree, which is in contrast to the recent fall in education from 4.4% in 2011 to 3.9% in 2019 (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

Despite low educational attainment, the median income in the Detroit MSA has steadily increased from $48,968 in 2011 to $72,574 in 2023. There has been a promising trend in poverty, with the percentage of people with income in the past 12 months below the poverty line decreasing steadily from 18% in 2011 to 13.6% in 2023. The number of housing units has also been steadily increasing, from 1,881,683 in 2011 to 1,934,332 in 2023. Over the past decade, the percentage of housing units that are owner-occupied peaked in 2015 at 32%, but has since then decreased steadily to 27.9% in 2023. Median gross rent has remained above 1-3 percentage points above 30% of income, except in 2019, where it reached a base of 29.6%. In 2011, 47.9% of people in Detroit's MSA were reported to have a gross rent greater than 35% of their income. In recent years, this number has decreased by about 5%, hovering at 40.6-42.9% of the population with gross rent greater than 35% of their income. Lastly, the percentage of Detroit's MSA population over 65 years of age has been steadily increasing in the past decade from 13.5%-18.4% (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

Milwaukee

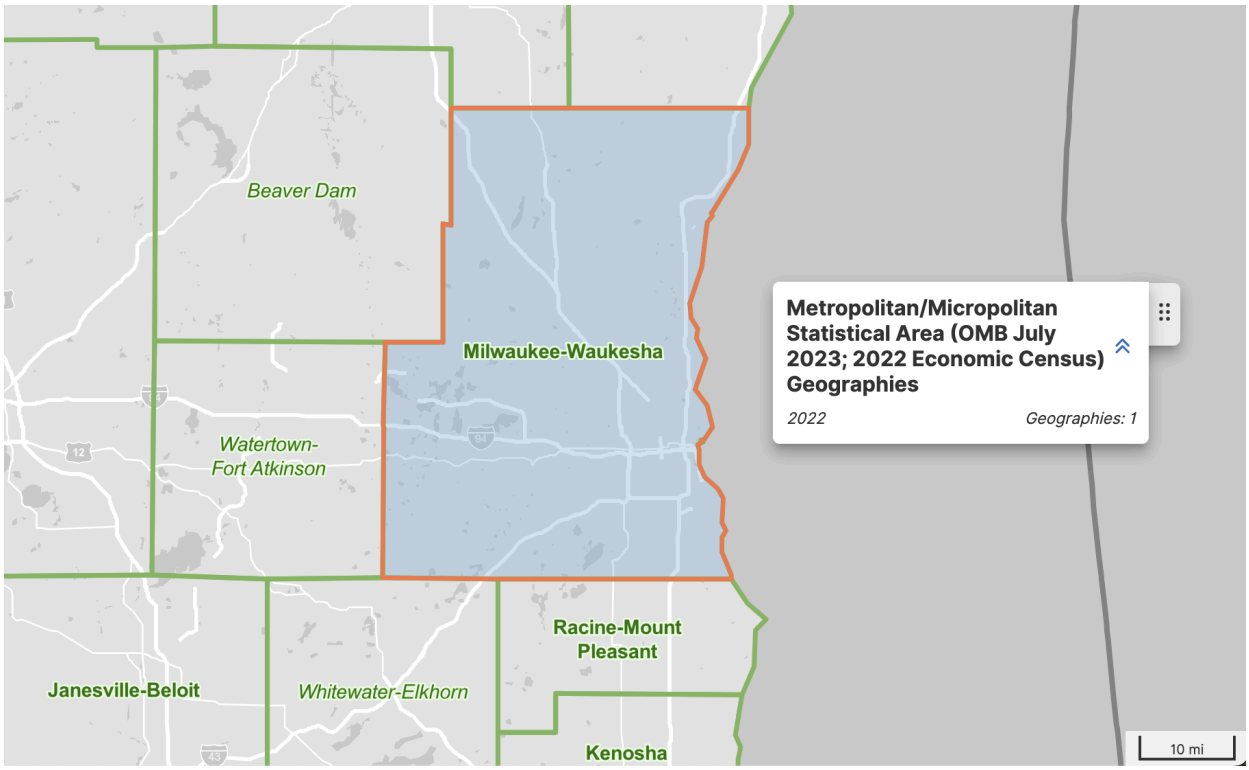


Figure 5. Map of Milwaukee, WI Metropolitan Statistical Area. Source: American Community Survey, U.S. Census Bureau, https://data.census.gov/map/310XX00US33340.

The City of Milwaukee, Wisconsin, sits on the southwest shore of Lake Michigan, due east of the state capital in Madison. The central business district sits at the confluence of the Menomonee, Kinnickinnic, and Milwaukee Rivers, where the trio flows into Lake Michigan. The riverways were important to the economic development of the city in the mid-19th century, used

for shipping primary exports of that era, which included beer, leather products, wheat, and electric motors by the century's end (Costello, n.d.; Orum, n.d).

Industrial production peaked between 1870 and 1920, drawing immigrants from Germany and other northern European countries. The population boomed, growing from a village of two thousand people in 1840 to over 285,000 in 1910 (Orum, n.d.). In the 1960s and 1970s, growing economies in Asia became strong competition for Milwaukee. Anchor companies left and took away over 40,000 jobs in manufacturing. There was a shift to a service sector economy with considerably lower hourly wages (Orum, n.d.).

Following the economic downturn of the Great Depression, post-World War II brought a boost in manufacturing and suburban housing development for returning veterans. Like most urbanized areas in the country at that time, the city centers emptied their middle-income residents into the new suburbs, leaving behind mostly impoverished Black residents. The city effectively became segregated, and still ranks as one of the worst cities in the U.S. in terms of racial segregation (Orum, n.d.).

The City of Milwaukee is the smallest of the four cities investigated in this study, covering an area of just under 1455 square miles. The U.S. Census Bureau defines the Milwaukee-Waukesha MSA as containing the following counties: Milwaukee, Ozaukee, Washington, and Waukesha (Overview of the Milwaukee Area, Wisconsin (Metro Area), 2018). The population of the metropolitan statistical area grew from approximately 1,562,000 in 2011 to 1,575,000 in 2015, but has since declined to 1,560,000 in 2023. Likewise, population density during the four years investigated peaked in 2015 at 1083 per square mile and dropped to 1072 in 2023. Racial makeup has shifted since 2011, with a steady decrease in percentage of black residents from 16.3% in 2011 to 15.4% in 2023 and white residents from 68.7% in 2011 to 63.8% in 2023, and an increase in percentage of Hispanic/Latino populations from 9.7% in 2011 to 12.2% in 2023. The percentage of residents over the age of 25 obtaining a bachelor's degree dropped slightly in 2015 and 2019 to 3.7% and 3.5% respectively, and increased by a percentage point in 2023 to 4.6% (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

Despite lower educational attainment, median household income was on par with the national median income in 2011 and 2015, but fell below that average in 2019 and 2023, by around $3000 in both years. There was a promising trend in the percentage of people below the poverty line, which dropped from 15.2% in 2011 to 12.2% in 2023. Housing units increased during that time from 671,857 to 699,688, while the percentage of renters remained steady between 38.8% to 41.1%. Median gross rent as a percentage of income dropped from 31.8% in 2011 to 27.9% in 2019, however, it rose again to 28.8% in 2023. The population of Milwaukee is aging like much of the U.S., with 12.7% of residents in 2011 age 65 and over to 17.6% in 2023. (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

Summary of Key Demographics

The following table shows key demographics, socioeconomic factors, and housing data at the MSA level that are relevant to our study. Included are select city-level demographics for comparison, in italics.

Table 1.

Summary of Key Demographic, Socioeconomic, and Housing Data 2023 – Metropolitan Statistical Area (MSA)*				
	Cincinnati, OH	Cleveland, OH	Detroit, MI	Milwaukee, WI
Population	2,272,910	2,158,932	4,342,304	1,560,424
*Legacy City Population**	311,112	362,670	633,221	561,369
*Living in Legacy City (%)**	13.7	16.8	14.6	36.0
*Pop. Loss (peak to 2010) (%)**	41.0	57.0	61.0	32.0
Area (square miles)	4385.2	2701.4	3892.3	1454.8
Population Density (per sq.mi.)	518.3	799.2	1,115.6	1,072.6
White (%)	75.7	68	63.5	63.8
Black/African American (%)	11.2	18.2	21.1	15.4
*Black/African American Living in Legacy City (%)**	35.3	46.7	75.9	36.7
Hispanic/Latino Ethnicity (%)	4.6	6.9	5.4	12.2
Bachelor Degree or Higher (%)	3.3	4.9	4.3	4.6
Age 65 and over (%)	17.1	20.1**	18.4	17.6
Maximum Temperature – Average Days Above 95th Percentile (2020-2022)	Under 5	6 to 13	6 to 10	6 to 10
Median Household Income ($)	77,844	67,586	72,574	77,006
*Median Household Income in Legacy City ($)**	54,314	39,041	38,080	52,992
People Below Poverty Line (%)	10.9	13.6	13.6	12.3

Summary of Key Demographic, Socioeconomic, and Housing Data 2023 – Metropolitan Statistical Area (MSA)*				
	Cincinnati, OH	Cleveland, OH	Detroit, MI	Milwaukee, WI
*People Below Poverty Line in Legacy City (%)**	21.3	30.7	31.9	22.1
Median Gross Rent as Percent of Income (%)	29	30	31.2	28.8
Total Housing Units	974,115	1,020,814	1,934,332	699,668
Renter Occupied Units (%)	32.6	32	27.9	38.8
*Renter Occupied Units in Legacy City (%)**	62.1	56.9	46.2	56.2
Homes Built Prior to 1960 (%)	31.5	41.6	40.3	42.2
*Homes in Legacy City Built Prior to 1960 (%)**	57.2	71.6	80.0	64.3
Median Value of Home ($)	270,100	217, 300	251,200	308,100
*Median Value of Home ($)**	247,300	107,100	86,400	183,700

Sources: American Community Survey, American Housing Survey, Griffin et al 2015
*Unless otherwise noted. Legacy city refers to the legally defined city boundary.
**2023 Data not available. Uses 2022 American Community Survey.

Comparison of Legacy Cities to MSAs

The following charts illustrate the vast discrepancies in demographics and socioeconomic status of residents of MSAs versus legacy city residents. Figures reflect values and percentages shown in Table 1.

Between 1950 and 2010, Cincinnati lost 41% of its population, Cleveland lost 57%, and Milwaukee, 32%. Detroit stands out with the greatest population loss, of 61%, which represents over one million people (Griffin, 2015). Of Detroit's 4.3 million residents, only 14.6% are living within the city limits (*American Community Survey 5-Year Data (2009-2023)*, n.d.).

