Understanding and Preparing for Extreme Heat in Wisconsin

By

Rebecca Rose

A dissertation submitted in partial fulfillment of

the requirements for the degree of

Doctor of Philosophy

(Geography, Environment and Resources)

at the

UNIVERSITY OF WISCONSIN-MADISON

2025

Date of final oral examination: 10/1/2025

The dissertation approved by the following members of the Final Oral Committee:

Matthew Turner, Professor, Geography & Environmental Studies

Christopher Kucharik, Professor, Agronomy & Environmental Studies

Aslıgül Göçmen, Associate Professor, Geography & Environmental Studies

Jonathan Patz, Professor, Population Health Sciences & Environmental Studies

Wenwen Cheng, Assistant Professor, Planning and Landscape Architecture & Environmental Studie

Table of Contents

List of Figures

List of Tables

Abstract

Extreme heat is increasingly a threat to human health as climate change makes high temperatures and other extreme weather events more frequent and intense. As risks mount and severe heat waves cause illness and death, well-informed and decisive action is critical to preserve human health and wellbeing. However, there are significant knowledge gaps to overcome between climate adaptation theory and practice. There is a need for more knowledge sharing and collaboration between scientists, designers, and decision makers in climate planning. To address these gaps, the work in this dissertation is interdisciplinary and utilizes mixed methods including interviews, public media analysis, statistical analyses of quantitative variables over time and across space. I ask: how is heat currently impacting people in Wisconsin, and what can we do about it? In my first chapter, I study differential exposure to heat around Madison utilizing an in-situ temperature and humidity sensor network. I investigate how feels-like temperatures diverge from temperatures themselves, with health implications for vegetated rural areas. In my second chapter, I analyze health outcomes from the heat in Wisconsin as measured by heat-related illness ambulance callouts, looking into meteorological and sociodemographic characteristics associated with elevated risk. In my third and final chapter, I conduct interviews with people whose work interfaces with heat to understand what contributes to vulnerability to heat, what is currently being done to increase heat resilience, and what kinds of actions people want to see going forward. Overall, I find that rural areas are more vulnerable to heat that might be assumed, both through underestimated feels-like temperatures and disproportionate negative health outcomes. I also find that a multitude of interconnected issues outside of heat itself that contribute to the problem, which suggests that many different kinds of action can in turn help.

Acknowledgements

Graduate school can be an incredible challenge, a tough time, seemingly endless, and isolating. But I am lucky to be so supported that this has also been a time full of joy, excitement, and discovery. I want to thank and acknowledge:

My advisors Matt and Chris, and my committee: Asli, Jonathan, and Wenwen, for an incredible amount of support and guidance on this journey as I've been wading through data, finding direction, building and losing confidence, and trying to make sense of it all.

An enormous thank you to the Geography and Nelson Institute staff who make everything possible, from admissions to coursework, teaching, guidance, research, and funding. Thank you to Mogi and Jim for being our north stars, Tino for keeping the building running physically and technologically. Jill, Tara, Emily, Steph; Mariah, Brian, Desi, Jacqueline, and everyone else who works behind the scenes: you know how much you do for all of us.

I'm so appreciative of the opportunity to design and teach an environmental studies capstone course, and for other opportunities to grow as a teacher. Thank you to the Morgridge Center for Public Service for all of the resources, knowledge, opportunities, and support that have been instrumental to my research and teaching.

Thank you to Applied Climatologists and The Wisconsin Heat Health Network: to Larry, Kate, Maggie, and Natalie, for opening the door and inviting me into the world of heat and climate action in Wisconsin and beyond. Thank you to the labmates who came before me and worked on the urban heat island sensor network, Elizabeth for helping me get my bearings, and everyone who helped with data collection. No one can beat our speed record of a readout in 0 minutes.

Old and new friends, Geography and Nelson colleagues over the years: the Green Mafia, Geograds, labmates, the Anything but Thinking Book Club, and housemates: I can't express how much your friendship, advice, and support mean to me. Thank you to everyone who has fought and worked to make this a better place for those who come after us. All of the meetings, conversations, emails, and times when someone said "I'll make a google doc for that" are a testament to how much you care and how much you will continue to change your surroundings for the better.

The Madison International Folk Dance community and the Bent Blades historical fencing club, my swordfriends: You've brought me so much joy over the years, have kept the world from shrinking to just my work, and helped keep my sanity through it all.

Vaish, thank you for everything: for being you, for being there when things were rough, and pushing me to reach for opportunities that I didn't know if I was ready for. I wouldn't have made it this far without you.

To my family, who have been so supportive and have nurtured my curiosity and whole self from the very beginning. I really won the lottery with this one.

Huge shoutout to artists, whatever you may create or perform, for giving us another way to see and understand the world, or giving us an escape so that we can come back to reality when we're ready.

Finally, I am indescribably grateful for the time, expertise, and patience of everyone I spoke to over the course of this research. Thank you for doing the good work, and thank you for showing what the way forward can look like.

Introduction

Heat is increasingly a threat to human health as climate change makes high temperatures and other extreme weather events more frequent and intense (Union of Concerned Scientists, 2019). As risks mount and severe heat waves cause illness and death, well-informed and decisive action is critical to preserve human health and wellbeing. The deadly 1995 heat wave in the Midwest and the 2003 European heat wave have served as watershed moments: through unprecedented meteorological conditions and resulting high death tolls, they forced people to realize that heat waves like these were possible in “cold” places, that they were dangerous, and that people, their infrastructure, and their safety nets were unprepared (Keller, 2013; Klinenberg, 2015). Wisconsin, while less well-studied than Chicago, was also heavily impacted by the 1995 heat wave. Temperatures reached 100 and up to 105°F in the southern part of the state, and together with dew points in the 70s to lower 80s, they brought feels-like heat index values into the range of 120-128°F. In Milwaukee, 85 deaths were identified as being heat-related (Brown, 1995), but this is likely an underestimate, given that heat exacerbates other health conditions and is chronically underreported as a cause of death (Basu & Samet, 2002; Donoghue et al., 1997; Shen et al., 1998). Even as our understanding of extreme heat as a problem has improved, the hazards continue to worsen; between 2008 and 2020, emergency department visits for heat-related illness (HRI) increased in the Midwest more than any other region in the US (Dring et al., 2022).

However, there are significant knowledge gaps to overcome between climate adaptation theory and practice. There is a need for more knowledge sharing and collaboration between scientists, designers, and decision makers in climate planning (Kleerekoper et al., 2012). Multiple studies on climate adaptation call for future research to investigate how adaptation is manifesting in local contexts, what actions are taking place, and what barriers impede success (Boeckmann, 2016; Guardaro et al., 2020; Marin-Puig et al., 2022; Martinez et al., 2019; Moser & Ekstrom, 2010; Olazabal et al., 2024). Relatedly, in my own conversations with practitioners in public health and emergency management that initiated this research (expanded on in Chapter 1), those engaged in climate adaptation on the ground want to know if their interventions are having the desired effects, what is working elsewhere, if there are best practices and research results that they are not aware of, and how their contributions fit into the larger picture. Additionally, there is great demand for more data to help practitioners and decision makers understand the current impacts of heat.

To address these gaps, the work in this dissertation is interdisciplinary and utilizes mixed methods including interviews, public media analysis, statistical analyses of quantitative variables over time, across space, and in association with sociodemographic characteristics (see more detail on methods in individual chapters). I focus my analysis on Wisconsin as a state that is increasingly having to cope with extreme heat despite being thought of as a "cold" state due to our winter climate.

In conducting this work, I explore the concept of vulnerability to heat. I apply the framework advanced by Turner et al. (2003) in which **vulnerability** is created by **exposure** and **sensitivity** to a hazard and is reduced by **adaptive capacity**. Drawing from definitions elaborated on by Smit & Wandel (2006) and the glossary for the 2018 IPCC (Intergovernmental Panel on Climate Change) report (Matthews, 2018), my working definitions of these concepts as applied to heat are:

1) **Exposure** – the severity, extent, or frequency of the stressor which people, livelihoods, ecosystems, and assets are exposed to; the presence of both a hazard and potentially impacted people or systems.
2) **Sensitivity** – the degree to which people or a system are impacted by a hazard
3) **Adaptive capacity** - the ability of systems, institutions, humans and other organisms to adjust or cope to potential damage; can also include the ability of the system to act to prevent future damage

These different aspects of vulnerability are addressed in the chapters that follow, and vulnerability to heat in this dissertation is conceptualized as a combination of these three concepts. **Exposure** to heat describes the harmful conditions that are experienced personally during a heat wave and/or in one's outdoor environment, home, workplace, or elsewhere. Heat exposure can be measured and communicated in numerous ways, each with its own implications and shortcomings: temperature; a feels-like temperature such as apparent temperature or Wet Bulb Globe Temperature; outdoor measured or modeled conditions; indoor conditions; daily maximum, minimum, or mean temperature, etc. **Sensitivity** describes how much people are impacted by heat; this is most commonly thought of in terms of measurable outcomes such as mortality, or cases of heat-related illness. Sensitivity is modified by variables such as health/comorbidities, demographics or marginalized identities associated with greater or less susceptible to heat-related illness. Epidemiology of heat as a field of study investigates disproportionate health outcomes, what conditions contribute to heat-related illness, and what makes people sensitive. Finally, **adaptive capacity** describes the channels available to a person or system to reduce heat exposure and the resulting negative outcomes. On an individual or household level, it can include whether someone has an air conditioner and whether they can afford to use it. At a more systemic level, it can describe the ability of a governing body to reach people with messaging about forecasts and guidance to stay safe, plan and implement physical infrastructure changes that cool an area, enact policy that protects people and provides assistance when a threshold is triggered, and to fund and staff these efforts in a sustainable manner. Adaptive capacity is not an inherent quality that exists in a vacuum; many social forces mediate/ enable or constrain it. People's differential abilities to cope with heat through air conditioning are tied to income and wealth, which in turn corresponds with racial inequality. One's ability to rely on social networks to check in on them and provide help is an essential component of adaptive capacity for heat in particular.

Studies of differential exposure (usually measured by outdoor temperatures, especially through urban heat island research) and sensitivity (typically epidemiological papers on mortality and morbidity) dominate the literature on extreme heat (Jonsson & Lundgren, 2015; Romero-Lankao et al., 2012; see also the Background sections of the following chapters). In contrast, adaptive capacity is a relatively newer, less explored concept. Some reports and studies address parts of adaptive capacity as measured by rates of air conditioning access, energy burden, distance to cooling shelters and other public spaces, access to vehicles or other forms of transportation, and existence of policies that address extreme heat. What is relatively new in the literature is studying *action* around heat: what people are doing through governance, nonprofit work, and within communities. This part of adaptive capacity, the work that it takes to reduce future harm, best practices, and obstacles to overcome, is essential to understand as we continue to move into a future of changing climate.

Also essential is understanding what processes create vulnerability through increased exposure to heat and factors that increase sensitivity and/or diminish adaptive capacity. Studies, reports, and plans may acknowledge the existence of workplace power dynamics or language barriers as contributors to vulnerability to heat (e.g., LA County CVA, 2021), and they may link historical redlining practices with present-day racialized disparities in exposure to high temperatures and access to greenery and other public amenities (Kephart, 2022; Li et al., 2022; Plumer et al., 2020; Wilson, B., 2020). But it is unusual to deeply engage those processes in the context of heat vulnerability and frame addressing them as necessary avenues for change as part of increasing adaptive capacity and reducing heat vulnerability.

Despite their articulation as separate components of vulnerability, these concepts of exposure, sensitivity, and adaptive capacity are deeply intertwined. If a worker must labor in the sun while wearing stifling protective equipment, these elements could be argued to contribute to all three: as a part of their personal exposure to heat; as factors that make them more sensitive to discomfort and negative health outcomes from the heat, and reducing their adaptive capacity, as they may not have the power or ability to stop working, slow down or rest substantially, or remove the protective equipment without risk of other harm. Factors that mediate a resident's adaptive capacity, such as being able to stay inside an air-conditioned space, also reduce their exposure to the heat and their likelihood of negative health outcomes, aligning with sensitivity. Delineating these three concepts makes for a useful framework, but they further reinforce the importance of understanding the deep interconnectedness of the different factors that mediate heat vulnerability across social, biophysical, and health dimensions. To build on our understanding of heat vulnerability in a state that is currently having to reckon with it, this dissertation pushes forward the science of understanding feels-like heat exposure, investigates a rich dataset around heat health outcomes that has implications about the processes that created this sensitivity, and convenes the knowledge of people whose work interfaces with extreme heat about what makes people vulnerable to heat and what action is ongoing or wanted to reduce this vulnerability.