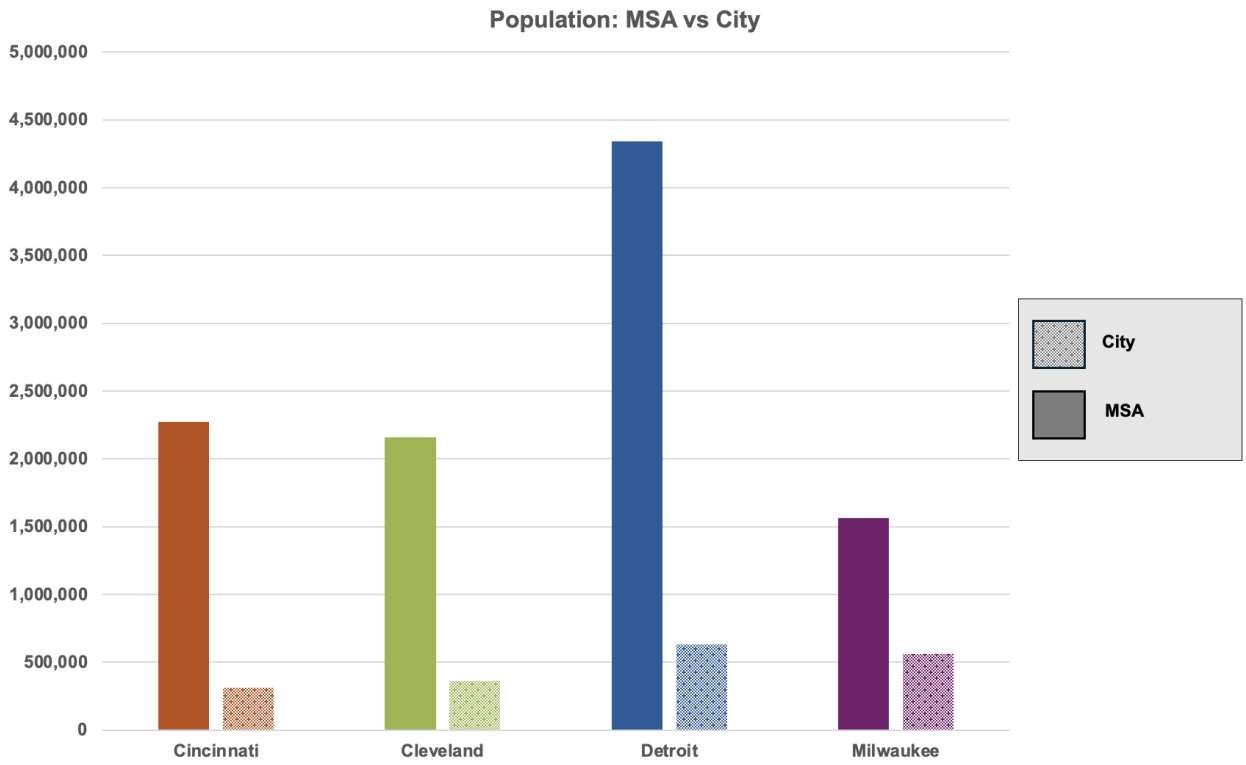


Figure 6. Data sources: American Community Survey, 2023; American Housing Survey, 2023

The following three socioeconomic factors also show a stark difference between MSAs and legacy cities. The cities of Cleveland and Detroit have slightly lower median household incomes than the cities of Milwaukee and Cincinnati. There is also a greater disparity in median household income between the cities and MSAs of Cleveland and Detroit.

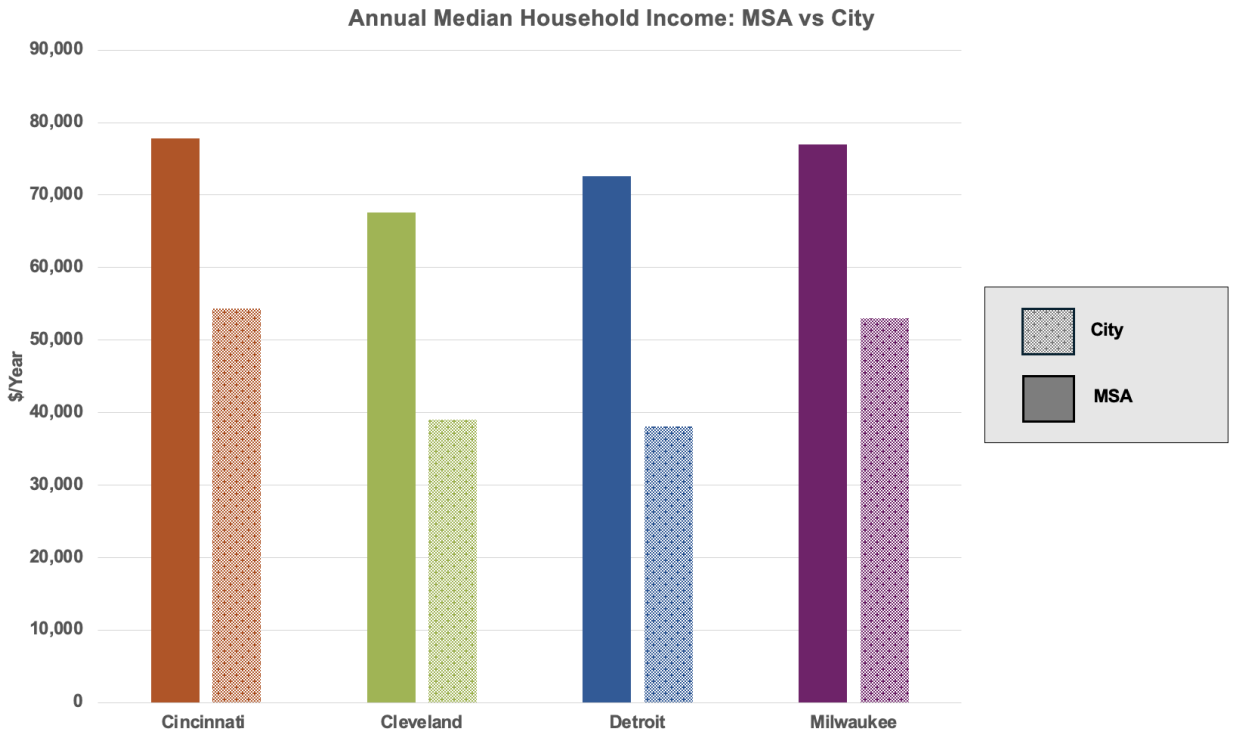


Figure 7. Data sources: American Community Survey, 2023; American Housing Survey, 2023

The difference in socio-economic indicators between the MSAs and the cities persists for the percent of population below the poverty line. Across all four cities, a greater percentage of the city populations are below the poverty line as compared to the MSA populations. Detroit and Cleveland show the greatest difference between city and MSA geographies with the greatest percentages of residents living below the poverty line.

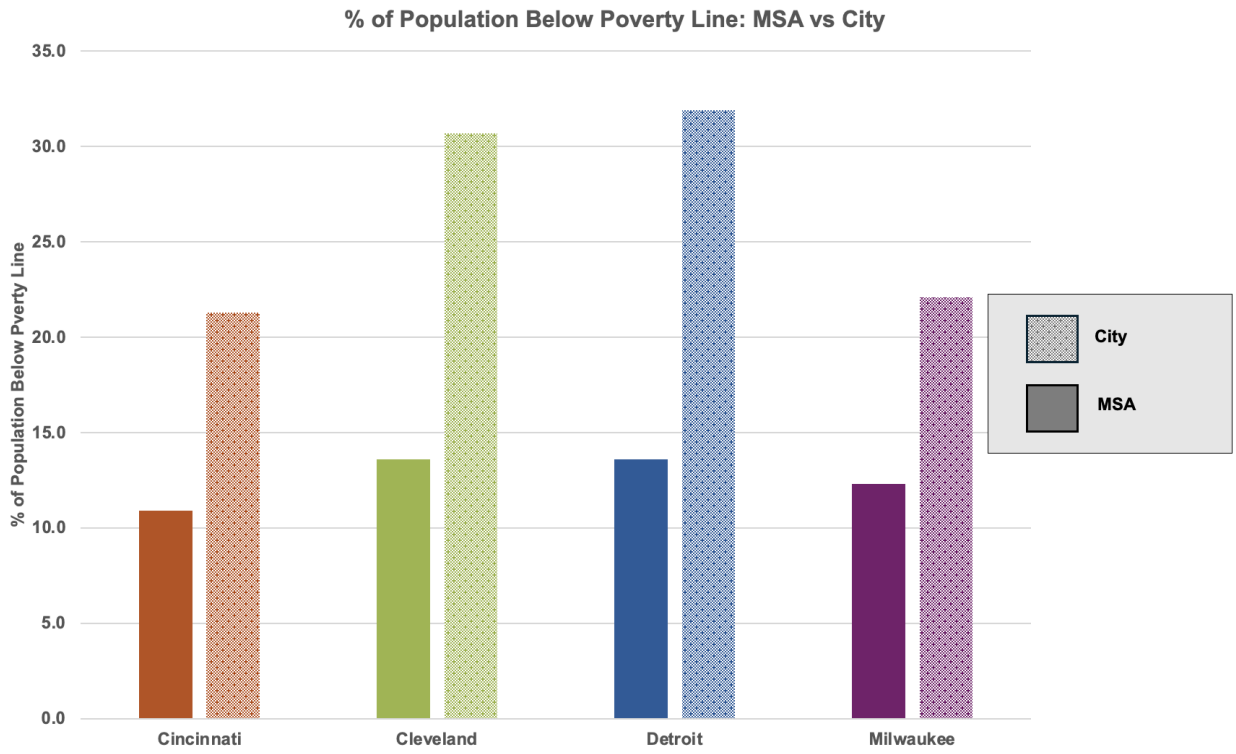


Figure 8. Data sources: American Community Survey, 2023; American Housing Survey, 2023

Home ownership is one of the most important ways to build generational wealth in the U.S., yet we see a greater percent of residents in Cincinnati, Cleveland, and Milwaukee are renting their homes. Interestingly, Detroit has the highest percentage of home ownership despite the city's relative position in the other categories.

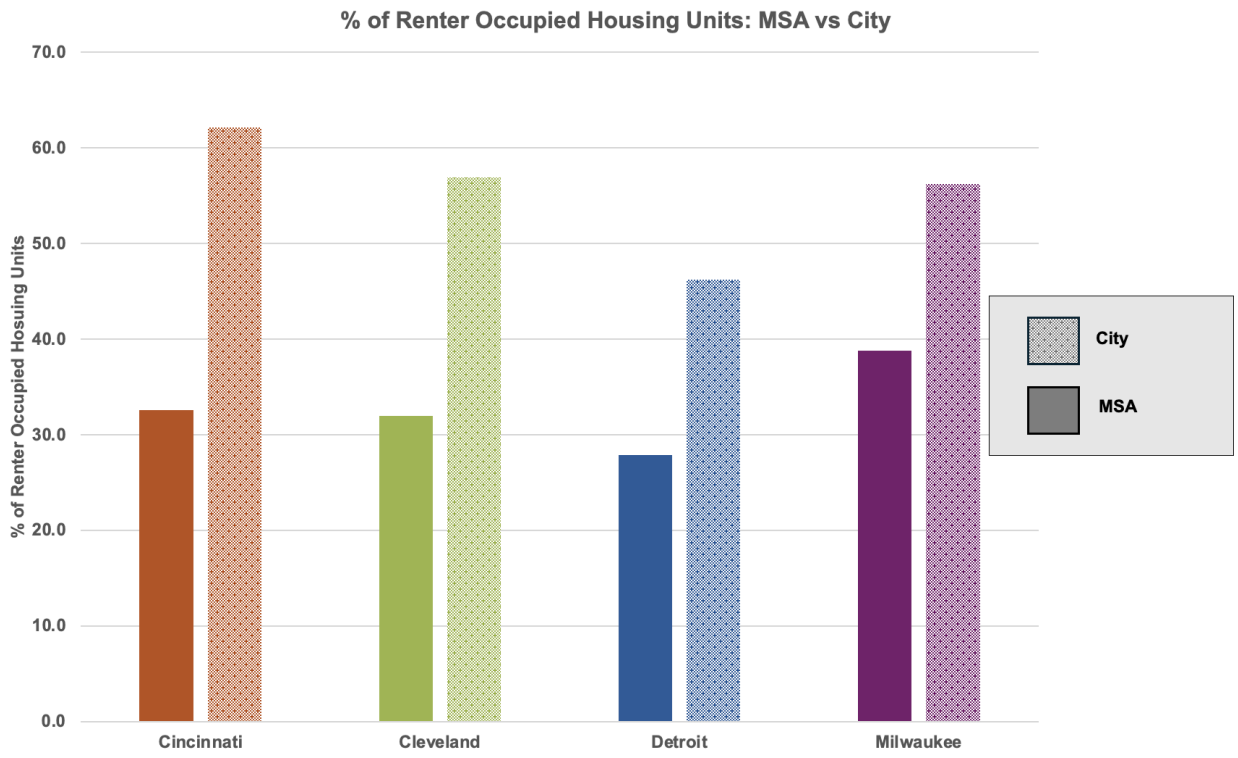


Figure 9. Data sources: American Community Survey, 2023; American Housing Survey, 2023

Lastly, there is a clear difference in the proportion of the population that is Black/African American for the cities compared to the MSAs. The most notable difference can be seen in Detroit, where the proportion of the city population that is Black/African American is more than double the proportion of the MSA population that is Black/African American.