In **Chapter 1**, I explore the role of **exposure** in creating vulnerability to extreme heat; this work examines differential exposure to harmful temperatures—and importantly, harmful feels-like temperatures—across rural and urban landcover types around Madison, Wisconsin. I utilize Dane County's urban heat island (UHI) sensor network to study the role of humidity in feels-like temperatures in and around Madison. Using this high-spatial and high-temporal resolution dataset that goes back to 2012, I compare the UHI magnitude as measured by temperature alone and by apparent temperature (AT), a metric that incorporates both heat and humidity. I conduct this analysis across summer months, days and nights, and during climatic extremes of extremely wet and extremely dry periods, in order to understand the interactions of landcover type (impervious urban vs. vegetated rural) and available moisture in the soil on this UHI effect. This chapter points to the importance of understanding the mechanisms and manifestations of differential heat exposure not only in cities, but also in understudied, highly vegetated, rural areas.

I examine **sensitivity**, the measurable impacts of the hazard, in my second chapter by analyzing heat health outcomes. Using records of ambulance calls for heat-related illness in the state, I investigate disproportionate impacts between demographics as well as patterns and implications of characteristics such as incident location type and time of day. I also analyze associations between counts of ambulance callouts, meteorological conditions, and county sociodemographic descriptors including population density, percent of families living in poverty, and percent outdoor workers. Results demonstrate a looser connection between heat exposure and adverse health outcomes than one might expect, and taken together they suggest that much more is at work than exposure alone that mediates sensitivity.

In my third chapter, I study **adaptive capacity** and conceptions of **vulnerability as a whole**. Exposure, sensitivity, and adaptive capacity interact uniquely in local contexts, and so it is important to study their manifestations in place. Accordingly, I apply the framework of **contextual vulnerability** to heat, interrogating not only who is exposed to heat, when, and where, but *why*, and through what processes. I conduct interviews with people whose work intersects with heat, both those working in government positions and in community-based groups, in order to better understand the landscape of heat preparedness and vulnerability in the state. Furthermore, I investigate how practitioners' perspectives and insights can help build a more contextual understanding of heat vulnerability, what kinds of action contribute to heat resilience even if they are not traditionally thought of as such, and what challenges impede actions to meaningfully address heat vulnerability where it exists. This chapter focuses on the *how* and *why* of heat vulnerability and action.

While these chapters confront the problem of extreme heat through different approaches, they all speak to and inform each other. The need for more data, as expressed in conversations with practitioners leading up to and within Chapter 3 (adaptive capacity and overall vulnerability), is an impetus for Chapters 1 and 2 (exposure and sensitivity). Findings from the Chapter 1 on the urban heat island effect of apparent temperature have implications for differential exposure to heat and, in turn, where interventions should be targeted. The health outcomes explored in Chapter 2 stem from both heat exposure and processes that create underlying vulnerability as articulated in Chapter 3.

I argue that we need to understand the full scope of vulnerability to heat in order to be able to better address it. Heat vulnerability stems from physical exposure as well as social, economic, and political forces that produce underlying vulnerabilities which then manifest as disproportionate negative health outcomes. Disasters and emergencies such as extreme heat waves can then push people who were living in precarity off the edge. We must address basic needs to bring people away from this edge, and we must do what we can to reduce the extremes that people are exposed to.

References

Basu, R., & Samet, J. M. (2002). Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiologic reviews, 24*(2), 190-202.

Boeckmann, M. (2016). Exploring the health context: A qualitative study of local heat and climate change adaptation in Japan. *Geoforum*, *73*, 1-5.

Brown, R. H. (1995). Natural Disaster Survey Report, July 1995 Heat Wave. *National Oceanic and Atmospheric Administration*.

Donoghue, E. R., Graham, M. A., Jentzen, J. M., Lifschultz, B. D., Luke, J. L., & Mirchandani, H. G. (1997). Criteria for the diagnosis of heat-related deaths: National Association of Medical Examiners: position paper. *The American journal of forensic medicine and pathology*, *18*(1), 11-14.

Dring, P., Armstrong, M., Alexander, R., & Xiang, H. (2022). Emergency department visits for heat-related emergency conditions in the United States from 2008–2020. *International journal of environmental research and public health, 19*(22), 14781.

Guardaro, M., Messerschmidt, M., Hondula, D. M., Grimm, N. B., & Redman, C. L. (2020). Building community heat action plans story by story: A three neighborhood case study. *Cities*, *107*, 102886.

Keller, R. C. (2013). Place matters: Mortality, space, and urban form in the 2003 Paris heat wave disaster. *French Historical Studies, 36*(2), 299-330.

Kephart, L. (2022). How racial residential segregation structures access and exposure to greenness and green space: A review. *Environmental Justice*, *15*(4), 204-213.

Kleerekoper, L., Van Esch, M., & Salcedo, T. B. (2012). How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, *64*, 30-38.

Klinenberg, E. (2015). *Heat wave: A social autopsy of disaster in Chicago.* University of Chicago Press.

LA County Climate Vulnerability Assessment. (2021). Our County. Retrieved from https://ceo.lacounty.gov/wp-content/uploads/2021/10/LA-County-Climate-Vulnerability-Assessment-1.pdf

Li, D., Newman, G. D., Wilson, B., Zhang, Y., & Brown, R. D. (2022). Modeling the relationships between historical redlining, urban heat, and heat-related emergency department visits: an examination of 11 Texas cities. *Environment and Planning B: Urban Analytics and City Science*, *49*(3), 933-952.

Marin-Puig, A., Ariza, E., & Casellas, A. (2022). Unattended gap in local adaptation plans: The quality of vulnerability knowledge in climate risk management. *Climate Risk Management*, *38*, 100465.

Martinez, G. S., Linares, C., Ayuso, A., Kendrovski, V., Boeckmann, M., & Diaz, J. (2019). Heat-health action plans in Europe: Challenges ahead and how to tackle them. *Environmental Research*, *176*, 108548.

Matthews, J. R. (2018). Annex I: glossary. *Global warming of*, *1*, 541-562.

Moser, S. C., & Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the national academy of sciences*, *107*(51), 22026-22031.

Olazabal, M., Amorim-Maia, A. T., Alda-Vidal, C., & Goodwin, S. (2024). What is limiting how we imagine climate change adaptation?. *Current Opinion in Environmental Sustainability*, *71*, 101476.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global environmental change*, *16*(3), 282-292.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., ... & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences, 100*(14), 8074-8079.

Union of Concerned Scientists. (2019). *Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days*. Retrieved from https://www.ucsusa.org/sites/default/files/attach/2019/07/killer-heat-analysis-full-report.pdf

Wilson, B. (2020). Urban heat management and the legacy of redlining. *Journal of the American Planning Association*, *86*(4), 443-457.

Chapter 1: Diverging Temperature and Apparent Temperature-Based Urban Heat Island of a Mid-Sized City

Rose & Kucharik

To be submitted to the journal Urban Climate; formatting follows author guidelines set by the journal.

Abstract

Although apparent temperature better describes conditions as they impact human health than temperature alone, moisture and its role in apparent temperature are not well-understood in the context of urban heat island (UHI) studies. Madison, Wisconsin's climate sensor network has been taking temperature humidity readings at 15-minute intervals for 13 years, giving us a rich dataset to understand these dynamics of a mid-size city surrounded by lakes and agricultural land. We utilize this dataset to examine the climatology of apparent temperature and the role of climate and soil moisture extremes on the UHI effect, vapor pressure, apparent temperature, and how much apparent temperature is elevated above temperature. We find that apparent temperature and temperature behave differently from each other across moisture extremes, landcover types, and times of day, indicating contrasting mechanisms at work. Importantly, rural areas may be exposed to hotter conditions than previously thought and than would be indicated by temperature alone when accounting for apparent temperature and elevated humidity due to greater amounts of evapotranspirating vegetation.

Highlights:

- The UHI of apparent temperature (AT) is lower than the UHI of temperature at ATmin
- The UHI is higher at night during dry extremes than wet extremes
- AT-T differences (the amount that the apparent temperature is elevated above the temperature) are higher during wet climatic extremes than dry extremes
- During daily maximum AT, AT-T differences are higher in rural areas than urban
- Rural feels-like temperatures may be underestimated, with serious implications for heat warnings, messaging, heat exposure, and health outcomes.

1. Introduction

While it is well-understood that the urban heat island (UHI) effect elevates temperatures within cities due to characteristics of the built vs. vegetated or natural environment (Oke, 1982), many National Weather Service offices typically issue forecasts and heat warnings based on numerical guidance from limited weather stations and weather prediction models that are unable to account for the physical differences between urban and rural landscapes that contribute to varying weather experienced by humans (see Williamson & Kucharik, 2023). As a result, forecasted conditions and warnings of danger can be disconnected from the actual conditions faced by residents. Additionally, humidity greatly impacts the apparent temperature (AT) or "feels-like" temperature which in turn affects human health, as humidity impedes the ability of human bodies to cool themselves via sweat (Berglund & Gonzalez, 1977). We have a very limited understanding of how the magnitude and spatiotemporal variation of humidity is affected by urban vs. rural landscapes, and so this is another important missing piece of accurate forecasts and warnings.

Madison, Wisconsin serves as an excellent and unique case to understand the urban heat island (UHI) effect in midsize temperate cities, and especially the contrast between a dense urban environment and its agricultural surroundings within Dane County. It has a high spatial density and high temporal resolution network of sensors that have each been recording air temperature and humidity measurements every 15 minutes since March 2012. This network has captured a variety of extreme conditions including hot summers, droughts, and high levels of summer precipitation. Furthermore, Madison is a midsize city, the same category that the majority of urbanites reside in (United Nations, 2014), and it is surrounded by large lakes and situated within a patchwork of intensive agriculture, which both greatly affect water and energy balance and in turn contribute to temperature variability. With the intensification of agriculture in recent years, scientists have observed a "warming hole" in the Midwest, in which regional summer temperatures are cooler than would be expected due to greater amounts of evapotranspiration (Mueller et al., 2016). According to the 2022 Agricultural Census, only 1% of farmland in Dane County is irrigated; rainfall dictates the water balance for the vast majority of land (USDA NASS, 2022). There is already an array of published work derived from this sensor network from which we can continue to build our understanding (Berg & Kucharik, 2022; Schatz & Kucharik, 2014, 2015, 2016; Zipper, 2017). Further investigation of sensor data and addressing some of the questions brought up by previous studies will provide a multitude of insights about extreme conditions that affect health and push forward urban heat island research.

This study is guided by the question: What is the climatology of apparent temperature in and around Madison during summer months, and how are spatiotemporal differences driven by variability in rainfall, soil moisture, and urban vs. vegetated rural landcover? We break this question down into the following components:

1. What is the climatology of apparent temperature (AT) in and around Madison during summer months?

2. How do extremely dry and extremely wet time periods (i.e. stored soil moisture) impact spatial variations and differences (e.g. urban vs. rural) in AT and UHI?

   2A: Under which is the UHI magnitude highest?

   2B: How do extremely dry and extremely wet time periods (i.e. stored soil moisture) shape apparent temperature minus temperature (AT-T) differences between urban and rural areas?

While the urban heat island effect has been extensively studied, it is often measured and analyzed with remote sensing and satellite measurements of land surface temperature, which is a useful proxy for air temperature, but it is not what people experience (Zhou et al., 2019). Moreover, some cities have temperature networks that provide air temperature data, but few measure humidity as well due to the added cost (Waugh et al., 2023), and so little research on the UHI effect incorporates the role of humidity or its effects on apparent temperature. Given that Madison's sensor network records both temperature and humidity, it presents a unique opportunity to characterize spatial and temporal patterns of these conditions that influence human health and lived experience.

Little work has examined to what extent humidity varies within urban areas; at this time, only Waugh et al. (2023) has raised this question. Studies have also yet to systematically analyze rural vs. urban differences in humidity and related effects on apparent temperature. Using this same sensor network in Madison but aggregating the data into a broad urban vs. rural comparison, Zipper et al (2017) demonstrated that there is a difference in humidity, as measured by VPD (vapor pressure deficit) between Madison's urban and rural areas, and that this is due to temperature differences. They also found that in both rural and urban areas, higher temperatures increase the evapotransporative demand of vegetation as more water is lost to warm air. This stress can be harmful in agricultural fields, as soil moisture may be depleted by midsummer (Zipper et al., 2017). This suggests that by putting vegetation under stress, hot and dry summers can result in less evapotranspiration-driven cooling in rural areas and possibly a diminished UHI effect, as urban areas have less vegetation to experience this effect.

Another contribution of this research is serving as the first to our knowledge to incorporate climatic proxies for soil moisture data into an urban heat island. One study has found that higher soil moisture increases microclimate temperature buffering in temperate broadleaf forests, and so these authors recommend including soil moisture in microclimate models (Greiser et al., 2024), but this has yet to be applied to the UHI effect.

2. Methods

Madison's in situ sensor network consists of 144 Onset HOBO U23 Pro v2 temperature/RH dataloggers that have collected continuous data since 2012 at 15-minute intervals. They are located on urban, agricultural, forested, park, wetland, and lakeside land, well-representing the varying landcover types across Madison and Dane County's rural and urban landscapes (see Figure 1.1A). Variables that are available from this entire time period and which are applied here include temperature (T), apparent temperature (AT), and vapor pressure (VP). Apparent temperature is calculated as:

$$AT = -1.3 + 0.92T + 2.2P$$

in which T is temperature in °C and P is vapor pressure in kPa (Steadman, 1984). We use vapor pressure itself as a variable, because it is an objective measurement of how much water vapor is in the air, while relative humidity depends heavily on temperature. When mapping UHI, we determine the UHI magnitude of each sensor by subtracting the lowest T recorded by any sensor at that time, following Schatz & Kucharik (2014).

Because high temperatures and their potential negative health outcomes are our focus, we use only data from summer months. We use daily maximum and minimum AT to represent the feels-like extremes: maximum AT covers the hottest, most extreme heat that bodies must cope with, and minimum conveys how much relief they get overnight. We also incorporate the variables of temperature, AT-T, and vapor pressure from each day at the times of ATmin and ATmax for consistency. We also generate monthly averages of these variables for each sensor to establish and map the climatology of a typical June/July/August day and night.

To examine urban-rural differences, 25 representative urban sensors and 33 rural sensors were selected, so that gaps in data or anomalous readings from any individual sensor would not detrimentally affect the results. First, following Schatz & Kucharik (2014) and Berg & Kucharik (2022), the percent impervious surface within a 500m radius of each sensor was derived using the 2016 National Landcover Database. Representative urban sensors were identified as having the highest percent impervious area, ranging from 76.25% down to 53.68%. Beyond this, sensors over 17km from the center of Madison were removed. Representative rural sensors all had the lowest percent impervious surface, ranging from 0.44% to 5.87%. Two sensors were removed from this category for being surrounded by more built-up area beyond the 500m buffer, and two more were removed because they were surrounded by one of Madison's lakes, meaning that it would indicate more about presence to water than the effects of forest or agricultural vegetation. See Figure 1.1B for a map of the study area and sensors representing these landcover categories.

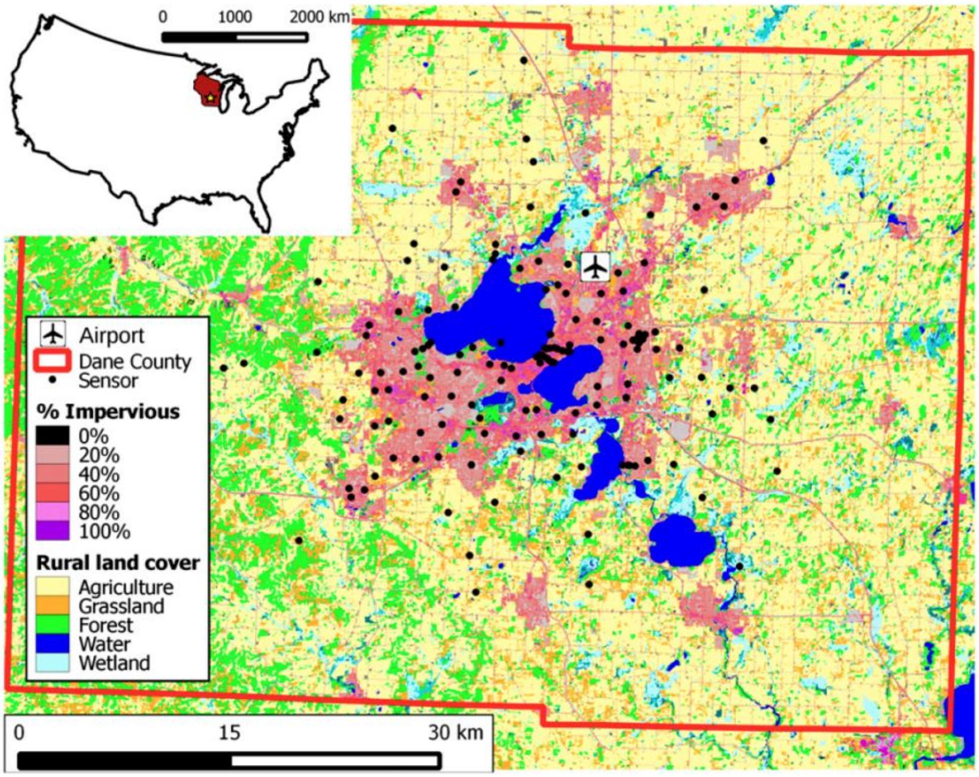


FIG. 1. Map of study area in Madison, including rural land-cover classes [Wisconsin Department of Natural Resources WISCLAND Land Cover (WLCGW930)], NLCD 2006% impervious surface coverage (Fry et al. 2012), and HOBO U23 Pro v2 temperature/RH sensor locations.

Figure 1.1A: Map of study area in Dane County, from Schatz & Kucharik (2014). Includes landcover classifications (Wisconsin Department of Natural Resources WISCLAND Land Cover (WLCGW930), NLCD 2006 % impervious surface coverage (Fry et al., 2012), and UHI sensor locations.

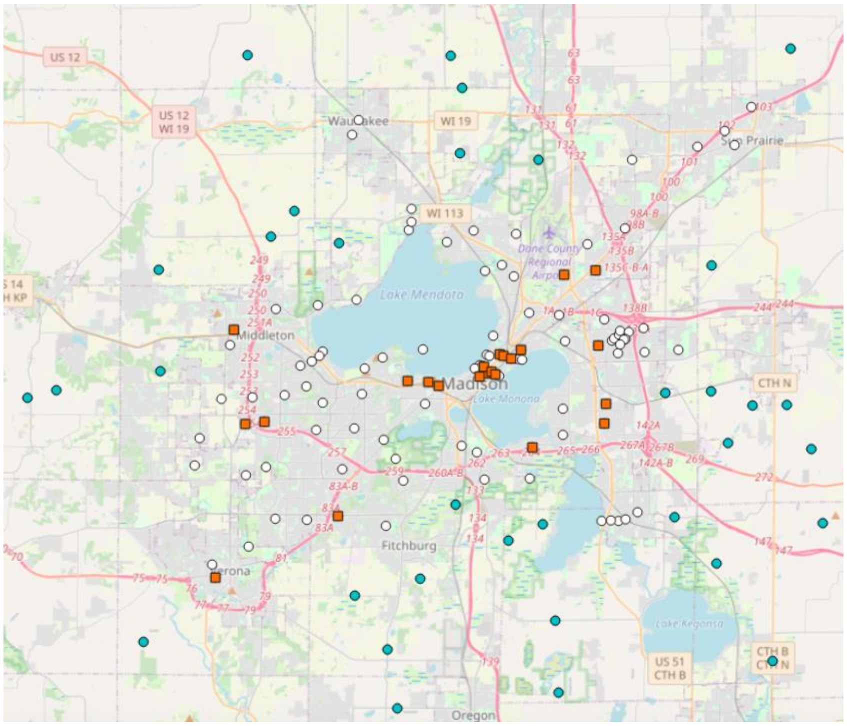


Figure 1.1B: From the Dane County sensor network, selected representative urban (orange squares) and rural (teal circles) sensors. The remaining sensors are white circles.

In our analyses, we use the difference between the high-density urban and rural categories to obtain UHI magnitudes (as measured by both T and AT) as well as rural-urban differences in AT-T and VP. We also count and map the number of hours each sensor spent above a high temperature threshold that represents potentially dangerous conditions (i.e., AT above 90, 95, 100°F, etc.).

To further understand interactions between moisture and these variables, we examine and contrast extremes in precipitation and soil moisture, identifying 10 of the wettest weeks and 10 of the driest over the study period. Wet, high-moisture extremes were 7-day periods with the highest 7-day precipitation accumulations (Wisconsin State Climatology Office, n.d.) and in which the NASA GRACE soil moisture model historical records also confirmed high surface soil moisture (above the 90th percentile for most of the duration of these weeks).[1] Dry, low-moisture extremes were identified from national drought archives (NIDIS. n.d.) and confirmed by the historical soil moisture model. During all of the selected weeks, the entire county was categorized as D0-D2 (Abnormally Dry, Moderate Drought, or Severe Drought) and at least 25% of the county was categorized as D3 (Extreme Drought). Since rainfall during a drought can contribute to soil moisture but not be enough to remove the drought category, we confirmed our selection with the same soil moisture model as above and removed one week that had high surface soil moisture; the rest averaged around the 5-10th percentile. Finally, we confirmed that the two extremes are comparable with each other, finding that the average daily maximum, minimum, and mean temperatures between wet and dry averages were within 1.02°C of each other.

3. Results

3.1 Climatology of AT in and around Madison

ATmin typically occurred around dawn, and ATmax was usually recorded during the late afternoon. Both generally occurred at the same times at Tmin and Tmax. Maps depicting typical June, July, and August average T, AT, VP, and AT-T at ATmax and at ATmin show both familiar and unexpected patterns. AT and T appear very similar to each other, both peaking in July. A strong and classic UHI pattern emerges for both T and AT at ATmin (night/early morning). At ATmax (late afternoon), temperatures show less spatial dependence and a weaker

---

[1] Data and maps are available at nasagrace.unl.edu through a partnership with the National Drought Mitigation Center.

association between the UHI magnitude and impervious surface or landcover type (see Figure 1.2).

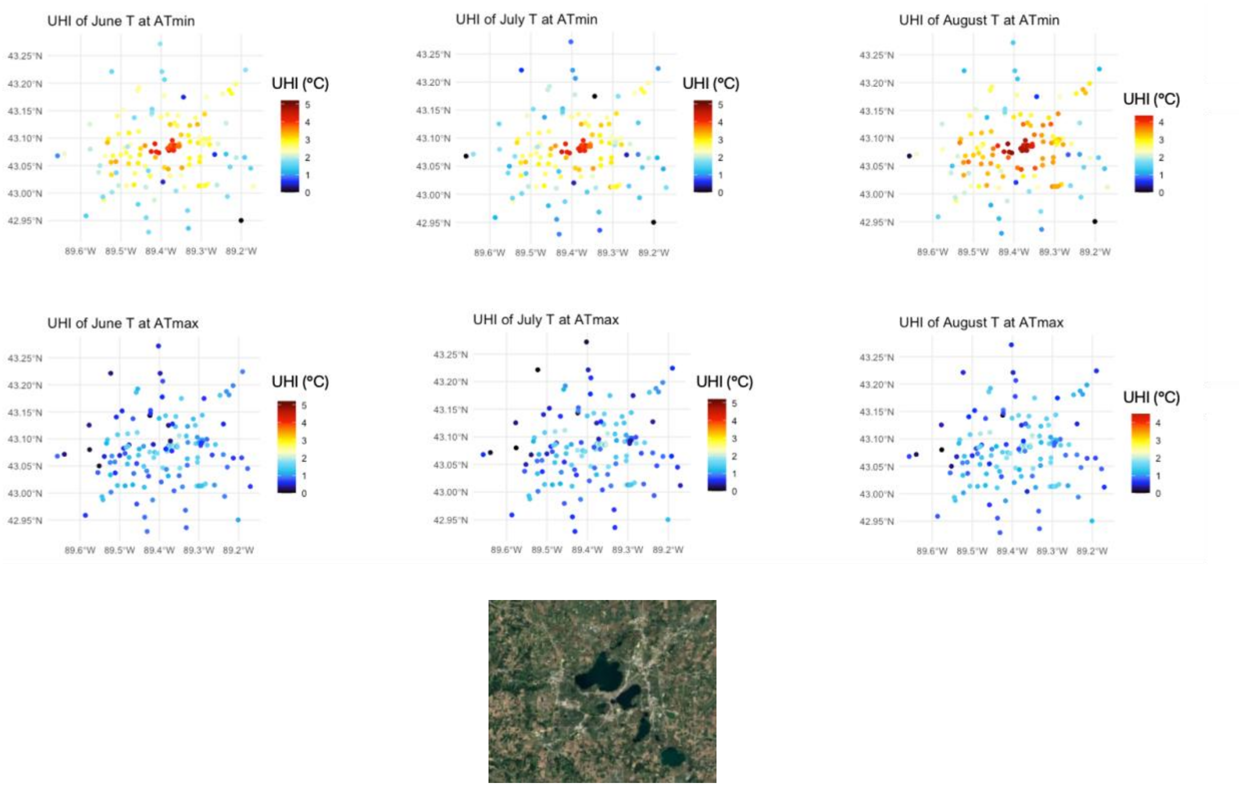


Figure 1.2: Maps of average UHI magnitude of AT (°C) by month from Dane County sensor network, 2012-2023, with a Google Maps satellite image of the same area for reference.