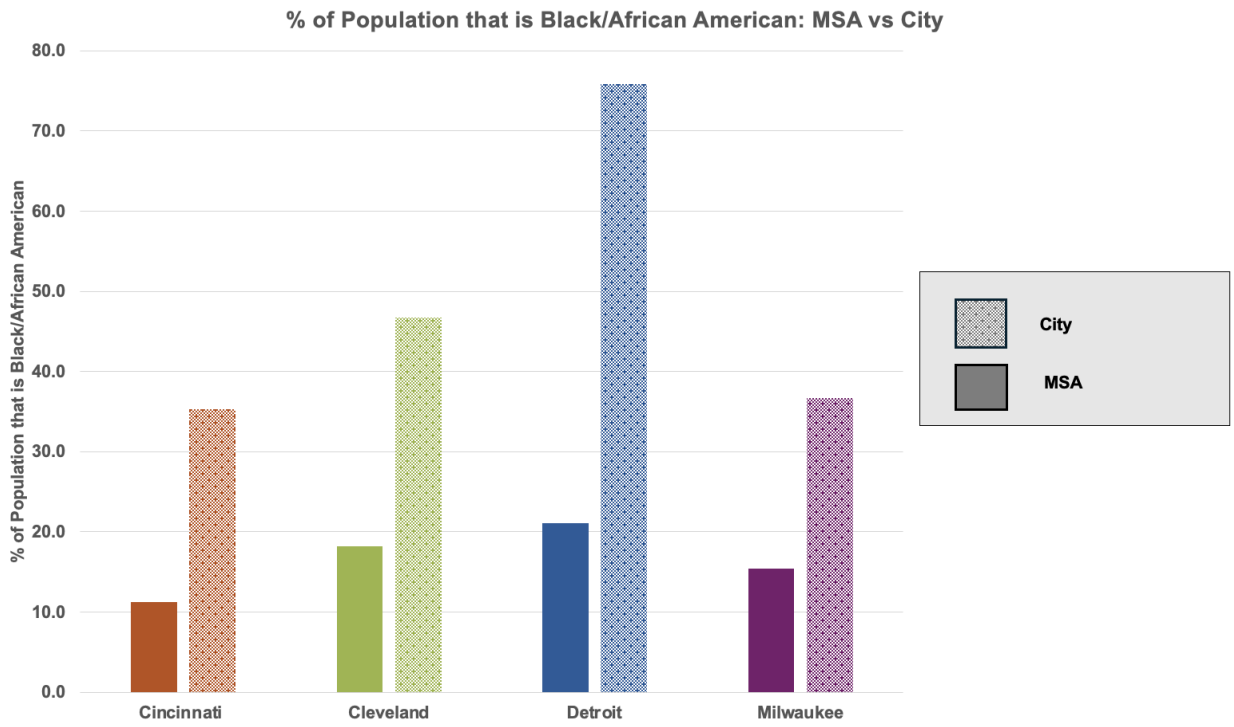


Figure 10. Data sources: American Community Survey, 2023; American Housing Survey, 2023

RESEARCH QUESTIONS

Our overarching research questions were: 1) How many people in our four cities have access to AC?; 2) How many people are experiencing heat burden (thermal discomfort)?; 3) To what degree is AC used as a coping mechanism?; 4) How is cooling ability impacted by grid failure?; and 5) What are reported health impacts due to loss of AC, such as visits to the ER? After seeing what data was available, we explored the questions shown in the following tables.

Table 2.

Research Questions with Corresponding 2023 AHS Survey Questions on Heat Risk and Cooling Problems	
AHS Research Questions for each MSA	2023 AHS Survey Questions
What percent of respondents were without AC at home?	Multiple questions were asked about AC systems, including whether the home has a heat pump or central air, and the use and number of room air conditioners.
What percent of respondents experienced extreme heat within their homes?	[In the past 12 months/Since you've lived here], for any reason, was your unit so hot for 24 hours or more that [you were/at least one person was] uncomfortable?

Research Questions with Corresponding 2023 AHS Survey Questions on Heat Risk and Cooling Problems	
AHS Research Questions for each MSA	2023 AHS Survey Questions
What percent of respondents with AC at home reported being uncomfortably hot?	*This question was not surveyed directly as written in the research question. Results were derived from contingency table analysis of two questions shown above.*
What percent of respondents reported being uncomfortably hot due to cooling equipment breakdown?	[Was your unit so hot] because the MAIN cooling equipment broke down?
What percent of respondents reported being uncomfortably hot due to utility interruption or power outage?	What was the reason your unit was uncomfortably hot for 24 hours or more? 1. Utility interruption or power outage 2. Inadequate cooling capacity 3. Leaking windows, doors, and walls 4. Inadequate insulation 5. Cost of cooling 6. Other
What percent of respondents with AC reported being uncomfortably hot due to inadequate cooling capacity?	
What percent of respondents with AC reported being uncomfortably hot due to leaking windows, doors, and walls?	
What percent of respondents with AC reported being uncomfortably hot due to inadequate insulation?	
What percent of respondents with AC reported being uncomfortably hot due to limiting use of AC due to the cost of electricity?	
What percent of respondents reported that their home stays cool without any cooling equipment?	How well does your unit stay cool in HOT WEATHER without the aid of air conditioning or other cooling devices? Would you say very well, Somewhat well, Not very well, or Not well at all?
What percent of respondents with AC reported going to the emergency room due to heat?	[During the last 12 months/since you've lived here], did any household member visit an emergency room or urgent care center due to heat stroke or other heat-related illness?
What percent of respondents without AC reported going to the emergency room due to heat?	

Source: American Housing Survey, 2023

Table 3.

Research and 2023 AHS Survey Questions on Power Outage	
AHS Research Questions for each MSA	Survey Questions
What percentage of residents experienced a power outage?	Was your home ever completely without power (since you've lived here/since your household has lived here/in the last 12 months) that is, since (date)?
What percent of respondents reported spoiled food due to power outage?	In the past 12 months/Since you have lived here) has any food spoiled as a result of a power outage?
What percent of respondents **reported** electrical medical devices were inoperable due to power outage?	Do you [or anyone else in your household] have any medical devices in your home that are important to health and that require electrical power to operate?
What percent of respondents reported spoiled refrigerated medicine due to power outage?	(In the past 12 months/ Since you have lived here) did any refrigerated medicine spoil (as a result of a power outage)?
What percent of respondents reported having to leave home and stay somewhere overnight due to power outage?	In the past 12 months/Since you have lived here) did you (or anyone in your household) have to leave your home and stay somewhere else overnight as a result of a power outage?
What percent of respondents reported missing work due to power outage?	(In the past 12 months/ Since you have lived here) did you (or anyone in your household) miss work (as a result of a power outage)?

Source: American Housing Survey, 2023

STATISTICAL METHODS

We used AHS 2023 Public Use File (PUF) microdata for each of the MSAs, where the "basic unit is an individual housing unit" (American Housing Survey, 2023). Cincinnati, Cleveland, and Milwaukee microdata were available in the Metropolitan PUF, and Detroit microdata were available in the National PUF.

The variables we selected are reflected in the survey questions in the tables above. The full set of survey questions, response options, and data variables can be found in Appendix 1.

We filtered the microdata for our target cities and target variables. We then aggregated responses corresponding to each research question We constructed a series of 2x2 contingency tables to explore relationships between key variables. These tables allowed us to compare how housing characteristics—especially AC prevalence and working AC characteristics—correlate

with reported heating and cooling issues. From these tables, we calculated proportions to identify and compare patterns across the four cities.

The percentages shown in the data were calculated using varying denominators depending on the context of each question. Some values, such as those reporting being uncomfortably hot for 24 hours or more, or whose homes stay cool without cooling equipment, were calculated as a percentage of the total number of respondents in each city. Other responses were filtered by specific subsets. For example, the percentage of respondents limiting AC use due to cost was based only on those who previously reported having air conditioning at home. Several other metrics—such as being uncomfortably hot due to cooling equipment breakdown, leaking windows, or inadequate insulation—were calculated using only those respondents who previously reported both having AC and also feeling uncomfortably hot.

This subset-based approach also applies to reported inadequate cooling capacity. Likewise, hospital visits due to heat were calculated based on those who reported feeling uncomfortably hot, not the total sample. For power outage-related responses, such as spoiled food, inoperable medical devices, and missed work, percentages were derived from only those who said they experienced a power outage. A nuanced understanding of these base groups is essential when interpreting the results, as it highlights the conditional nature of many responses and ensures accurate comparisons across cities.

CHAPTER 3: RESULTS I

Our research questions and corresponding results are shown in the following tables.

Table 4.

Household Responses to American Housing Survey Questions Related to Heat Risk and Cooling Problems 2023 Metropolitan Statistical Areas (MSA) (Shown as absolute numbers and percentages)				
AHS Research Questions	Cincinnati (N= 1936)	Cleveland (N=1555)	Detroit (N=1986)	Milwaukee (N=1905)
What percent of respondents were without AC at home?	3.5% (68)	10.28% (160)	12.13% (241)	6.5% (125)
What percent of respondents experienced extreme heat within their homes?	7.49% (145)	6.24% (97)	8.26% (164)	6.72% (128)
What percent of respondents reported being uncomfortably hot due to cooling equipment breakdown?	6.16% (9)	29.67% (27)	2.78% (4)	6.42% (7)
What percent of respondents reported that their home stays cool [very well] without any cooling equipment?	13.53% (272)	16.14% (211)	13.34% (376)	14.49% (260)
The following rows are a subset of the total number surveyed. Responses are filtered by the presence of air conditioning.				
What percent of respondents with AC at home reported being uncomfortably hot?	7.82% (146)	6.52% (91)	8.25% (144)	6.12% (109)
What percent of respondents with AC reported being uncomfortably hot due to inadequate cooling capacity?	4.79% (7)	17.58% (16)	1.39% (2)	1.83% (2)

Household Responses to American Housing Survey Questions Related to Heat Risk and Cooling Problems 2023 Metropolitan Statistical Areas (MSA) (Shown as absolute numbers and percentages)				
AHS Research Questions	Cincinnati (N= 1936)	Cleveland (N=1555)	Detroit (N=1986)	Milwaukee (N=1905)
What percent of respondents with AC reported being uncomfortably hot due to leaking windows, doors, and walls?	1.37% (2)	2.20% (2)	2.08% (3)	4.59% (5)
What percent of respondents with AC reported being uncomfortably hot due to inadequate insulation?	2.74% (4)	3.30% (3)	7.64% (6)	5.50% (11)
What percent of respondents with AC reported being uncomfortably hot due to limiting use of AC due to the cost of electricity?	3.42% (5)	2.20% (2)	1.39% (2)	7.34% (8)
What percent of respondents with AC reported going to the emergency room due to heat?	0.92% (18)	1.09% (17)	0.70% (14)	0.78% (15)
What percent of respondents without AC reported going to the emergency room due to heat?	0.05% (1)	0.06% (1)	0.05% (1)	0.16% (3)

Source: American Housing Survey, 2023

Table 5.