As shown in Figure 1.3, the UHI at ATmin has a greater magnitude (~2.3°C) than at ATmax (0.5-0.9°C). UHI has a much broader range at ATmin than at ATmax; ATmax has a generally narrower spread but contains many outliers. The UHI of AT is lower than the UHI of T at ATmin ($p < 0.0001$), but their values are near-identical at ATmax. Vapor pressure differs across urban and rural areas and between day and night. Urban VP is greater than rural at ATmin ($p < 0.0001$), but the opposite is true during the day: urban VP is less than rural VP at ATmax ($p < 0.0001$). For both urban and rural sensors, there is more moisture in the air at ATmax than ATmin ($p < 0.0001$). Variables' averages, comparisons, and results of statistical significance tests are summarized in Table 1.1.

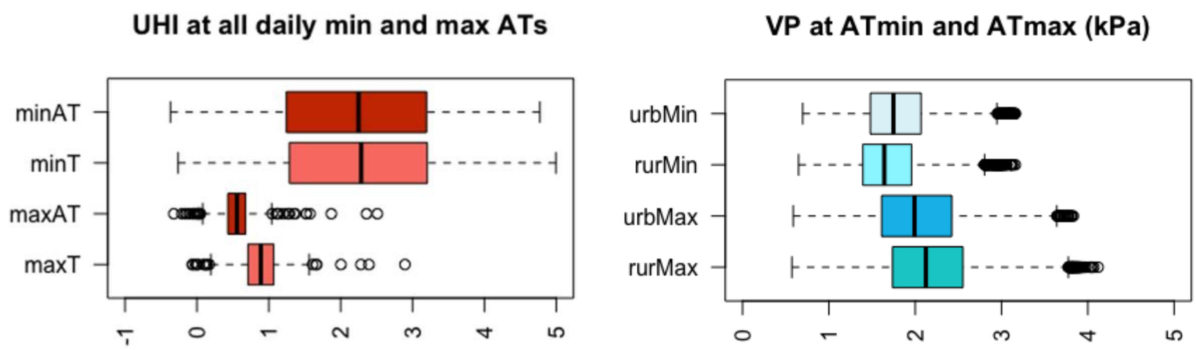


Figure 1.3: Daily UHI of T and AT at day and night; VP of urban vs. rural areas at ATmin and ATmax. From Dane County sensor network, summer months, 2012-2023.

In Figure 1.4, the derived variable AT-T shows how far the feels-like temperature AT is elevated above T due to a combination of heat and humidity for each sensor on average. AT-T values are highest at ATmax and in July and August, and they are lowest in June. At ATmax, the AT-T differences are highest far from downtown, in more rural and vegetated area, while there is less spatial variability at ATmin. In general, among the summer months, July has the highest Ts and ATs at both night and afternoon, as well as the highest VPs and AT-T differences.

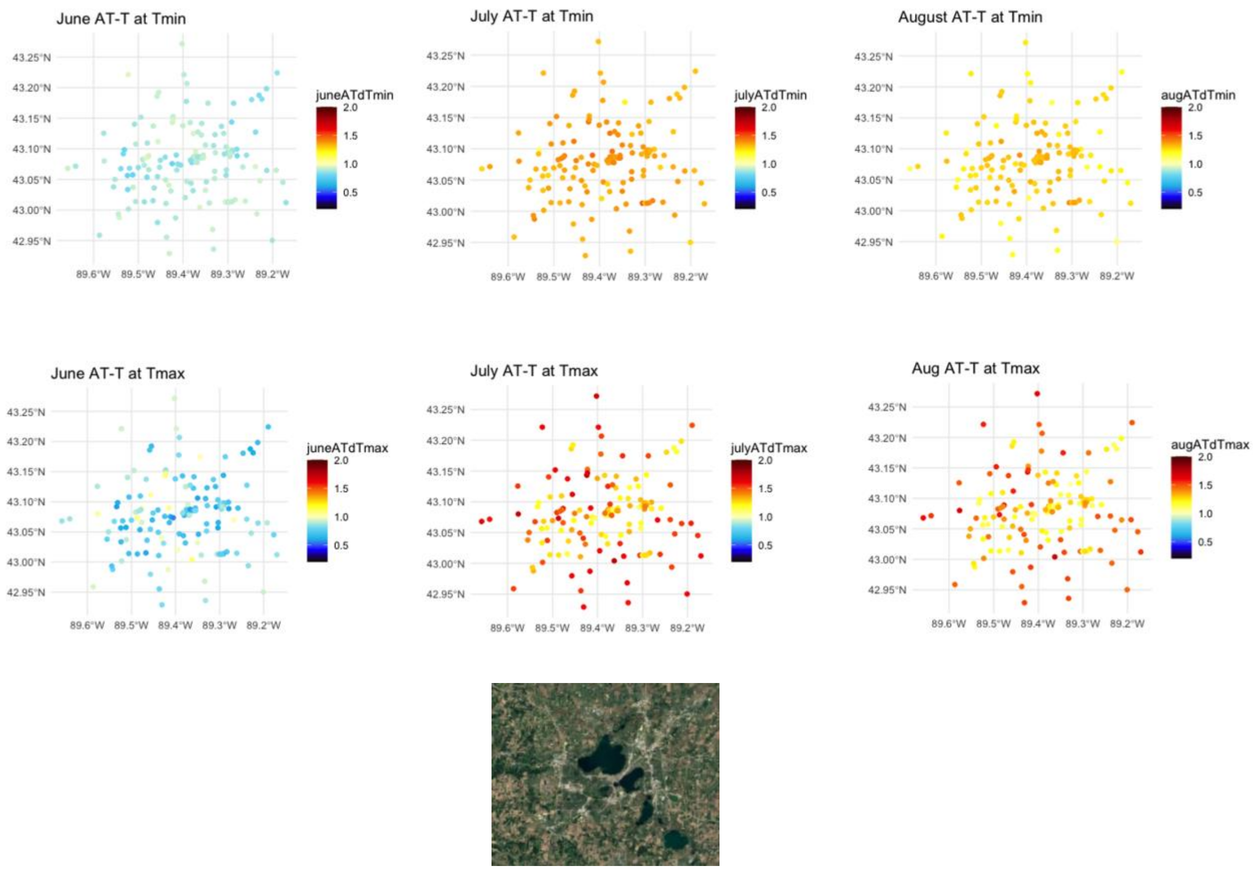


Figure 1.4: Maps of monthly averages of AT-T differences (°C). From Dane County sensor network, summer months, 2012-2023, with a Google Maps satellite image of the same area for reference.

3.2 Role of moisture

Comparisons of variables across the moisture extremes can be found below in Figure 1.5. The lowest minimum T and ATs occur in rural areas during the dry extremes; the highest minimum T and ATs occur in urban areas during the wet extremes. The average UHI over the dry period is greater than the wet UHI for both T and AT at ATmin, but wet and dry UHIs behave similarly at ATmax. When examining the derived variable AT-T, across both urban and rural areas and at both ATmin and ATmax, AT-T of wet extremes is greater than the AT-T during dry. At ATmin, there is not a significant difference between rural and urban areas' AT-T differences in either wet or dry moisture extremes, but at ATmax, rural areas have a greater AT-T difference than urban areas in both wet and dry moisture extremes.

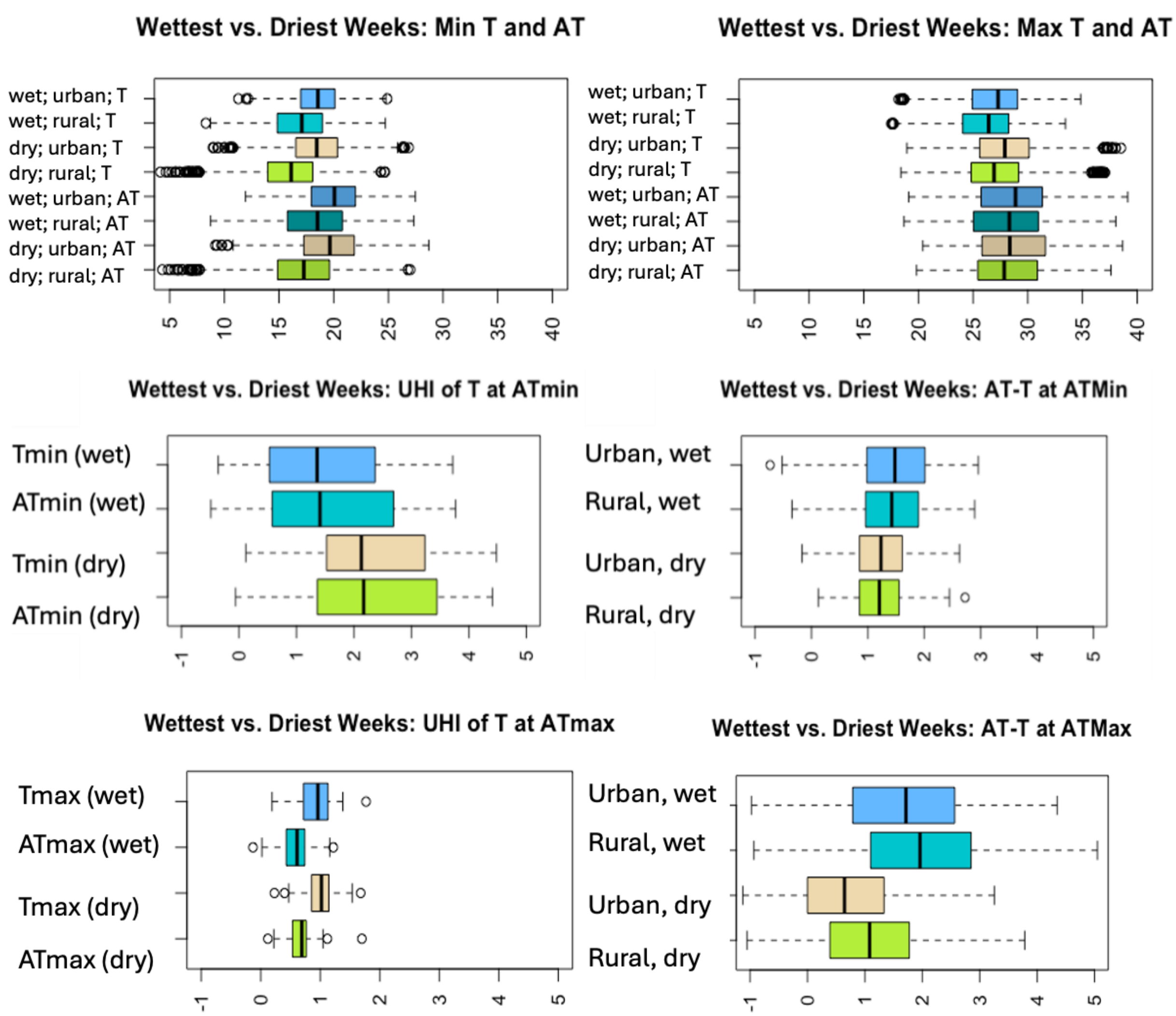


Figure 1.5: Boxplots depicting T, AT, UHI, and AT-T at wet and dry moisture extremes. From Dane County sensor network, summer months, 2012-2023.