Household Responses to American Housing Survey Questions Related to Power Outages 2023 Metropolitan Statistical Areas (MSA) (Shown as absolute numbers and percentages)				
AHS Research Questions	Cincinnati (N=1936)	Cleveland (N=1555)	Detroit (N=1986)	Milwaukee (N=1905)
What percentage of residents experienced a power outage?	14.56% (272)	15.13% (211)	21.55% (376)	14.61% (260)
The following rows are a subset of the total number surveyed. Responses are filtered by the percentage of respondents who experienced power outages.				
What percent of respondents reported being uncomfortably hot due to utility interruption or power outage?	14.38% (21)	4.40% (4)	21.55% (51)	14.61% (12)
What percent of respondents reported spoiled food due to power outage?	13.24% (36)	9.48% (20)	34.57% (130)	14.23% (37)
What percent of respondents reported having electrically powered medical devices?	44.12% (120)	48.34% (102)	25.53% (96)	36.92% (96)
What percent of respondents reported spoiled refrigerated medicine due to power outage?	0.74% (2)	1.42% (3)	4.26% (16)	2.69% (7)
What percent of respondents reported having to leave home and stay somewhere overnight due to power outage?	10.66% (29)	8.53% (18)	23.67% (89)	6.15% (16)

Household Responses to American Housing Survey Questions Related to Power Outages 2023 Metropolitan Statistical Areas (MSA) (Shown as absolute numbers and percentages)				
AHS Research Questions	Cincinnati (N=1936)	Cleveland (N=1555)	Detroit (N=1986)	Milwaukee (N=1905)
What percent of respondents reported missing work due to power outage?	4.78% (13)	2.37% (5)	12.50% (47)	5.38% (14)

Source: American Housing Survey, 2023

AHS Research Results

The 2023 American Housing Survey data reveal notable variations in cooling access and heat-related challenges across the four Midwestern metropolitan statistical areas (MSAs) in our study: Cincinnati, Cleveland, Detroit and Milwaukee.

Access to Air Conditioning

Detroit reported the highest rate of households without air conditioning (12.13%, n=241), followed by Cleveland (10.28%, n=160), Milwaukee (6.5%, n=125), and Cincinnati with the lowest rate (3.5%, n=68).

Thermal Discomfort

When asked whether they experienced extreme heat inside their homes, 8.26% (n=164) of Detroit respondents affirmed, followed by Cincinnati (7.49%, n=145), Milwaukee (6.72%, n=128), and Cleveland (6.24%, n=97). Among households with air conditioning, Detroit (8.25%, n=144) and Cincinnati (7.82%, n=146) reported the highest percentages of respondents still experiencing thermal discomfort. This was slightly lower in Cleveland (6.52%, n=91) and Milwaukee (6.12%, n=109).

A notable share of households across all four cities indicated their homes stay cool without any equipment: Cleveland (16.14%, n=211), Milwaukee (14.49%, n=260), Cincinnati (13.53%, n=272), and Detroit (13.34%, n=376). This was calculated as a percentage of total respondents.

Causes of Thermal Discomfort

We calculated proportions for seven different reasons for experiencing thermal discomfort (feeling uncomfortably hot) for more than 24 hours. These were cooling equipment

breakdown, inadequate cooling capacity, costs of cooling, leaky windows, insufficient insulation, utility interruptions and outages and; other reasons not listed.

Breakdowns in cooling equipment were reported most frequently by respondents in Cleveland (29.67%, n=27), followed by Milwaukee (6.42%, n=7), Cincinnati (6.16%, n=9), and Detroit (2.78%, n=4). In terms of cooling capacity, Cleveland stood out, with 17.58% (n=16) of AC-equipped households reporting inadequate cooling, compared to Cincinnati (4.79%, n=7), Milwaukee (1.83%, n=2), and Detroit (1.39%, n=2).

Uncomfortable indoor heat was also frequently attributed to structural issues such as poor insulation and air leaks. Respondents in Milwaukee reported the highest rate of discomfort due to leaks around windows, doors, and walls (4.59%, n=5), followed by Cleveland (2.20%, n=2), Detroit (2.08%, n=3), and Cincinnati (1.37%, n=2). Inadequate insulation was most commonly cited in Detroit (7.64%, n=6), with lower rates in Milwaukee (5.50%, n=11), Cleveland (3.30%, n=3), and Cincinnati (2.74%, n=4).

When asked whether households limit AC usage due to high costs, Milwaukee had the highest percentage of respondents limiting AC use due to electricity costs (7.34%, n=8), followed by Cincinnati (3.42%, n=5), Cleveland (2.20%, n=2), and Detroit (1.39%, n=2).

Finally, among those who experienced outages, 21.55% (n=51) of Detroit households reported being uncomfortably hot due to utility interruptions, compared to Milwaukee (14.61%, n=12), Cincinnati (14.38%, n=21), and Cleveland (4.40%, n=4).

Health Impacts

Overall emergency room visits due to heat were relatively rare but noteworthy. Interestingly, among households with AC, Cleveland (1.09%, n=17), Cincinnati (0.92%, n=18), Milwaukee (0.78%, n=15), Detroit (0.70%, n=14) more respondents reported going to the emergency room due to heat related issues. Whereas fewer respondents went to the ER among households without AC, Milwaukee (0.16%, n=3), Cleveland (0.06%, n=1), Cincinnati (0.05%, n=1), Detroit (0.05%, n=1).

Power Outage Incidence

Detroit had the highest reported incidence of power outages (21.55%, n=376), followed by Cleveland (15.13%, n=211), Milwaukee (14.61%, n=260), and Cincinnati (14.56%, n=272). Among those who experienced outages, 21.55% (n=51) of Detroit households reported being uncomfortably hot due to utility interruptions, compared to Milwaukee (14.61%, n=12), Cincinnati (14.38%, n=21), and Cleveland (4.40%, n=4).

Food spoilage due to outages was most prevalent in Detroit (34.57%, n=130), followed by Milwaukee (14.23%, n=37), Cleveland (13.24%, n=36), and Cincinnati (9.48%, n=20).

Refrigerated medicine spoilage, though less common, was highest in Detroit (4.26%, n=16), followed by Milwaukee (2.69%, n=7), Cincinnati (1.42%, n=3), and Cleveland (0.74%, n=2).

Respondents relying on electric medical devices during outages were most concentrated in Cleveland (48.34%, n=102) and Cincinnati (44.12%, n=120), with lower rates in Milwaukee (36.92%, n=96) and Detroit (25.53%, n=96).

Detroit had the highest rate of displacement due to outages (23.67%, n=89), followed by Cleveland (10.66%, n=29), Cincinnati (8.53%, n=18), and Milwaukee (6.15%, n=16). Work disruptions followed a similar pattern: Detroit (12.50%, n=47), Milwaukee (5.38%, n=14), Cleveland (4.78%, n=13), and Cincinnati (2.37%, n=5)

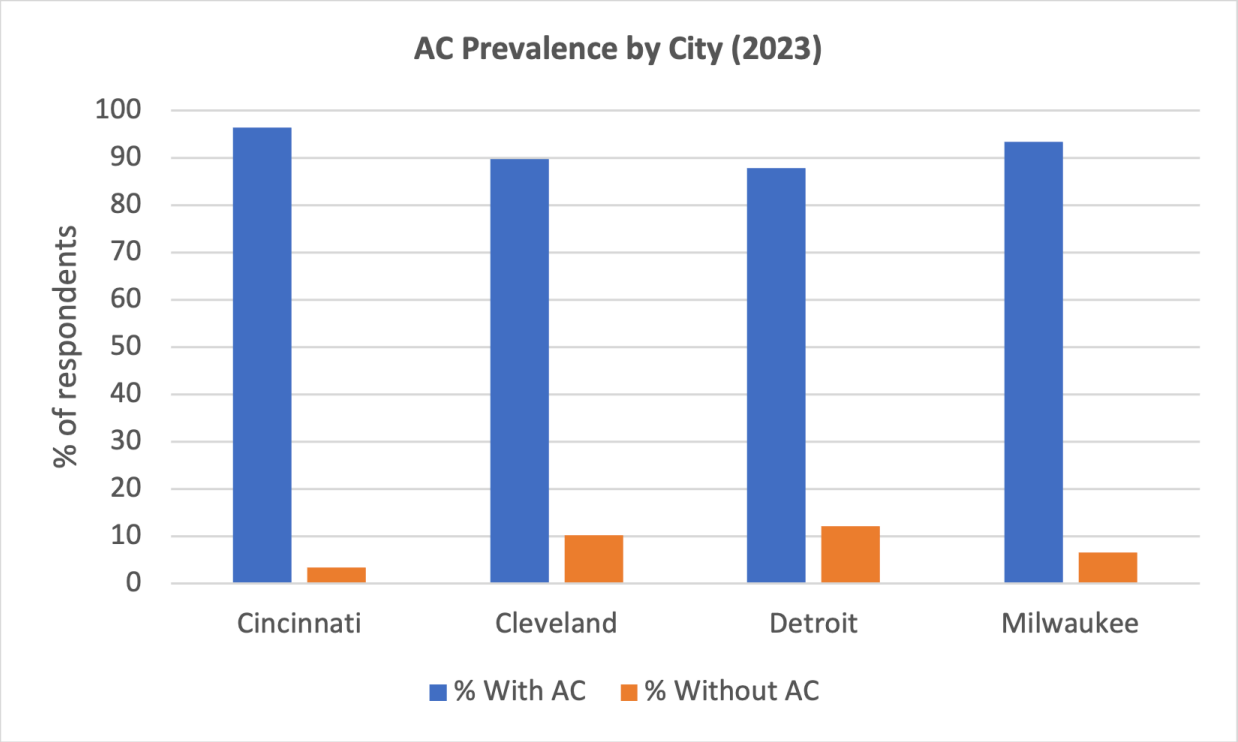


Figure 11: Data sources: American Housing Survey, 2023

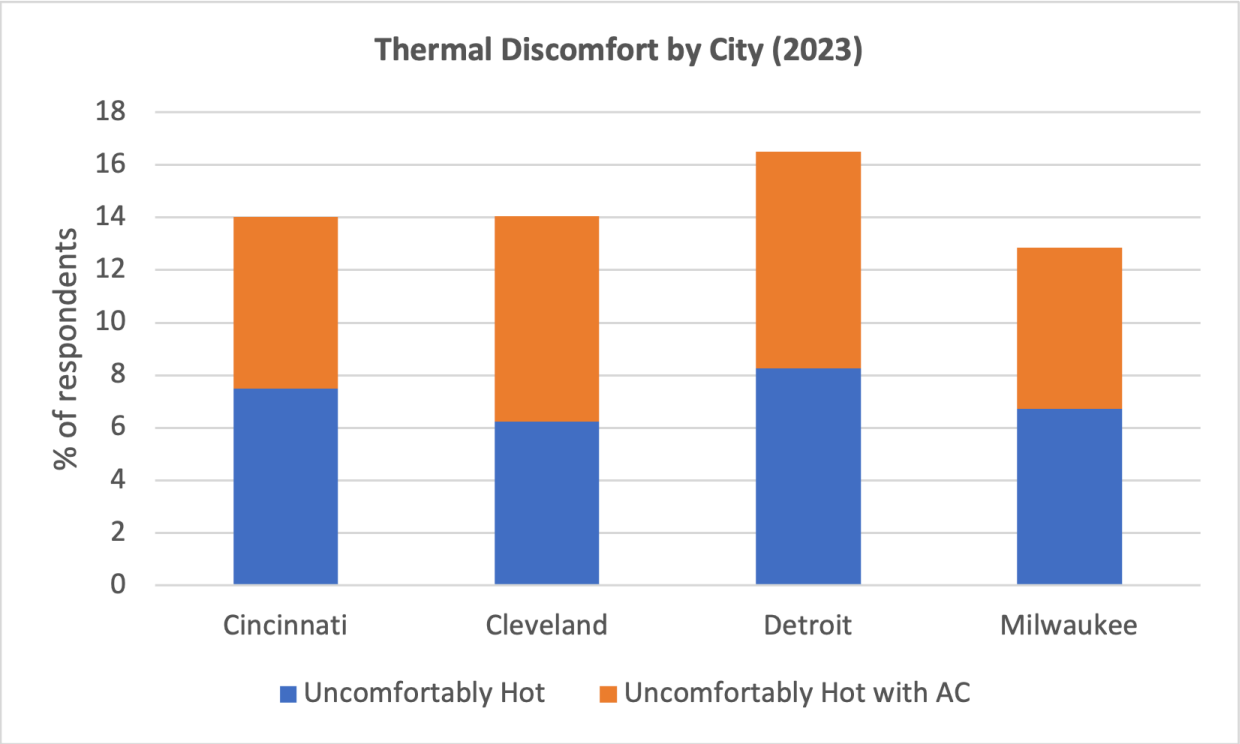


Figure 12: Data sources: American Housing Survey, 2023

CHAPTER 4: DISCUSSION

Limitation: Level of Geographic Analysis

The study was limited due to the level of geographic granularity available through the 2023 American Housing Survey. The most fine-grain geographical level the American Housing Survey presents is at the metropolitan statistical area. For comparison, the American Community Survey, which is also conducted through the Census Bureau, has a geographical level as specific as the census block level. As a result of being limited to a geographic boundary that includes areas outside of the legal boundaries of the legacy cities, the results cannot be directly attributable to the previously defined characteristics of each legacy city.

Implication: Skewed Results

Of particular importance is the inclusion of surrounding suburbs within the metropolitan statistical area. As mentioned previously, the legacy cities explored in this study all share a common history of population loss and economic decline. This shared pattern can be attributed in part to the phenomenon of suburbanization that was experienced broadly across the United States during the 1950s and 1960s, but may have been especially prominent in declining legacy cities where those who could afford to leave migrated to suburban municipalities. In conjunction with declining economies and suburbanization, the historical practice of redlining systematically segregated neighborhoods. As a result, communities of color, low-income, and in the case of the legacy cities studied in this case, Black/African American communities, were confined to urban centers, while whiter and wealthier communities congregated in the suburbs.

In regards to the results, the historically unique suburban-urban dynamic that exists in the study's four legacy cities suggests the difference in experienced heat burden may be dramatically different between suburban and urban communities. Especially when combined with:

(1) the known difference in heat indexes between suburban and urban areas,

(2) the known importance of socio-economic factors in contributing to energy burden, and

(3) the suburban-urban contrast between characteristics such as income, population, and race,

it is plausible to assume a similar difference between urban and suburban areas would be visible in regards to experienced heat burden. Therefore, the inclusion of suburban data presents the challenge of deciphering what heat challenges wealthier, more affluent, and more white populations are facing in suburban areas in comparison to the heat challenges that are being faced by poorer, less affluent, and majority black communities in the legacy cities.

Limitation: Small Data Set

The American Housing Survey has a sample size of roughly 2,000 for each metropolitan statistical area surveyed. The four legacy cities explored in this case had data with even fewer

than 2,000 respondents (1936 for Cincinnati; 1555 for Cleveland; 1986 for Detroit; and 1905 for Milwaukee). In addition, the American Housing Survey only surveys every other year. For comparison, the American Community Survey has a sample size of 3-3.5 million and surveys annually. In addition to having a relatively small sample size to begin with, the design of the 2023 American Housing Survey questions resulted in subsets of data that were even smaller.

This was particularly impactful for our study because our analysis relied heavily on filtering data by previous responses. The most prominent example is in the case of analyzing the responses to the survey question "Were you uncomfortably hot as a result of limiting your AC due to cost?" In this scenario, the original data had already been filtered for respondents who has reported having AC, then filtered again for respondents who reported having AC and being uncomfortably hot, and then filtered for a final time into the four categories "Equipment Breakdown," "Cost of Cooling," "Leakage/Insulation," and "other." The results are subsets of data with as few as 34 to 78 respondents depending on the metropolitan statistical area.

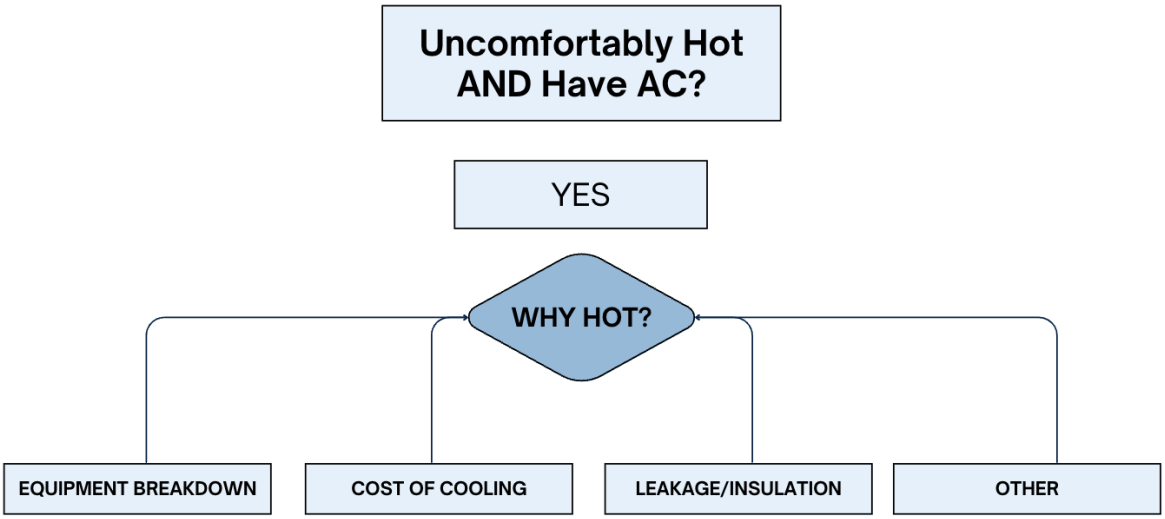


Figure 13. Diagram showing flow of survey questions

As a result of having a small data set for the questions explored in our study, there was reduction in the power of any statistical tests that could have been performed. Therefore, the analysis relies on interpretation of our results from a logical interpretation, wherein the results are contextualized within pre-existing literature to better understand the relative significance of the results. Greater efforts to collect data pertaining to heat risk, cooling problems, and power outages at a larger scale and with finer geographic granularity would allow for statistical analyses of the data to be more powerful. Accordingly, our team recommends that the test survey questions explored in the 2023 American Housing Survey should be included within the

American Community Survey which has the resources and funding to collect comprehensive data on these questions regarding heat risk, cooling problems, and power outages.

Interpretation of Results

Despite the small sample size and limited geographic granularity of the data, our results offer an important initial insight into the heat burden experienced by individuals in the four legacy cities. The results from our data show that of our legacy cities, Detroit and Cleveland have relatively high rates of households without AC. Additionally, our results show that individuals are experiencing heat burden even when the household has access to AC. Proportionally, inadequate cooling capacity, inadequate insulation, leaking windows, doors, and walls, and the cost of electricity make up roughly 12.32% to 25.28% of the reported reasoning for respondents who experienced being uncomfortably hot within the four legacy cities explored. These results suggest that not only the presence of AC, but also the characteristics/quality of housing stock contributes to individual experienced heat burden. Of particular interest to our study is that the relative proportion of respondents who limited use of AC due to electricity costs was relatively small (1.39% to 7.34%), implicating that AC may be a coping mechanism that individuals are willing to pay for even if it means sacrificing other goods and services.

Regarding power outages, it is notable that 21.55% of Detroit's MSA households reported experiencing a power outage, in comparison to 14.56% for Cincinnati, 15.13% for Cleveland, and 14.61% for Milwaukee. Moreover, this pattern carried forward in the subsequent finding that 21.55% of Detroit's MSA population that experienced a power outage were uncomfortably hot as a result, in comparison to 14.38% for Cincinnati, 4.40% for Cleveland, and 14.61% for Milwaukee. Beyond Detroit, around 14% of respondents who experienced a power outage were uncomfortably hot as a result in both Cleveland and Milwaukee. In addition to experiencing heat burden, at least 25% of the legacy cities respondents who experienced a power outage also reported having electrically-powered medical devices. The combination of reported heat burden as a result of power outages and reported electrically-powered medical devices suggests a potential exacerbation of pre-existing health conditions for individuals in the legacy cities, a characteristic that makes an individual more vulnerable to extreme heat. Therefore, these initial results offer a crucial initial insight into the realized impact of extreme heat, cooling problems, and power outages, and highlight the importance of continuing efforts to collect relevant data.

CHAPTER 5: CONCLUSION

Our study explored the experienced heat burden in residents of the four legacy cities Cincinnati, Cleveland, Detroit, and Milwaukee. Utilizing data from the American Housing Survey's 2023 test questions regarding heat burden, cooling problems, and power outages the study examined the following research questions:

1) How many people in our four cities have access to AC?

The results indicate that the majority of the population (87.87% - 96.5%) of each city's MSA has access to AC, with Cleveland and Detroit having the highest proportion of residents without access to AC (10.28% and 12.13% respectively).

2) How many people are experiencing heat burden (thermal discomfort)?

The results indicate that there is a considerable portion of the four cities' MSA populations (6.24%-8.26%) that experience heat burden, with Cincinnati and Detroit having the highest proportion of residents who experience heat burden (7.49% and 8.26% respectively).

3) To what degree is AC used as a coping mechanism?

We used survey questions as proxies to determine the relative effectiveness and implications of AC as a coping mechanism. The results indicate that although AC is prominent in the four legacy cities' MSA populations, simply having access to AC as a coping mechanism does not guarantee individuals are protected from extreme temperatures in their homes. Additionally, the results suggest that the cost of electricity does not greatly impact the use of AC as a coping mechanism, however our results cannot discern whether individuals sacrifice other necessities in order to afford the electricity costs associated with AC. Lastly, the results suggest that the characteristics of an individual's housing quality may be of greater importance than the cost of electricity, as the effectiveness of AC as a cooling mechanism is contingent on the quality of housing.

4) How is cooling ability impacted by grid failure?

The results indicate that grid outages that result in the failure of cooling equipment, cause a relatively considerable portion of the legacy cities' MSA populations to experience heat burden (4.4%-21.55%). Cleveland's MSA (14.38%), Detroit's MSA (21.55%), and Milwaukee's MSA (14.61%) had the highest rates of heat burden as a result of a power outage.