As shown in Figure 1.6, when mapping AT-T differences across these moisture extremes, the highest AT-T values occur at ATmax and during the wet extreme. The lowest AT-T values also occur at ATmax, but during the dry extreme. AT-T values within each map are rather homogenous, showing little spatial dependence. The highest contrast between wet and dry periods occurs at ATmax, where wet extreme values range from 0.06 to 1.5°C higher than dry, and lowest at ATmin, where wet extreme values are all ~0.4°C higher than dry.

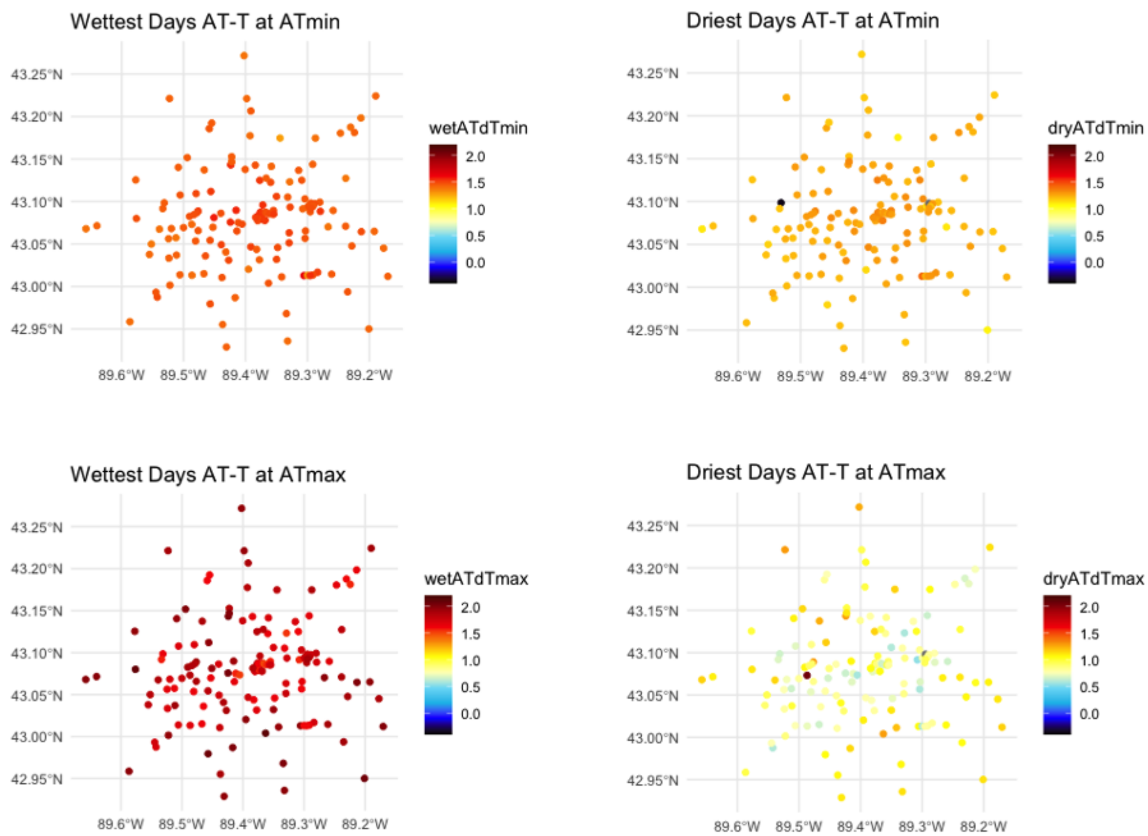


Figure 1.6: Maps of AT-T differences across moisture extremes and at ATmin and ATmax during summer months between 2012 and 2023 in Dane County. Dark gray points are N/A.

3.3 Amount of time spent above thresholds

In addition to capturing daily high and low temperatures and AT, we also count the number of hours that each sensor has recorded conditions above thresholds of T and AT to convey how long and how often potentially dangerous conditions are reached in each location. We use thresholds of 80, 85, 90, 95, 100, and 105°F. We also find the difference of the number of hours each sensor spends with AT above the threshold vs. the T (ex: # hours AT at 95 ° F - #

hours T at 95°F). These hours are then converted into percentages showing what fraction of the study period (the number of hours in June, July, and August, 2012-2023, which is 26,496 hours total) sensors reached these thresholds. As before, we use an average of the identified representative urban and rural sensors to compare urban and rural environments. See Figures 1.7 and 1.8 below for these results.

Sensors' recorded ATs exceeded 80°F almost 25% of the time within summers, 85°F about 10% of the time, 90°F approximately 4% of the time, and 95°F for less than 1% of the time. Averaged urban sensors consistently have more hours spent exceeding each threshold for both T and AT ($p < 0.001$). However, at the lower end of the range of temperature thresholds (<85°F), *rural* sensors have a higher percentage of hours where AT (and not T) exceeds the threshold ($p < 0.05$). In other words, rural areas experience a greater relative contribution of AT compared to T, as may reflect their higher humidity levels from evapotranspirating vegetation. Even so, at higher temperature thresholds, the overall higher temperatures of urban areas may outweigh this effect.

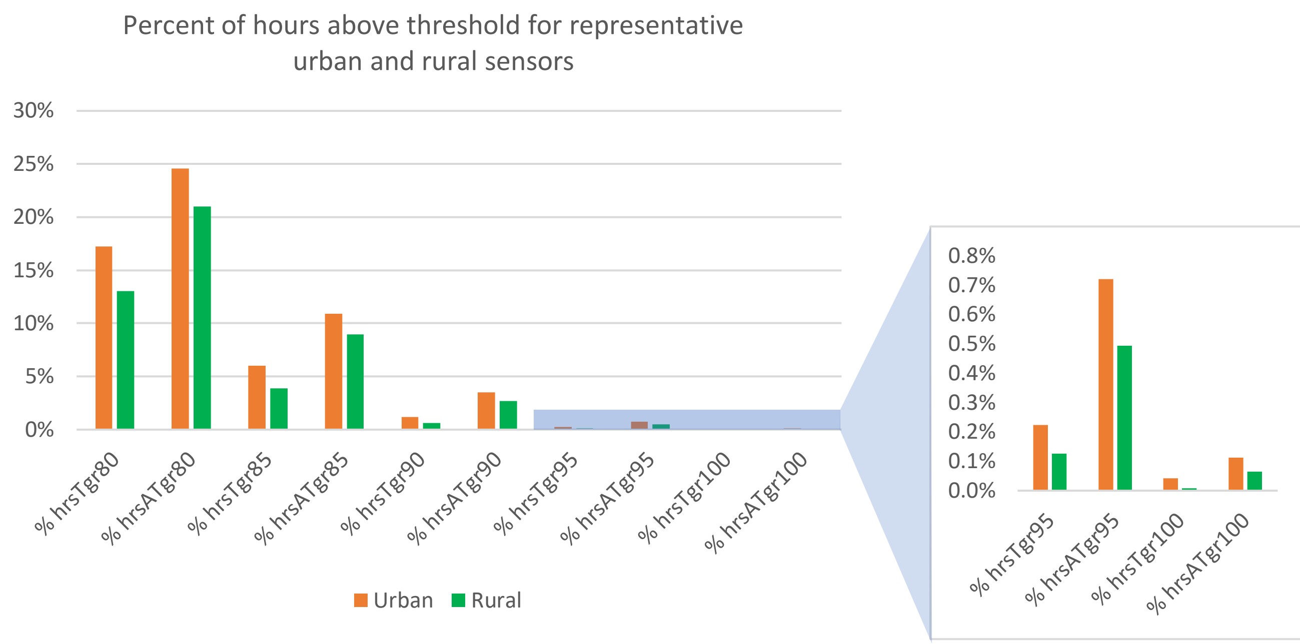


Figure 1.7: The percentage of hours spent above thresholds for representative urban and rural sensors in Dane County during summer months between 2012 and 2023.

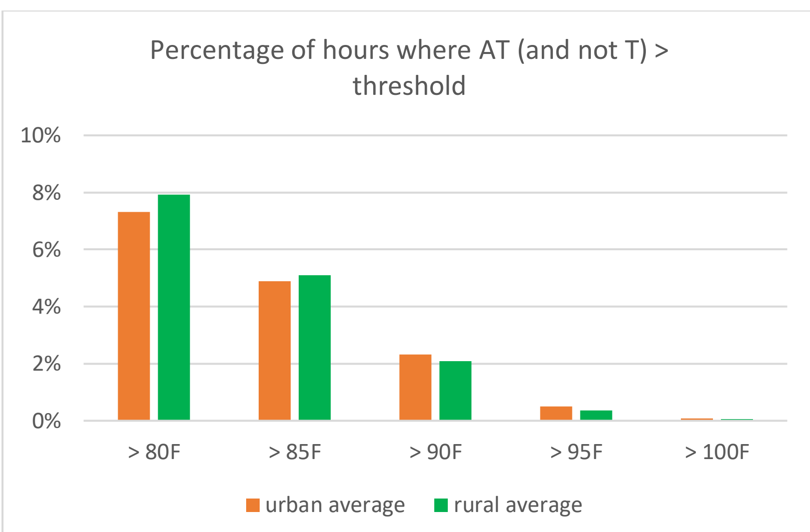


Figure 1.8: The percentage of hours where AT but not T exceeded thresholds for representative urban and rural sensors in Dane County during summer months between 2012 and 2023.

Q1: Climatology of AT			Sig.
UHI of Tmax	>	UHI of ATmax	****
urban VP at ATmin	>	rural VP at ATmin	****
urban VP at ATmax	<	rural VP at ATmax	****
urban - rural VP at ATmin	>	urban - rural VP at ATmax	****
Q2A: UHI across moisture extremes			
wet T UHI at ATmin	<	dry T UHI at ATmin	****
wet AT UHI at ATmin	<	dry AT UHI at ATmin	***
wet urb AT at ATmin	>	dry urb AT at ATmin	****
wet rur T at ATmin	>	dry rur T at ATmin	****
wet rur AT at ATmin	>	dry rur AT at ATmin	****
wet urb T at ATmax	<	dry urb T at ATmax	****
Q2B: AT-T across moisture extremes			
wet urb AT-T at ATmin	>	dry urb AT-T at ATmin	****
wet rur AT-T at ATmin	>	dry rur AT-T at ATmin	****
wet urb AT-T at ATmax	>	dry urb AT-T at ATmax	****
wet rur AT-T at ATmax	>	dry rur AT-T at ATmax	****
wet urb AT-T at ATmax	<	wet rur AT-T at ATmax	****
dry urb AT-T at ATmax	<	dry rur AT-T at ATmax	****

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, **** $p < 0.0001$

Table 1.1: Comparisons of variables which were found to have statistically significant differences. See Table 1.2 in the Supplementary Figures section for all variables, average values, and differences.

4. Discussion

These findings have many implications for understanding the role of moisture and landcover type on exposure to extreme heat as measured by the “feels-like” temperature AT, UHI magnitude, and human health.

4.1 The UHI of apparent temperature (AT) is lower than the UHI of temperature at ATmin

At ATmax, the AT UHI is lower than the T UHI. Accordingly, when accounting for the effects of humidity on feels-like temperature, at the hottest time of day people living in rural areas are exposed to more heat than would be accounted for by only measuring T and the T-based UHI. At the same time, VP is higher in rural areas than urban areas at ATmax, but the opposite is true at ATmin, indicating that opposing mechanisms shape urban-rural moisture during the day and at night. It makes sense that because rural areas have more evapotranspirating vegetation, during the day when the sun is out and photosynthesis can occur they are more humid, which in turn contributes to an elevated AT. This aligns with the findings of Chakraborty et al. (2022) in which urban areas experience lower relative humidity than rural areas, which can moderate the urban feels-like temperature and reduce urban heat stress (Chakraborty et al., 2022). In contrast, a higher nighttime UHI, in which urban areas experience elevated thermal inertia and do not cool down as much as rural areas, contributes to higher urban temperatures, and warmer air allows for more moisture to remain in the air. Because the month of July has the highest temperatures, highest VPs, and highest AT-T differences, it is apparent that these effects are magnified during the hottest extremes.