5) What are reported health impacts due to loss of AC, such as visits to the ER?

We were able to utilize specific survey questions as proxies to examine the relative health impacts. The results indicate that there are potentially considerable health impacts associated

with the concurrence of extreme heat and electrical grid outages, however the details of these impacts are beyond the scope of the data utilized in this study.

In combination, the results suggest that heat burden is an important human health concern in legacy cities. Especially when coupled with the general socio-economic conditions of legacy cities, increasing prevalence of extreme heat events, and the impact of extreme heat on the electrical grid there are important implications for policy makers and researchers moving forward. In regards to policy making, the results suggest that continued efforts to mitigate the urban heat island effect in legacy cities should be prioritized, paying particular attention to the most vulnerable communities. In regards to researchers, the results suggest that there are significant data patterns concerning heat burden and cooling problems in legacy cities. As the American Housing Survey's 2023 "test questions" explored in this study are revised and implemented in the coming years, it will be important to prioritize data collection at a finer geographic granularity in order to better understand the how the historical context of legacy cities is impacting experienced heat burden in comparison to surrounding suburbs.

BIBLIOGRAPHY

About the ACS. (n.d.). Retrieved April 8, 2025, from https://www.census.gov/programs-surveys/acs/about.html

Ahrentzen, S., Erickson, J., & Fonseca, E. (2016). Thermal and health outcomes of energy efficiency retrofits of homes of older adults. *Indoor Air*, *26*(4), 582–593. https://doi.org/10.1111/ina.12239

Aivalioti, S. (2015). *Electricity Sector Adaptation to Heat Waves* (SSRN Scholarly Paper 2563037). Social Science Research Network. https://papers.ssrn.com/abstract=2563037

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy*, *70*(3), 295–310. https://doi.org/10.1016/S0038-092X(00)00089-X

American Community Survey 5-Year Data (2009-2023). (n.d.). Census.Gov. Retrieved April 19, 2025, from https://www.census.gov/data/developers/data-sets/acs-5year.html

American Housing Survey for the Cleveland Metropolitan Area (H-170-88-45). (1990). Bureau of the Census. https://www2.census.gov/prod2/ahsscan/h170-8845.pdf

Anderson, G. B., & Bell, M. L. (2011). Heat waves in the United States: Mortality risk during heat waves and effect modification by heat wave characteristics in 43 U.S. communities. *Environmental Health Perspectives*, *119*, 210–218. https://doi.org/10.1289/ehp.1002313

Ayala, R., & Dewey, A. (2024, September). *Data Update: City Energy Burdens | ACEEE*. https://www.aceee.org/policy-brief/2024/09/data-update-city-energy-burdens

Banister, D. (2024). The Compact City. *Built Environment*, *50*(3), 507–534. https://doi.org/10.2148/benv.50.3.507

Banister, D., Marshall, S., & Natajaran, L. (2024). Built Environment at Fifty: Perspectives, Landmarks, and Prospects. *Built Environment*, *50*(3), 389–397. https://doi.org/10.2148/benv.50.3.389

Bartos, M., Chester, M., Johnson, N., Gorman, B., Eisenberg, D., Linkov, I., & Bates, M. (2016). Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States. *Environmental Research Letters*, *11*(11), 114008. https://doi.org/10.1088/1748-9326/11/11/114008

Basu, R. (2009). High ambient temperature and mortality: A review of epidemiologic studies from 2001 to 2008. *Environmental Health*, *8*(1), 40. https://doi.org/10.1186/1476-069X-8-40

Basu, R., Malig, B., & Ostro, B. (2010). High Ambient Temperature and the Risk of Preterm Delivery. *American Journal of Epidemiology*, *172*(10), 1108–1117. https://doi.org/10.1093/aje/kwq170

Beat The Heat: Extreme Heat. (n.d.). U.S. Center for Disease Control and Prevention. Retrieved April 21, 2025, from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cdc.gov/extreme-heat/media/pdf/beat-the-heat-2017.pdf.pdf

Berland, A., Schwarz, K., Herrmann, D., & Hopton, M. (2015). How Environmental Justice Patterns are Shaped by Place: Terrain and Tree Canopy in Cincinnati, Ohio, USA. *Cities and the Environment (CATE)*, *8*(1). https://digitalcommons.lmu.edu/cate/vol8/iss1/1

Bowser, R. M. M., Morgan D. Bazilian, Jacob Kincer, Brooke. (n.d.). *Air-Conditioning Should Be a Human Right in the Climate Crisis*. Scientific American. Retrieved January 25, 2025, from https://www.scientificamerican.com/article/air-conditioning-should-be-a-human-right-in-the-climate-crisis/

Built Environment. (n.d.). Alexandrine Press. Retrieved January 25, 2025, from https://www.ingentaconnect.com/content/alex/benv

Built Environment (1978-) | JSTOR. (n.d.). Retrieved January 25, 2025, from https://www.jstor.org/journal/builenvi1978

Bureau, U. C. (n.d.-a). *About the American Community Survey*. Census.Gov. Retrieved April 22, 2025, from https://www.census.gov/programs-surveys/acs/about.html

Bureau, U. C. (n.d.-b). *AHS 1988 Summary Tables*. Census.Gov. Retrieved April 19, 2025, from https://www.census.gov/programs-surveys/ahs/data/1988/ahs-1988-summary-tables.html

Bureau, U. C. (n.d.-c). *American Community Survey 1-Year Data (2005-2023)*. Census.Gov. Retrieved April 19, 2025, from https://www.census.gov/data/developers/data-sets/acs-1year.html

Bureau, U. C. (n.d.-d). *American Housing Survey (AHS)*. Census.Gov. Retrieved April 19, 2025, from https://www.census.gov/AHS

Carley, S., Graff, M., Konisky, D. M., & Memmott, T. (2022). Behavioral and financial coping strategies among energy-insecure households. *Proceedings of the National Academy of Sciences*, *119*(36), e2205356119. https://doi.org/10.1073/pnas.2205356119

Case Western Reserve. (2018a, May 28). *ECONOMY | Encyclopedia of Cleveland History | Case Western Reserve University*. https://case.edu/ech/articles/e/economy

Case Western Reserve. (2018b, June 14). *SUBURBS | Encyclopedia of Cleveland History | Case Western Reserve University*. https://case.edu/ech/articles/s/suburbs

Case Western Reserve. (2022, June 25). *ETHNIC AND RACE RELATIONS | Encyclopedia of Cleveland History | Case Western Reserve University*. https://case.edu/ech/articles/e/ethnic-and-race-relations

CDC. (n.d.). *Extreme Heat | A Prevention Guide to Promote Your Personal Health and Safety*. Retrieved April 21, 2025, from https://web.archive.org/web/20041021114216/www.bt.cdc.gov/disasters/extremeheat/heat_guide.asp

Climate Change and Extreme Heat Events. (n.d.). U.S. Center for Disease Control and Prevention. Retrieved April 21, 2025, from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.cdc.gov/climate-health/media/pdfs/ClimateChangeandExtremeHeatEvents.pdf

Climate change indicators in the United States (EPA 430-R-14-004). (2014). U.S. Environmental Protection Agency. https://www.epa.gov/sites/default/files/2016-07/documents/climateindicators-full-2014.pdf

Contreras-Lisperguer, R., & de Cuba, K. (2008). *The Potential Impact of Climate Change on the Energy Sector in the Caribbean Region*.

Costello, M. (n.d.). Milwaukee River. *Encyclopedia of Milwaukee*. Retrieved April 1, 2025, from https://emke.uwm.edu/entry/milwaukee-river/

Cusack, L., van Loon, A., Kralik, D., Arbon, P., & Gilbert, S. (2013). Extreme weather-related health needs of people who are homeless. *Australian Journal of Primary Health*, *19*(3), 250–255. https://doi.org/10.1071/PY12048

Davis, Robert, Knappenberger, Paul, Michaels, Patrick, & Novicoff, Wendy. (2003, July 23). *Changing heat-related mortality in the United States.* https://doi.org/10.1289/ehp.6336

de Guzman, E. (2023). Evaluating the Impact of Trees on Residential Thermal Conditions in Los Angeles Using Community Science. *Cities and the Environment (CATE)*, *16*(2). https://doi.org/10.15365/cate.2023.160208

Dilworth, R., & Gardner, T. (2019). *White Flight*. https://doi.org/10.1002/9781118568446.eurs0413

Dugan, J., Chen-Glasser, M., & Mohagheghi, S. (2023). Associations Between Redlining and Social Vulnerability to Long-Duration Power Outages. *2023 IEEE Global Humanitarian Technology Conference (GHTC)*, 282–289. https://doi.org/10.1109/GHTC56179.2023.10354665

Energy Burden: What It Is and How Renewables Can Help. (2020, March 10). The Climate Reality Project. https://www.climaterealityproject.org/blog/energy-burden-what-it-and-how-renewables-can-help#:~:text=Energy%20burden%20can%20be%20a,to%20fight%20the%20climate%20crisis.

Finnigan, R., & Meagher, K. (2018, November). *Missed Housing and Utility Payments Are Common and Persistent in the United States*. Center for Poverty and Inequality Research. https://poverty.ucdavis.edu/policy-brief/missed-housing-and-utility-payments-are-common-and-persistent-united-states

Francomb, S. (2024, May 17). *A Semi-Brief History of the Cincinnatian Industrial Revolution—Journal of Cincinnati Thought*. https://cincinnatithought.com/a-semi-brief-history-of-the-cincinnatian-industrial-revolution/

**From Larissa_to read and file*. (n.d.). Google Drive. Retrieved February 3, 2025, from https://drive.google.com/drive/folders/1f0CC54H3sssjF_BMQn9z1MSJWwSQ6Ph2

Genter, S., Virgile, M., & Keeve, C. (2022, November 16). *Cognitive Pretesting of 2023 American Housing Survey Modules*. Census.Gov. https://www.census.gov/library/working-papers/2022/adrm/rsm2022-11.html

Gronlund, C. J. (2014). *Racial and socioeconomic disparities in heat-related health effects and their mechanisms: A review—PMC*. https://pmc.ncbi.nlm.nih.gov/articles/PMC4264980/

Gronlund, C. J., & Berrocal, V. J. (2020). Modeling and comparing central and room air conditioning ownership and cold-season in-home thermal comfort using the American Housing Survey. *Journal of Exposure Science & Environmental Epidemiology*, *30*(5), 814–823. https://doi.org/10.1038/s41370-020-0220-8

Groundwork Buffalo Feasibility Study. (2009). Urban Design Project. https://regional-institute.buffalo.edu/wp-content/uploads/sites/155/2020/11/Groundwork-Buffalo-Feasibility-Study.pdf

Gupta, S. D., Kundu, S., & Mallik, A. (2012). *Monitoring of Sag & Temperature in the Electrical Power Transmission lines*. *1*(4).

Harlan, S. L., Declet-Barreto, J. H., Stefanov, W. L., & Petitti, D. B. (2013). Neighborhood effects on heat deaths: Social and environmental predictors of vulnerability in Maricopa County, Arizona. *Environmental Health Perspectives*, *121*(2), 197–204. https://doi.org/10.1289/ehp.1104625

Heat and health. (2024, May 28). https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health

Heat Index | National Oceanic and Atmospheric Administration. (n.d.-a). Retrieved February 6, 2025, from https://www.noaa.gov/jetstream/synoptic/heat-index

Heat Index | National Oceanic and Atmospheric Administration. (n.d.-b). Retrieved April 22, 2025, from https://www.noaa.gov/jetstream/synoptic/heat-index

Heat-Related Deaths—Philadelphia and United States, 1993-1994. (1994, July 1). https://www.cdc.gov/mmwr/preview/mmwrhtml/00031773.htm

Heat-Related Mortality—Chicago, July 1995. (1995, November 7). https://www.cdc.gov/mmwr/preview/mmwrhtml/00038443.htm

Helfand, J., & Doremus, F. (2020). *Docuseek | Cooked*. https://docuseek2.com/bf-cook

Howden-Chapman, P., Bennett, J., Edwards, R., Jacobs, D., Nathan, K., & Ormandy, D. (2023). Review of the Impact of Housing Quality on Inequalities in Health and Well-Being. *Annual Review of Public Health*, *44*(Volume 44, 2023), 233–254. https://doi.org/10.1146/annurev-publhealth-071521-111836

Hyde, C. K. (2013). *Arsenal of Democracy The American Automobile Industry in World War II*. Wayne State University Press. https://wsupress.wayne.edu/9780814339510/

James Chen (2025, February 25). *Rust Belt: Definition, Why It's Called That, List of States*. Investopedia. https://www.investopedia.com/terms/r/rust-belt.asp

Kaiser, R., Le Tertre, A., Schwartz, J., Gotway, C. A., Daley, W. R., & Rubin, C. H. (2007). The Effect of the 1995 Heat Wave in Chicago on All-Cause and Cause-Specific Mortality. *American Journal of Public Health*, *97*(Suppl 1), S158–S162. https://doi.org/10.2105/AJPH.2006.100081

Kalkstein, L. S., Greene, S., Mills, D. M., & Samenow, J. (2011). An evaluation of the progress in reducing heat-related human mortality in major U.S. cities. *Natural Hazards*, *56*(1), 113–129. https://doi.org/10.1007/s11069-010-9552-3

Kent, S. T., McClure, L. A., Zaitchik, B. F., Smith, T. T., & Gohlke, J. M. (2014). Heat Waves and Health Outcomes in Alabama (USA): The Importance of Heat Wave Definition. *Environmental Health Perspectives*, *122*(2), 151–158. https://doi.org/10.1289/ehp.1307262

Kishanrao, S. (2024). Extremes of Weather Conditions and Child Health. *Open Journal of Pediatrics and Child Health*, *9*(1), 050–057. https://doi.org/10.17352/ojpch.000058

Klein, T., & Anderegg, W. R. L. (2021). A vast increase in heat exposure in the 21st century is driven by global warming and urban population growth. *Sustainable Cities and Society*, *73*, 103098. https://doi.org/10.1016/j.scs.2021.103098

Klinenberg, E. (2015). *Heat Wave: A Social Autopsy of Disaster in Chicago, Klinenberg*. https://press.uchicago.edu/ucp/books/book/chicago/H/bo20809880.html

Kovats, R. S., & Hajat, S. (2008). Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*, *29*(Volume 29, 2008), 41–55. https://doi.org/10.1146/annurev.publhealth.29.020907.090843

Kumar, K. (1978). First In, First Out? Britain as a Post-Industrial Society. *Built Environment (1978-)*, *4*(4), 257–265.

Kunkel, K. E., Stevens, L. E., Stevens, S. E., Sun, L., Janssen, E., Wuebbles, D., Konrad, C. E., Fuhrman, C. M., Keim, B. D., Kruk, M. C., Billot, A., Needham, H., Shafer, M., & Dobson, J. G. (2013). *Regional Climate Trends and Scenarios for the U.S. National Climate Assessment: Part 2. Climate of the Southeast U.S.* https://repository.library.noaa.gov/view/noaa/56807

Larsen. (2024, February 4). Measuring A/C Access To Prepare Against Extreme Heat. *Federation of American Scientists*. https://fas.org/publication/air-conditioning-data/

Larsen, L., Gronlund, C. J., Ketenci, K. C., Harlan, S. L., Hondula, D. M., Stone Jr., B., Lanza, K., Mallen, E., Wright, M. K., & O'Neill, M. S. (2023). Safe at Home? *Journal of the American Planning Association*, *89*(3), 363–375. https://doi.org/10.1080/01944363.2022.2087724

Lavigne, E., Gasparrini, A., Wang, X., Chen, H., Yagouti, A., Fleury, M. D., & Cakmak, S. (2014). Extreme ambient temperatures and cardiorespiratory emergency room visits: Assessing risk by comorbid health conditions in a time series study. *Environmental Health*, *13*(1), 5. https://doi.org/10.1186/1476-069X-13-5

Li, L., Zha, Y., & Wang, R. (2020). Relationship of surface urban heat island with air temperature and precipitation in global large cities. *Ecological Indicators*, *117*, 106683. https://doi.org/10.1016/j.ecolind.2020.106683

Lin, S., Luo, M., Walker, R. J., Liu, X., Hwang, S.-A., & Chinery, R. (2009). Extreme High Temperatures and Hospital Admissions for Respiratory and Cardiovascular Diseases. *Epidemiology*, *20*(5), 738. https://doi.org/10.1097/EDE.0b013e3181ad5522

Lise, W., & Van Der Laan, J. (2015). Investment needs for climate change adaptation measures of electricity power plants in the EU. *Energy for Sustainable Development*, *28*, 10–20. https://doi.org/10.1016/j.esd.2015.06.003

Loughnan, M., Carroll, M., & Tapper, N. J. (2015). The relationship between housing and heat wave resilience in older people. *International Journal of Biometeorology*, *59*(9), 1291–1298. https://doi.org/10.1007/s00484-014-0939-9

Luber, G., & McGeehin, M. (2008). Climate Change and Extreme Heat Events. *American Journal of Preventive Medicine*, *35*(5), 429–435. https://doi.org/10.1016/j.amepre.2008.08.021

Madamba, P. (2024, February 10). *About 1 in 4 Households Experienced a Power Outage in the Span of a Year*. Census.Gov. https://www.census.gov/library/stories/2024/10/power-outages.html

Madrigano, J., Mittleman, M. A., Baccarelli, A., Goldberg, R., Melly, S., von Klot, S., & Schwartz, J. (2013). Temperature, Myocardial Infarction, and Mortality: Effect Modification by Individual- and Area-level Characteristics. *Epidemiology*, *24*(3), 439. https://doi.org/10.1097/EDE.0b013e3182878397

Magavern, S. (2007). *Affordable Housing and the Environment In Buffalo, New York*. https://ecommons.cornell.edu/server/api/core/bitstreams/37df6850-014b-49fd-9be9-e45f6835680e/content

Marshall, Madeline. (2021, March 4). *Texas's power disaster is a warning sign for the US*. Vox.Com. https://volume.vox-cdn.com/embed/4138d6c0f

Marshall, S. (2024). Enabling Vital Streets. *Built Environment*, *50*(3), 433–471. https://doi.org/10.2148/benv.50.3.433

Mateyka, P. J., & Yoo, J. (2023, February 3). *Share of Income Needed to Pay Rent Increased the Most for Low-Income Households From 2019 to 2021*. Census.Gov. https://www.census.gov/library/stories/2023/03/low-income-renters-spent-larger-share-of-income-on-rent.html

McGough, D., & Norry, L. (1988). *American Housing Survey for the United States in 1985* (H-150-85). https://www2.census.gov/prod2/ahsscan/h150-85.pdf

Mcwhirter, S. (2024, September 26). *Frailty of Michigan's power grid revealed in 'deep dive' audit of DTE, Consumers Energy—Mlive.com*. https://www.mlive.com/environment/2024/09/frailty-of-michigans-power-grid-revealed-in-deep-dive-audit-of-dte-consumers-energy.html

Merry, K., Siry, J., Bettinger, P., & Bowker, J. M. (2014). Urban tree cover change in Detroit and Atlanta, USA, 1951–2010. *Cities*, *41*, 123–131. https://doi.org/10.1016/j.cities.2014.06.012

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1–24. https://doi.org/10.1002/qj.49710845502

Orum Anthony (n.d.). Economy. *Encyclopedia of Milwaukee*. Retrieved April 1, 2025, from https://emke.uwm.edu/entry/economy/

Overbey, S. (2020a, May 12). *Redlining in Cincinnati: Effects on Black Well Being*. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/d76e295c27bc45deba50273ac9fc06fd

Overbey, S. (2020b, May 12). *Redlining in Cincinnati: Effects on Black Well Being*. ArcGIS StoryMaps. https://storymaps.arcgis.com/stories/d76e295c27bc45deba50273ac9fc06fd

Parker, D. E. (2010a). Urban heat island effects on estimates of observed climate change. *WIREs Climate Change*, *1*(1), 123–133. https://doi.org/10.1002/wcc.21

Parker, D. E. (2010b). Urban heat island effects on estimates of observed climate change. *WIREs Climate Change*, *1*(1), 123–133. https://doi.org/10.1002/wcc.21

Phelan, P. E., Kaloush, K., Miner, M., Golden, J., Phelan, B., Iii, H. S., & Taylor, R. A. (2015). Urban Heat Island: Mechanisms, Implications, and Possible Remedies. *Annual Review of Environment and Resources*, *40*(Volume 40, 2015), 285–307. https://doi.org/10.1146/annurev-environ-102014-021155

Quality (CEQ), T. C. on E. (2025). *Extracted Data from: Climate and Economic Justice Screening Tool 2.0 (CEJST / Justice40 2.0)* [Dataset]. Harvard Dataverse. https://doi.org/10.7910/DVN/XRNMXK

Reames, T. G. (2016). Targeting energy justice: Exploring spatial, racial/ethnic and socioeconomic disparities in urban residential heating energy efficiency. *Energy Policy*, *97*, 549–558. https://doi.org/10.1016/j.enpol.2016.07.048

Sailor, D. J. (2014). Risks of summertime extreme thermal conditions in buildings as a result of climate change and exacerbation of urban heat islands. *Building and Environment*, *78*, 81–88. https://doi.org/10.1016/j.buildenv.2014.04.012

Sampson, N. R., Gronlund, C. J., Buxton, M. A., Catalano, L., White-Newsome, J. L., Conlon, K. C., O'Neill, M. S., McCormick, S., & Parker, E. A. (2013). Staying cool in a changing climate: Reaching vulnerable populations during heat events. *Global Environmental Change: Human and Policy Dimensions*, *23*(2), 475–484. https://doi.org/10.1016/j.gloenvcha.2012.12.011

Sarofim, M., Saha, S., Hawkins, M. D., & Mills, D. M. (2016). *Chapter 2: Temperature-Related Death and Illness | Climate and Health Assessment*. https://health2016.globalchange.gov/temperature-related-death-and-illness

Smith, T. T., Zaitchik, B. F., & Gohlke, J. M. (2013). Heat waves in the United States: Definitions, patterns and trends. *Climatic Change*, *118*(3), 811–825. https://doi.org/10.1007/s10584-012-0659-2

Steinmetz, G. (2009). Detroit: A Tale of Two Crises. *Environment and Planning D*, *27*(5), 761–770. https://doi.org/10.1068/d2705ed

Stone, B., Hess, J. J., & Frumkin, H. (2010). Urban Form and Extreme Heat Events: Are Sprawling Cities More Vulnerable to Climate Change Than Compact Cities? *Environmental Health Perspectives*, *118*(10), 1425–1428. https://doi.org/10.1289/ehp.0901879