4.2 The impact of moisture extremes on AT, UHI, and AT-T

The UHI magnitude is greater during dry extremes than wet at ATmin; that is, when there is little soil moisture, the nighttime urban-rural temperature contrast increases, and city temperatures do not cool off overnight as much as their rural surroundings. However, in wet extremes, urban and rural areas behave more similarly to each other. This runs counter to the understanding that under drought conditions, vegetation becomes water-stressed and this reduces the cooling effects of evapotranspiration in highly vegetated rural areas, lessening the UHI effect (Zipper et al., 2017). Compared to urban areas, agricultural fields do allow far more water to infiltrate into the soil to be slowly released later, though availability of water limits this input and subsequent cooling (Mueller et al., 2016). Due to the high thermal inertia of water, soil moisture itself acts to mitigate extreme temperatures, as water has a higher specific heat than dry land. As such, wet soil is more resistant to the effects of heating (Runnalls & Oke, 2000; Schatz & Kucharik, 2014), and soil that has dried loses this relative immunity. This aligns with our findings that the lowest minimum T and ATs occur in rural areas during the dry extremes, as there is little moisture or impervious surfaces in these places at these times to hold in the heat at night. The highest minimum T and ATs occur in urban areas during the wet extremes, in which a combination of impervious surface and heat-storing moisture can prevent temperatures from dropping any further.

AT-T differences are higher during wet periods than dry; in other words, when recent precipitation has been high and soil is moist, more moisture contributes to an elevated AT. This is especially true for rural areas at ATmax, when photosynthesis and evapotranspiration are occurring and transferring this soil moisture into the nearby air. AT-T differences behave near-identically between rural and urban areas at ATmin, as evapotranspiration does not occur at night. The fact that this effect of elevated AT is highest at the hottest time of day in rural areas has severe implications for agricultural workers and other laborers who must exert themselves in the heat. Parajuli et al. (2024) found that increased soil moisture as effected by irrigation increases farmworker heat stress. These findings all support the idea that especially during periods of high soil moisture, AT important to use as a measurement of heat exposure for health implications.

4.3 Limitations and further work

While we have worked to better understand the role of moisture in the UHI and AT, note that this study did not examine other factors that may interact with the UHI effect, such as incoming solar radiation and wind, and so future studies may seek to untangle these connections. As AT is derived from both temperature and humidity, it is of interest to further investigate what contributes the most to increased AT: is it temperature increases, a greater amount of water vapor in the lower atmosphere, or a combination of both? There are also other heat indices that incorporate more variables including radiant heat and wind, such as Wet-Bulb Globe Temperature, but measuring and analyzing radiant heat and wind provide many complications and challenges in measurement, and they can vary extensively even across a short distance. Warnings issued by the National Weather Service utilize only a heat index generated by temperature and humidity, and apparent temperature has been extensively used in epidemiological studies on the impacts of heat on health (Basu, 2009).

An important set of implications for this study regards the uneven distribution of heat stress across space and especially what is experienced in rural areas. In Wisconsin and Minnesota, a recent study has found that at the county-level, population-adjusted heat-related illness rates are significantly higher in rural areas than metropolitan areas (Minnesota Department of Health and Wisconsin Department of Health Services, 2019). Despite the well-known fact that urban areas experience elevated temperatures compared to rural areas, combined heat and humidity conditions that people in rural areas experience are understudied and underdiscussed. The biophysical insights gained here combined with interrogations of the social, economic, and infrastructural contexts shaping urban-rural differences in heat exposure and vulnerability can help to address this apparent paradox.

Traditional quantification of UHIs and measurements of temperature, which important, fail to consider the impacts of humidity on the human body's ability to cool itself. Our findings demonstrate the importance of using AT rather than T alone to measure and communicate about heat risk, as well as the importance of understanding the sometimes life-threatening conditions that people living in rural areas face.

5. Works Cited

Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., ... & Tangang, F. (2022). The impact of heatwaves on mortality and morbidity and the associated vulnerability factors: a systematic review. *International journal of environmental research and public health*, *19*(23), 16356.

Berg, E., & Kucharik, C. (2022). The Dynamic Relationship between Air and Land Surface Temperature within the Madison, Wisconsin Urban Heat Island. *Remote Sensing, 14*(1), 165.

Berglund, L. G., & Gonzalez, R. R. (1977). Evaporation of sweat from sedentary man in humid environments. *Journal of Applied Physiology*, *42*(5), 767-772.

Chakraborty, T., Venter, Z. S., Qian, Y., & Lee, X. (2022). Lower urban humidity moderates outdoor heat stress. *AGU Advances, 3*(5), e2022AV000729.

Fry, J. A., Xian, G., Dewitz, J. A., Homer, C. G., Barnes, C. A., Herold, N. D., & Wickham, J. D. (2011). Completion of the 2006 national land cover database for the conterminous United States. *Photogrammetric Engineering & Remote Sensing*, *77*(9).

Greiser, C., Hederová, L., Vico, G., Wild, J., Macek, M., & Kopecký, M. (2024). Higher soil moisture increases microclimate temperature buffering in temperate broadleaf forests. *Agricultural and Forest Meteorology*, *345*, 109828.

Guo, Y., Gasparrini, A., Armstrong, B. G., Tawatsupa, B., Tobias, A., Lavigne, E., ... & Tong, S. (2016). Temperature variability and mortality: a multi-country study. *Environmental health perspectives*, *124*(10), 1554-1559

Harlan, S. L., Brazel, A. J., Darrel Jenerette, G., Jones, N. S., Larsen, L., Prashad, L., & Stefanov, W. L. (2007). In the shade of affluence: The inequitable distribution of the urban heat island. In *Equity and the Environment* (pp. 173-202). Emerald Group Publishing Limited.

Li, Y., Akkus, C., Yu, X., Joyner, A., Kmet, J., Sweat, D., & Jia, C. (2019). Heatwave events and mortality outcomes in Memphis, Tennessee: testing effect modification by socioeconomic status and urbanicity. *International journal of environmental research and public health, 16*(22), 4568.

Minnesota Department of Health and Wisconsin Department of Health Services. (2019). “Extreme heat: who’s at risk? Findings from a collaborative project between Minnesota and Wisconsin.” https://www.dhs.wisconsin.gov/publications/p02386.pdf

Mueller, N. D., Butler, E. E., McKinnon, K. A., Rhines, A., Tingley, M., Holbrook, N. M., & Huybers, P. (2016). Cooling of US Midwest summer temperature extremes from cropland intensification. *Nature Climate Change*, *6*(3), 317-322.

Nairn, J. R., & Fawcett, R. J. (2015). The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. *International journal of environmental research and public health*, *12*(1), 227-253.

NIDIS. n.d. Historical data and conditions. https://www.drought.gov/historical-information?dataset=0&selectedDateUSDM=20120124

Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, *108*(455), 1-24.

Parajuli, S. P., Biggs, T., de Sales, F., Zavala Pérez, M. A., He, C., Jones, C., ... & Soucier, M. (2024). Impact of irrigation on farmworker's heat stress in California differs by season and during the day and night. Communications Earth & Environment, 5(1), 787.

Runnalls, K. E., & Oke, T. R. (2000). Dynamics and controls of the near-surface heat island of Vancouver, British Columbia. *Physical Geography*, *21*(4), 283-304.

Schatz, J. & Kucharik, C.J. (2014). Seasonality of the urban heat island effect in Madison, Wisconsin USA. *Journal of Applied Meteorology and Climatology, 53*: 2371-2386.

Schatz, J., & Kucharik, C. J. (2015). Urban climate effects on extreme temperatures in Madison, Wisconsin, USA. *Environmental Research Letters, 10*(9), 094024.

Schatz, J., & Kucharik, C. J. (2016). Urban heat island effects on growing seasons and heating and cooling degree days in Madison, Wisconsin USA. *International Journal of Climatology, 36*(15), 4873-4884.

Steadman, R. G. (1984). A universal scale of apparent temperature. *Journal of Applied Meteorology and Climatology, 23*(12), 1674-1687.

United Nations. (2014). World urbanization prospects: the 2014 revision. United Nations Department of Economic and Social Affairs (UN DESA) Population Division, New York.

USDA National Agricultural Statistics Service. (2022). 2022 Census of Agriculture. Complete data available at www.nass.usda.gov/AgCensus. Dane County statistic retrieved from https://www.nass.usda.gov/Publications/AgCensus/2022/Online_Resources/County_Profiles/Wisconsin/cp55025.pdf

Waugh, D. W., Zaitchik, B., Scott, A. A., Ibsen, P. C., Jenerette, G. D., Schatz, J., & Kucharik, C. J. (2023). Limited Role of Absolute Humidity in Intraurban Heat Variability. *Journal of Applied Meteorology and Climatology*, *62*(12), 1845-1854.

Williamson, M., & Kucharik, C. J. (2023). Urban Warming Challenges Verification of Frost Advisories and Freeze Warnings in Madison, Wisconsin. *Weather and Forecasting*, *38*(6), 1011-1023.

Wisconsin State Climatology Office (n.d). Historical Madison Precipitation Data. Retrieved from https://climatology.nelson.wisc.edu/first-order-station-climate-data/madison-climate/historical-precipitation/

Zhou, D., Xiao, J., Bonafoni, S., Berger, C., Deilami, K., Zhou, Y., ... & Sobrino, J. A. (2019). Satellite remote sensing of surface urban heat islands: progress, challenges, and perspectives. *Remote Sensing, 11*(1), 48.

Zipper, S. C., Schatz, J., Kucharik, C. J., & Loheide, S. P. (2017). Urban heat island-induced increases in evapotranspirative demand. *Geophysical Research Letters*, *44*(2), 873-881.

6. Supplementary figures

Columns

variable1 / avg	≈ > <	variable2 / avg	p-value	sig?	means diff	summary
Q1: Climatology of AT						
UHI of Tmin		UHI of ATmin				There is no significant difference between UHI magnitudes of AT and T at ATmin
2.27	≈	2.27	0.894		0.00	
UHI of Tmax		UHI of ATmax				UHI of Tmax > UHI of ATmax
0.89	>	0.55	p < 0.0001	*	0.34	
urban VP at ATmin		rural VP at ATmin				At ATmin (night/dawn), urban VP > rural VP
1.769	>	1.679	p < 0.0001	*	0.09	
urban VP at ATmax		rural VP at ATmax				At ATmax (afternoon), urban VP < rural VP
2.031	<	2.152	p < 0.0001	*	-0.12	
urban minus rural VP at ATmin		urban minus rural VP at ATmax				At ATmin (night/dawn), urban VP > rural VP; at ATmax (afternoon), urban VP < rural VP
0.090	>	-0.120	p < 0.0001	*	0.21	
Q2A: UHI across moisture extremes						
wet T UHI at ATmin		dry T UHI at ATmin				The dry UHI > wet for both T and AT at ATmin (night/dawn)
1.49	<	2.26	p < 0.0001	*	-0.77	
wet AT UHI at ATmin		dry AT UHI at ATmin				
1.53	<	2.26	p = 0.00014	*	-0.73	
wet T UHI at ATmax		dry T UHI at ATmax				There is not a significant difference between wet and dry UHI at ATmax (afternoon)
0.91	≈	1.01	p = 0.033		-0.10	
wet AT UHI at ATmax		dry AT UHI at ATmax				
0.60	≈	0.67	p = 0.065		-0.07	
wet urb T at ATmin		dry urb T at ATmin				In most instances, rural vs. urban landcover types have different average T and AT values across wet and dry extremes, but the directionality differs, indicating contrasting mechanisms.
18.50	≈	18.32	p = 0.044		0.18	
wet urb AT at ATmin		dry urb AT at ATmin				
19.97	>	19.51	p < 0.0001	*	0.46	
wet rur T at ATmin		dry rur T at ATmin				
16.87	>	15.88	p < 0.0001	*	0.99	
wet rur AT at ATmin		dry rur AT at ATmin				
18.31	>	17.09	p < 0.0001	*	1.22	
wet urb T at ATmax		dry urb T at ATmax				
27.03	<	27.96	p < 0.0001	*	-0.93	
wet urb AT at ATmax		dry urb AT at ATmax				
28.66	≈	28.64	p = 0.901	*	0.02	
wet rur T at ATmax		dry rur T at ATmax				
26.20	<	26.99	p < 0.0001		-0.79	
wet rur AT at ATmax		dry rur AT at ATmax				
28.16	≈	28.09	p = 0.528		0.07	
Q2B: AT-T across moisture extremes						
wet urb AT-T at ATmin		dry urb AT-T at ATmin				Across all permutations of landcover and at ATmin or ATmax, AT-T of wet extremes > AT-T of dry
1.47	>	1.18	p < 0.0001	*	0.29	
wet rur AT-T at ATmin		dry rur AT-T at ATmin				
1.43	>	1.21	p < 0.0001	*	0.22	
wet urb AT-T at ATmax		dry urb AT-T at ATmax				
1.62	>	0.68	p < 0.0001	*	0.94	
wet rur AT-T at ATmax		dry rur AT-T at ATmax				
1.96	>	1.1	p < 0.0001	*	0.86	
wet urb AT-T at ATmax		wet rur AT-T at ATmax				Rural areas have a greater AT-T difference (a more elevated AT compared to T) than urban areas at ATmax (afternoon) in both wet and dry moisture extremes.
1.62	<	1.96	p < 0.0001	*	-0.34	
dry urb AT-T at ATmax		dry rur AT-T at ATmax				
0.68	<	1.1	p < 0.0001	*	-0.42	
wet urb AT-T at ATmin		wet rur AT-T at ATmin				There is not a significant difference between rural and urban areas' AT-T differences at ATmin (night/dawn) in both wet and dry moisture extremes.
1.47	≈	1.43	p = 0.035		0.04	
dry urb AT-T at ATmin		dry rur AT-T at ATmin				
1.18	≈	1.21	p = 0.270		-0.03	

Table 1.2: Comparisons of variables and statistical significance. Conditional formatting is applied to each difference of means to highlight steepest contrast, wherein the lowest values are blue and the highest values are red.

Chapter 2: Understanding differential vulnerability to heat from EMS calls for heat-related illness in Wisconsin

1. Introduction

Understanding the impacts of heat on health is critical to take actions that reduce the negative impacts of future climate conditions on the quality and duration of peoples' lives. Studying past heat-caused morbidity can tell us who or what groups are vulnerable to heat events, which places experience a higher burden of heat-related illness, what meteorological conditions merit what levels of heat warnings, expected capacity demands on emergency medical services, and where more interventions are needed.

The objective for this chapter is to quantify heat-health relationships in Wisconsin, especially in understudied rural areas. I ask: **What meteorological and sociodemographic conditions are associated with elevated rates of heat-related illness in Wisconsin?** Who and what parts of the state are disproportionately impacted, and under what circumstances? Here I specifically investigate the demographics of gender, race, and ethnicity, rural vs. urban areas, counties, what we can tell about labor and heat illness, and weather conditions. Furthermore, in seeking answers, I have identified strengths and limitations of different data sources on health responses to heat.

2. Background

Linking heat exposure with health outcomes provides essential information for heat planning, but the ways in which these interactions play out can be difficult to study. It is well-known that prolonged exposure to heat can cause a variety of illnesses and even death (Barrow & Clark, 1998; Bouchama & Knochel, 2002). Sudden exposure to much higher temperatures does not give the body time to acclimate and is especially dangerous to human health (Guo et al., 2016; Sheridan & Kalkstein, 2010). Heat can be especially dangerous for the elderly; people with respiratory issues; those on medications which disrupt sweating processes or water and electrolyte balances; and young children (Bouchama & Knochel, 2002; Cheng & Brown, 2020; Kilbourne et al., 1982; Semenza et al., 1996; Semenza et al., 1999; Sun & Cheng, 2025). Exertion and exposure both increase the risk of heat illness among manual laborers, outdoor workers, athletes, and military personnel (Bouchama & Knochel, 2002; Gubernot et al., 2014; Knochel & Reed, 1994; Stocker et al., 2014). Additional risk factors relating to social context are wealth, race, social isolation, greenery and shade in one's neighborhood, and one's effective access to cooling and medical help during heat crises (Hicken et al., 2012; Yardley et al., 2011).

The epidemiology of extreme heat is a complex field of study with a number of methodological issues and considerations. To begin with, there is no single agreed-upon definition of a heat wave (Smith et al., 2013), making it difficult to find common ground for identifying what qualifies as dangerously hot conditions and having comparable results across studies. Exposure misclassification is a daunting challenge for studies of heat-health relationships (Brand, 2023). It is impossible for the temperature conditions recorded by a weather station or sensor to represent the precise environmental conditions experienced by every person. Generalizations are necessarily made about temperature, let alone humidity, wind, sun exposure, or human exertion, but the degree of this generalization can be at least somewhat addressed by choices in study design (Hondula et al., 2012; Hondula et al., 2014a; Schatz, 2015).

Health outcomes have also been studied through a variety of approaches, the most common measurement being mortality (Basu, 2009). However, there is no single definition of heat-induced mortality (Basu & Samet, 2002; Wolfe et al., 2001), and the narrow criteria for categorizing a death as being caused by cause its true impact on health to be underreported (Basu & Samet, 2002; Donoghue et al., 1997; Shen et al., 1998). To address this uncertainty, studies of heat and mortality have increasingly sought to estimate excess mortality from a baseline of all-cause mortality. Overall deaths are notably elevated during extreme heat events, and while some may be coincidental, excess all-cause mortality remains a much-used measure (Basu, 2009). One consideration in understanding heat-health relationships in recent years is effects of the COVID-19 pandemic. Keller (2024) argues that in the face of increasing severe heat and in a post-pandemic world, we must rethink how we count and analyze heat-related illness and mortality. The pandemic has both devastated vulnerable populations with comorbidities and has brought about new lasting health problems in some (Hacker et al., 2021), both of which affect health outcomes to heat by reducing or adding to medically vulnerable populations.

One additional difficulty in linking heat conditions with health outcomes is the harvesting effect, wherein those most susceptible to heat-related illness (HRI) suffer illness and death during early season heat waves, leaving behind fewer members vulnerable populations in the heat events that follow, in turn resulting in lower counts of mortality and illness in these subsequent events (Hatvani-Kovacs et al., 2016; Langlois et al., 2013; Li et al., 2012). Furthermore, even when excess mortality is used and deaths due to heat are not undercounted, researchers must untangle the time lag between exposure and response, and mortality only captures the worst health outcomes (Tolika, 2018).

Morbidity metrics are more sensitive than mortality and capture more cases, and the higher numbers can yield more statistically powerful results (Li et al., 2012). Morbidity has been measured by heat-coded or all-cause hospital admissions (Vaidyanathan et al., 2018; Zhao et al., 2019), emergency department admissions, and ambulance callouts (Arsad et al., 2022; Hatvani-Kovacs et al., 2016; Nitschke et al., 2011; Williams et al., 2012). Studies on emergency department admissions have identified heat-related illness through the codes under the International Classification of Diseases (ICD) assigned by first responders or by identifying keywords in free-text fields under their chief complaint notes (Gubernot et al., 2013; Morano & Watkins, 2017). Emergency medical services (EMS), often in the form of ambulance runs, are vital in saving lives from the dangers of overheating. Bringing someone experiencing HRI to a cool place within 60 minutes drastically reduces mortality (Vicario et al., 1986), and EMS calls are an even more sensitive metric of heat-related illness than emergency department visits (Kue and Dyer, 2013; Lee and Brown, 2022; Li et al., 2021; Seong et al., 2023; Zottarelli et al., 2021; Wang et al. 2021; Xu et al. 2018). In addition to providing insights into the impacts of heat on health, analyzing EMS calls alongside extreme heat can help public health and emergency medical staff understand and prepare for increases in call volume with extreme heat and adjust their capacity accordingly (Bassil, 2010; Kue & Dyer, 2013; Xu et al., 2018).

Data contained in EMS patient care reports contain a high amount of information that has been underutilized to gain insights into HRI (Yeargin et al., 2020). The National EMS Information System (NEMSIS) is a standardized database for paramedics to report information about their cases (patient care reports), which includes patient age, gender, race, location type of incident, address, and timestamps of the initial call, arrival to scene, and arrival at medical facility if applicable. Location of incident is a useful variable and otherwise difficult to come by;

it is not available for ED visits, where the most precise location information available is the healthcare facility and patient's address, and this may not be the location where the person became ill.

Heat and Public Health in Wisconsin

Wisconsin has far from the hottest temperatures experienced in the United States, but it is an important place to study the health impacts of heat. Between 2008 and 2020, emergency department visits for HRI increased in the Midwest more than any other region in the country (Dring et al., 2022). Relatively few studies have been conducted on heat and health in Wisconsin, but they provide some useful insights.

In the scorching 1995 heat wave that is especially famous for its impacts on Chicago, 154 casualties in Wisconsin were attributed to heat; 59% of these were in Milwaukee, which makes up 30% of the state population, representing a disproportionate health impact (CDC, 1996; Christenson et al., 2013; Nashold et al., 2013). In the extremely hot summer of 2012, a total of 27 deaths were attributed to heat in the state, and a map showing rates of incidence by county can be found in Supplementary Figures (Figure 2.12). An investigation revealed that all victims lacked air conditioning in their homes, 70% were 65 or older, and 75% had a cardiovascular disease (Christenson et al., 2013). While these counts of heat-attributed deaths may be underestimated, and low counts make the data less statistically robust, these studies still provide useful insights into factors that shape vulnerability to HRI.

Li et al. (2012) used a generalized additive model to quantify the relationship between morbidity (as measured by hospital admissions) and high temperatures during the years 1989-2005 in Milwaukee. Meteorological variables included daily maximum and minimum temperature and relative humidity, but these were considered as separate variables and not combined to generate apparent temperature (AT), which expresses the joint effects of temperature and humidity. Hospital admission data included illnesses that heat may have contributed to, even if they may not directly be considered as heat-related illness (e.g., respiratory and cardiovascular conditions). The authors also acknowledge that acclimatization and the harvesting effect were not accounted for (Li et al., 2012).

In 2014, the Wisconsin Department of Health Services generated Heat Vulnerability Indices (HVI) for the state's counties as well as accompanying county-level reports. Deriving their methods from a HVI analysis of San Francisco (San Francisco Department of Public Health, 2013), the authors generated statewide and county-wide Heat Vulnerability Indices using land surface air temperature on July 6, 2012 as an indicator of exposure to high temperatures; percentage of the population that was admitted to an emergency department for heat stress between 2002 and 2012 as an indicator of typical health outcomes; population density, health factors, demographic and socioeconomic factors; and natural and built environment factors. Maps showing these variables and the final HVI values can be found in Supplementary Figures (Figure 2.13). However, these reports did not conduct statistical analyses to determine which factors contributed the most variability to indices (Wisconsin Department of Health Services, 2014). Furthermore, land surface temperatures on one extremely hot day may not be representative of how heat typically manifests in the state, spatially and otherwise, let alone account for the role that humidity may play, or identify which meteorological conditions led to which cases of heat-related illness. Additional studies can build upon this work and our understanding of the different facets of vulnerability to heat in the state.

In a 2019 report on heat impacts in Wisconsin and Minnesota, both states' Departments of Health Services utilized emergency department admission data between 2006 and 2015. They assessed county-level variables including urban vs. rural, climate regions, percent of 65+ year-old people living alone, poverty rates, language barriers, and occupation as well as individual characteristics of admissions including age, gender, insurance status, and county. They found that out of all age demographics, those between the ages of 15 and 34 had the highest rate of heat-related emergency department visits; men's admission rates were twice those of women in Wisconsin; counties that are hotter on average generally had more cases; and HRI rates per capita were much higher in rural areas than urban (see Figure 2.14 in Supplementary Figures). Given these patterns, especially the unexpected ones,[2] the authors assert that it is important not only to prioritize the elderly with messaging and assistance around the heat, but also younger people (Minnesota and Wisconsin DHS, 2019). Because this report compares overall population-adjusted rates of heat-related illness over the entire study period, the conditions which caused these emergency department visits were not investigated.