Stone, B. Jr., Gronlund, C. J., Mallen, E., Hondula, D., O'Neill, M. S., Rajput, M., Grijalva, S., Lanza, K., Harlan, S., Larsen, L., Augenbroe, G., Krayenhoff, E. S., Broadbent, A., & Georgescu, M. (2023). How Blackouts during Heat Waves Amplify Mortality

and Morbidity Risk. *Environmental Science & Technology*, *57*(22), 8245–8255. https://doi.org/10.1021/acs.est.2c09588

Stone, B., Mallen, E., Rajput, M., Broadbent, A., Krayenhoff, E. S., Augenbroe, G., & Georgescu, M. (2021). Climate change and infrastructure risk: Indoor heat exposure during a concurrent heat wave and blackout event in Phoenix, Arizona. *Urban Climate*, *36*, 100787. https://doi.org/10.1016/j.uclim.2021.100787

Stone, B., & Rodgers, M. O. (2001). Urban Form and Thermal Efficiency: *How the Design of Cities Influences the Urban Heat Island Effect*. *Journal of the American Planning Association*, *67*(2), 186–198. https://doi.org/10.1080/01944360108976228

Stone, J., Brian. (2012). *The City and the Coming Climate: Climate Change in the Places We Live*. Cambridge University Press. https://doi.org/10.1017/CBO9781139061353

Stone Jr., B., & Rodgers, M. O. (2001). Urban Form and Thermal Efficiency: How the Design of Cities Influences the Urban Heat Island Effect. *Journal of the American Planning Association*, *67*(2), 186–198. https://doi.org/10.1080/01944360108976228

Suburbanization and Segregation in Detroit. (n.d.). *The North | Newark*. Retrieved April 1, 2025, from https://riseupnewark.com/suburbanization-segregation-detroit/

The Demographic Statistical Atlas of the United States—Statistical Atlas. (n.d.-a). Retrieved April 19, 2025, from https://statisticalatlas.com/metro-area/Ohio/Cincinnati/Overview

The Demographic Statistical Atlas of the United States—Statistical Atlas. (n.d.-b). Retrieved April 22, 2025, from https://statisticalatlas.com/metro-area/Ohio/Cincinnati/Overview

The Demographic Statistical Atlas of the United States—Statistical Atlas. (n.d.-c). Retrieved April 22, 2025, from https://statisticalatlas.com/metro-area/Michigan/Detroit/Overview

The Demographic Statistical Atlas of the United States—Statistical Atlas. (n.d.-d). Retrieved April 22, 2025, from https://statisticalatlas.com/metro-area/Wisconsin/Milwaukee/Overview

The Demographic Statistical Atlas of the United States—Statistical Atlas. (n.d.-e). Retrieved April 22, 2025, from https://statisticalatlas.com/metro-area/Michigan/Detroit/Overview

Toni L. Griffin, Esther Yang, Michele Flournoy, & Julie Bartocci. (2015, September 14). *Mapping America's Legacy Cities*. J.Max Bond Center on Design for the Just City. https://ssa.ccny.cuny.edu/wp-content/uploads/2015/12/MappingAmericanLegacyCities_15Dec2015.pdf

Urban Forests Case Studies: Challenges, Potential and Success in a Dozen Cities. (2012). American Forests.

US Department of Commerce, N. (n.d.). *During a Heat Wave*. NOAA's National Weather Service. Retrieved February 7, 2025, from https://www.weather.gov/safety/heat-during

U.S. Department of Energy Grid Deployment Office. (2023, October 19). *What does it take to modernize the U.S. electric grid?* Energy.Gov. https://www.energy.gov/gdo/articles/what-does-it-take-modernize-us-electric-grid

US EPA, O. (2022, January 10). *U.S. Electricity Grid & Markets* [Overviews and Factsheets]. https://www.epa.gov/green-power-markets/us-electricity-grid-markets

Vaidyanathan, A. (2020). Heat-Related Deaths—United States, 2004–2018. *MMWR. Morbidity and Mortality Weekly Report*, *69*. https://doi.org/10.15585/mmwr.mm6924a1

Wagner, G. (2018). *Rust and Renewal: A Cincinnati Retrospective*. Federal Reserve Bank of Cleveland. file:///Users/maggiecooney/Downloads/report%20cincinnati%20(2).pdf

Walton, R. (2024, September 18). *Rising demand could drive US wholesale electricity prices 19% higher by 2028: ICF*. Utility Dive. https://www.utilitydive.com/news/us-electricity-prices-19-percent-higher-2028-ICF/727317/

What Is an Urban Heat Island? (n.d.). NASA Climate Kids. Retrieved April 8, 2025, from https://climatekids.nasa.gov/heat-islands/

Williams, A. A., Spengler, J. D., Catalano, P., Allen, J. G., & Cedeno-Laurent, J. G. (2019). Building Vulnerability in a Changing Climate: Indoor Temperature Exposures and Health Outcomes in Older Adults Living in Public Housing during an Extreme Heat Event in Cambridge, MA. *International Journal of Environmental Research and Public Health*, *16*(13), Article 13. https://doi.org/10.3390/ijerph16132373

Wilson, B. (2020). Urban Heat Management and the Legacy of Redlining. *Journal of the American Planning Association*, *86*(4), 443–457. https://doi.org/10.1080/01944363.2020.1759127

Worfolk, J. B. (2000). Heat Waves: Their Impact on the Health of Elders. *Geriatric Nursing*, *21*(2), 70–77. https://doi.org/10.1067/mgn.2000.107131

Wuebbles, D. J., & Hayhoe, K. (2004). Climate Change Projections for the United States Midwest. *Mitigation and Adaptation Strategies for Global Change*, *9*(4), 335–363. https://doi.org/10.1023/B:MITI.0000038843.73424.de

Xu, Z., Etzel, R. A., Su, H., Huang, C., Guo, Y., & Tong, S. (2012). Impact of ambient temperature on children's health: A systematic review. *Environmental Research*, *117*, 120–131. https://doi.org/10.1016/j.envres.2012.07.002

Zamuda, C. D., Bilello, D. E., Carmack, J., Davis, X. J., Efroymson, R. A., Goff, K. M., Hong, T., Karimjee, A., Loughlin, D. H., Upchurch, S., & Voisin, N. (2023). Energy Supply, Delivery, and Demand. In *Fifth National Climate Assessment*. U.S. Global Change Research Program, Washington, DC. https://nca2023.globalchange.gov/chapter/5/

Zamuda, C., Mignone, Bryan, Bilello, Dan, Hallet, KC, Lee, Courtney, Macknick, Jordan, Newmark, Robin, & Steinberg, Daniel. (2013). *US Energy Sector Vulnerabilities to Climate Change*. U.S. Department of Energy.

Zehner, E., Bernstein, A. E., & Jason, W. (2020, September 9). *Lincoln Institute of Land Policy Launches Legacy Cities Initiative*. Lincoln Institute of Land Policy. https://www.lincolninst.edu/publications/articles/2020-09-lincoln-institute-land-policy-launches-legacy-cities-initiative/

APPENDIX 1. Research Questions, Variables, Survey Questions & Response Codes

AHS Research Questions Heat Risk & Cooling Problems	Primary & Instrument Variables & Survey Question Referenced	Response Codes
What percent of respondents were without AC at home?	ACPRIMARY is used; determined based on responses to multiple questions about air conditioning systems, including whether the home has a heat pump or central air (AIRSYS1, AIRSYS2, OARSYS1, OARSYS2), the use and number of room air conditioners (AIR, NUMAIR), and the type of fuel used by primary and secondary systems (AFUEL, OAFUEL).	01: Electric powered central air conditioning system 02: Piped gas powered central air conditioning system 03: Liquefied petroleum gas powered central air conditioning system 04: Other fuel source powered air conditioning system 05: 1 room air conditioner 06: 2 room air conditioners 07: 3 room air conditioners 08: 4 room air conditioners 09: 5 room air conditioners 10: 6 room air conditioners 11: 7 or more room air conditioners 12: No air conditioning
What percent of respondents experienced extreme heat within their homes?	HOT; HOTUNIT: In the past 12 months for any reason, was your unit so hot for 24 hours or more that you were uncomfortable?	1: Yes 2: No M or -9: Not reported N or -6: Not applicable
What percent of respondents reported being uncomfortably hot due to cooling equipment breakdown?	ACBREAK: [Was your unit so hot] because the MAIN cooling equipment broke down?	1: Yes 2: No
What percent of respondents reported being uncomfortably hot due to utility interruption or power outage?	HOTOTHER; HOTUTIL; OTHHOT2: What was the reason your unit was uncomfortably hot for 24 hours or more?	Enter all that apply, separate with commas 1. Utility interruption or power outage 2. Inadequate cooling capacity 3. Leaking windows, doors, and walls 4. Inadequate insulation 5. Cost of cooling 6. Other 1: Yes 2: No M or -9: Not reported N or -6: Not applicable
What percent of respondents with AC reported being uncomfortably hot due to inadequate cooling capacity?		
What percent of respondents with AC reported being uncomfortably hot due to leaking windows, doors, and walls?		
What percent of respondents with AC reported being uncomfortably hot due to inadequate insulation?		
What percent of respondents with AC reported being uncomfortably hot due to limiting use of AC due to the cost of		

electricity?		
What percent of respondents reported that their home stays cool without any cooling equipment?	STAYCOOL: How well does your unit stay cool in HOT WEATHER without the aid of air conditioning or other cooling device? Would you say Very well, Somewhat well, Not very well, or Not well at all?	1: Very well 2: Somewhat well 3: Not very well 4: Not well at all M or -9: Not reported N or -6: Not applicable
What percent of respondents with AC reported going to the hospital due to heat?	ERHEATREL: [During the last 12 months/since you've lived here], did any household member visit an emergency room or urgent care center due to heat stroke or other heat-related illness?	1: Yes 2: No M or -9: Not reported N or -6: Not applicable
What percent of respondents without AC reported going to the hospital due to heat?		
AHS Research Questions Power Outages	**Primary & Instrument Variables & Survey Question Referenced**	**Response Codes**
What percentage of residents experienced a power outage?	OUTAGE: Was your home ever completely without power (since you've lived here/since your household has lived here/in the last 12 months) that is, since (date)?	1: Yes 2: No M or -9: Not reported N or -6: Not applicable
What percent of respondents reported spoiled food due to power outage?	OUTFOOD: (In the past 12 months/ Since you have lived here) has any food spoiled as a result of a power outage?	1: Yes 2: No M or -9: Not reported N or -6: Not applicable
What percent of respondents reported having electrically powered medical devices?	OUTMEDDEV: Do you (or anyone in your household) have any medical devices in your home that are important to health and that require electrical power to operate?	1: Yes 2: No M or -9: Not reported N or -6: Not applicable
What percent of respondents reported spoiled refrigerated medicine due to power outage?	OUTMED: (In the past 12 months/ Since you have lived here) did any refrigerated medicine spoil (as a result of a power outage)?	1: Yes 2: No 3: No refrigerated medicine M or -9: Not reported N or -6: Not applicable
What percent of respondents reported having to leave home and stay somewhere overnight due to power outage?	OUTSTAY: In the past 12 months/ Since you have lived here) did you (or anyone in your household) have to leave your home and stay somewhere else overnight as a result of a power outage?	1: Yes 2: No M or -9: Not reported N or -6: Not applicable
What percent of respondents reported	OUTWORK: (In the past 12 months/	1: Yes

missing work due to power outage?	Since you have lived here) did you (or anyone in your household) miss work (as a result of a power outage)?	2: No 3: Did not have work M or -9: Not reported N or -6: Not applicable