Studying heat and health in rural areas

Finally, understanding the impacts of heat on health in rural areas is both necessary and difficult. Most studies on heat-health outcomes have concentrated on urban areas, leaving rural areas understudied (Dalgo, 2023). Rural areas typically have a lower density of automated weather stations, which contributes to the exposure misclassification problem, as well as limited funding and low population densities, which make it difficult to generate statistically robust

---

[2] We might expect urban areas to have higher HRI rates because of elevated temperatures due to the urban heat island effect, and to see higher rates among the elderly because of the biophysical vulnerability of older adults.

findings (Hashizume et al. 2009; Henderson et al. 2013; Lee et al. 2016; Odame, 2019). Although temperatures may be lower than those in cities, studies suggest that rural areas may be just as vulnerable to heat, if not more vulnerable, than cities when population-adjusted health outcomes are considered (Li et al. 2019; Minnesota and Wisconsin DHS, 2019; Odame et al. 2018). Population characteristics of rural areas can also correspond to greater heat vulnerability. Agricultural workers, and especially migrant seasonal farmworkers, experience high rates of exposure to heat and often fall under other categories of social vulnerability relating to poverty, language barriers, immigration status, and power differences. Rural populations can also have relatively high populations of children as well as elderly, low-income, unemployed, underemployed, uninsured, and/or underinsured people, as well as those with chronic health conditions. There may also be challenges in access to health infrastructure and its capacity to meet the needs of a dispersed population (Hassenger and Hobbs 1992; Hart et al. 2005; Odame et al., 2018). Given the high number of unknowns and relative difficulties in studying rural areas, it is important to design research questions and methods to intentionally shed light on these areas and to take into consideration factors such as low population density, access to health infrastructure, and outdoor work.

While their exact results and conclusions may differ depending on the sites and methods chosen, all of these studies can help us predict health outcomes from future heat events, address vulnerable areas and populations with appropriate interventions, and better prepare residents and local services for heat waves. By addressing their limitations and deliberately studying the understudied, we can build on this knowledge and provide a foundation for further improving resilience to heat and improving health outcomes in Wisconsin.

Health data availability

In order to study heat-health relationships, it is important to know: What do different health datasets (all-cause/excess mortality, emergency department visits, heat-related EMS patient care reports, heat-related EMS counts and all-cause EMS counts) tell us about these differing impacts? At what spatial and temporal resolutions can we get meaningful results from? What are the insights and limitations of each dataset? From an initial exploration into different kinds of data available in Wisconsin, focusing on the months of June, July, and August, overall characteristics of each dataset that may be useful to others studying heat and health in the future are described below in Table 2.1.

	Total/excess mortality	HRI ED visits	HRI and secondary ED visits	Total EMS counts	HRI EMS counts and patient care reports
Frequency/order of magnitude, statewide:					
Annual avg of counts 2017-2024 (summer-only if not HRI-specific)	13,458	971	1,951*	552,770	1,282
Weekly counts per year	1,035	75	150*	42,521	99
Data shifts/range limits	Available for decades; ICD switch in 1999 to include >1 cause of death relevant if looking at specific diagnostic codes, not all-cause	Prior to 2005 is less reliable; ICD switch in 2015	Prior to 2005 is less reliable; ICD switch in 2015; risk of double-counting if adding up different ICD codes	Available starting in 2008; EMS data dictionary version switch in 2017	Available starting in 2008; EMS data dictionary version switch from V2 to V3 in 2017; V2 may be less sensitive
Benefits	Underreporting extremely rare; single counts (not repeated hospitalizations for one patient); secondary causes not missed	Heat-specific. Both statewide yearly totals and county-by-county available	Specific diagnostic codes for different conditions	More sensitive than mortality; higher counts increase statistical robustness	Heat-specific; can show disproportionate impacts on demographics; can be very spatially or temporally specific
Limitations	Because dataset is all-cause, may include a substantial amount of non-heat-related noise compared to signal	Costly if not working within health department; chance of under-reporting HRI	Costly if not working within health department; chance of under-reporting HRI; *secondary counts may include double-counting with HRI	Because dataset is all-cause, may include a substantial amount of non-heat-related noise compared to signal	Chance of under-reporting HRI
	All: moving baseline; impact of COVID pandemic since 2020 (see Keller, 2024)				

Table 2.1: Summary of data sources, strengths, limitations, and considerations for understanding heat-related illness in Wisconsin.

A commonality across data sources is tradeoffs. The need to protect patient privacy results in datasets mostly being available at either a high spatial resolution or temporal resolution but not both, or having demographic information about patients but without a high spatial nor high temporal resolution. Relatedly, especially in counties with low populations, EMS counts aggregated to a weekly level are not high enough to confidently attribute weather conditions to health outcomes. Some level of aggregation is necessary, whether it is combining counties into regional or statewide totals or weeks into yearly totals. As a result, each analysis can excel in gaining insights on one main issue, whether that be spatial vulnerability, timing and corresponding weather conditions, or demographics and other specific characteristics around the incident. Across heat-specific metrics, reporting is a serious question; it can be difficult to tell whether low HRI counts are due to truly low rates of illness or low levels of documentation.

From this exploration, considering the merits and limitations of these different data sources, HRI EMS data were selected for deeper analysis largely due to the metric's sensitivity and insights that it can provide, such as location type (as outlined above in Background).

3. Methods

To investigate what meteorological and sociodemographic conditions are associated with elevated rates of heat-related illness in Wisconsin, I utilized EMS data for heat-related illness. The dataset was retrieved by the Wisconsin DHS Office of Preparedness and Emergency Health Care. Following their recommendations, EMS counts were identified as being heat-related for this study following the definition used by Biospatial, a data analytics company that has been working alongside EMS. This definition is more complex than solely ICD-based ones in order to utilize the patient care report. In short, EMS calls were included in this study if the phrase "feeling overheated," "heat emergency," "heat exposure," "heat exhaustion," "heat stroke," or "outside in the sun" appeared in the report, or if the diagnostic codes specified heat exposure or hyperthermia. The full definition can be found in the Supplementary Figures section in Figure 2.15.

From these criteria of ambulance calls, two forms of data were available. First, patient care report information included gender, race, and ethnicity of patients; location type (private residence, street/road, public space, recreation area, industrial, agricultural, health care facility, or group quarters); time of day divided into four-hour intervals (six per day); and whether or not the incident was tagged as being work-related (NEMSIS, 2023). Because this dataset is detailed at the individual patient level, to protect patient privacy it was aggregated spatially and temporally by year and into one of the state's five DHS regions. Patient care report-derived data is available since 2008. To understand how population breakdowns of EMS calls compare with county populations, county demographic information is utilized from the Department of Health Service's WISH (Wisconsin Interactive Statistics on Health) Query System (https://www.dhs.wisconsin.gov/wish/index.htm).

County-by-county counts of HRI EMS calls available since 2017 were also used and aggregated by week to protect patient privacy. The NEMSIS data dictionary changed from version 2 to version 3 in 2017, resulting in changes to the variables used to detect heat-related illness. The definition used for V3 data may be more sensitive than the V2 definition and reporting patterns may have changed with the shift from V2 to V3 versions.[3] Additionally, schools were only listed as a location type beginning in 2017, which created new patient care report categories. Low count numbers are sometimes suppressed to protect patient privacy, and so the actual number of incidents may be slightly higher than reported. County populations have

[3] In V2, there is no field for whether HRI protocols were used; the primary impression and secondary impression options were more limited and not ICD-10 code based. Only cases that fit under the code "569011 Heat Exhaustion / Stroke" qualified under V2. Furthermore, while both V2 and V3 allow only one primary impression code, V2 allows only one secondary impression while in V3 there is an unlimited number of secondary impression codes that can be entered. As a result, the V2 definition is more restrictive and may be less sensitive and inclusive (Will Koehne, Preparedness and Emergency Health Care Epidemiologist, personal communication).

been relatively stable over this study period, the state itself experiencing a 2% population increase (US Census Bureau 2020), and so census data from one year of the study period are used for comparison.

To connect meteorological conditions with health outcomes, weekly summer county HRI EMS data were linked with hourly temperature and humidity data from the nearest weather observation stations available from the Midwestern Regional Climate Center (MRCC; https://mrcc.purdue.edu/) (see Figure 2.1 below). The intent of county-by-county comparisons is to further investigate findings from the 2019 DHS report that suggest when adjusting for population, rural counties are in fact disproportionately vulnerable to heat when compared to urban areas, despite the presence of elevated temperatures in cities due to the urban heat island effect. Past studies have examined demographics and home addresses of people affected by heat-related illness, but what exactly makes rural populations vulnerable in comparison to urban populations is less known. It is understood that outdoor work, exertion, and laboring in the heat (which may include non-air-conditioned environments such as warehouses and delivery vehicles) increase exposure to extreme heat and risk of heat-related illness, but a focused breakdown on rurality is more rare.

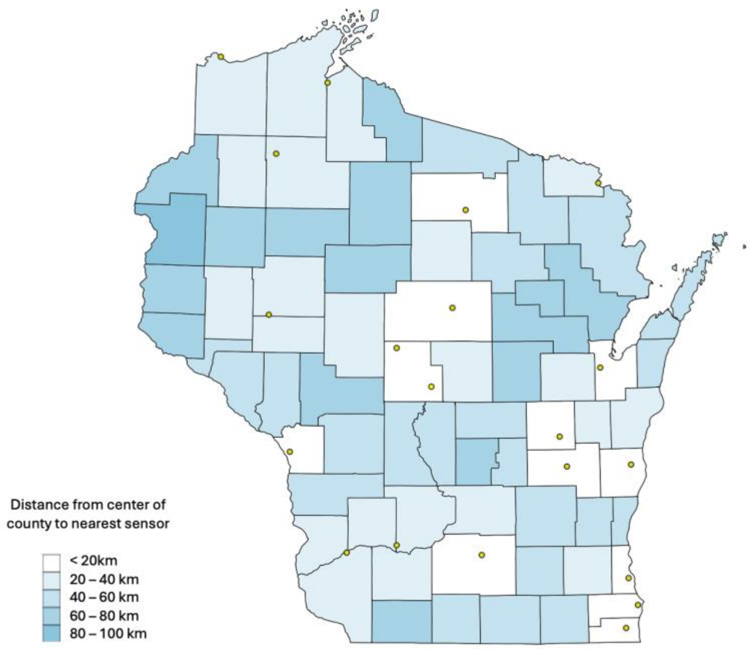


Figure 2.1: Wisconsin counties and MRCC weather stations utilized (yellow circles). Coloring indicates distance from the center of each county to the nearest weather station used in analysis.

For individual counties, population-adjusted (per 100,000) HRI EMS rates were compared with variables including the maximum apparent temperature (ATmax) during the week that the HRI data were recorded. Furthermore, a regression analysis was also conducted in which the dependent variable was each week's population-adjusted EMS HRI count (per 100,000). Independent variables evaluated included the meteorological variables of the maximum AT that week (i.e., the most extreme conditions the human body has to endure that week); the difference between that week's averaged ATmean[4] and the ATmean of the previous month as a proxy for acclimatization; the week number to indicate how early or late in the summer the period fell; and the year. Independent variables also included county characteristics such as population density, percent of families living in poverty, and percent outdoor workers.

[4] Mean AT, which averages the daily high and low ATs and incorporates how low temperatures reached; these lows indicate how much of a respite the body was able to have that night.

Population information is from the census (US Census Bureau 2020), and race and gender demographics are from the DHS WISH (Wisconsin Interactive Statistics on Health) Query System and pertain to the year 2023 (https://www.dhs.wisconsin.gov/wish/index.htm). Data on the percentage of families living in poverty are from the National Institute on Minority Health and Health Disparities (https://hdpulse.nimhd.nih.gov/data-portal/home), and data on percent outdoor workers by county are from the CDC's National Environmental Public Health Tracking Network (https://ephtracking.cdc.gov/DataExplorer/). The year 2017 was removed from this analysis because this was the year in which the data dictionary changed, and my data correspondent informed me that the records of EMS calls submitted during this transition may be incomplete (Will Koehne, Preparedness and Emergency Health Care Epidemiologist, personal communication). Door County was omitted from this analysis, as its geographic location next to Lake Michigan contributes to cooler temperatures during summer (US Federal Insurance Administration, 1977), and the nearest suitable MRCC weather station does not accurately represent Door County's meteorological conditions. This is the first study of HRI in Wisconsin that incorporates the element of time (years, weeks during the summer, and corresponding thermal conditions) into the analysis outside of Li et al. (2012), which examined Milwaukee 1989-2005.

4. Results

4.1 Counties with the highest population-adjusted HRI rates have the lowest population densities

While not all low-population counties have high HRI rates, the counties with the highest HRI rates in the state all have low population densities. A map of these HRI rates is shown alongside population density in the state Figure 2.2, and county population density is plotted against population-adjusted HRI EMS rates in Figure 2.3. The full table of county HRI EMS runs and population-adjusted totals can be found in the Table 2.5 in the Appendix. It is notable that these trends do not match what we would expect given the urban heat island effect. Furthermore, many of the highest rates occur in the northern part of the state, which is relatively less exposed to heat than the south. This implies that heat-related illness is influenced by more factors than outdoor temperatures alone.

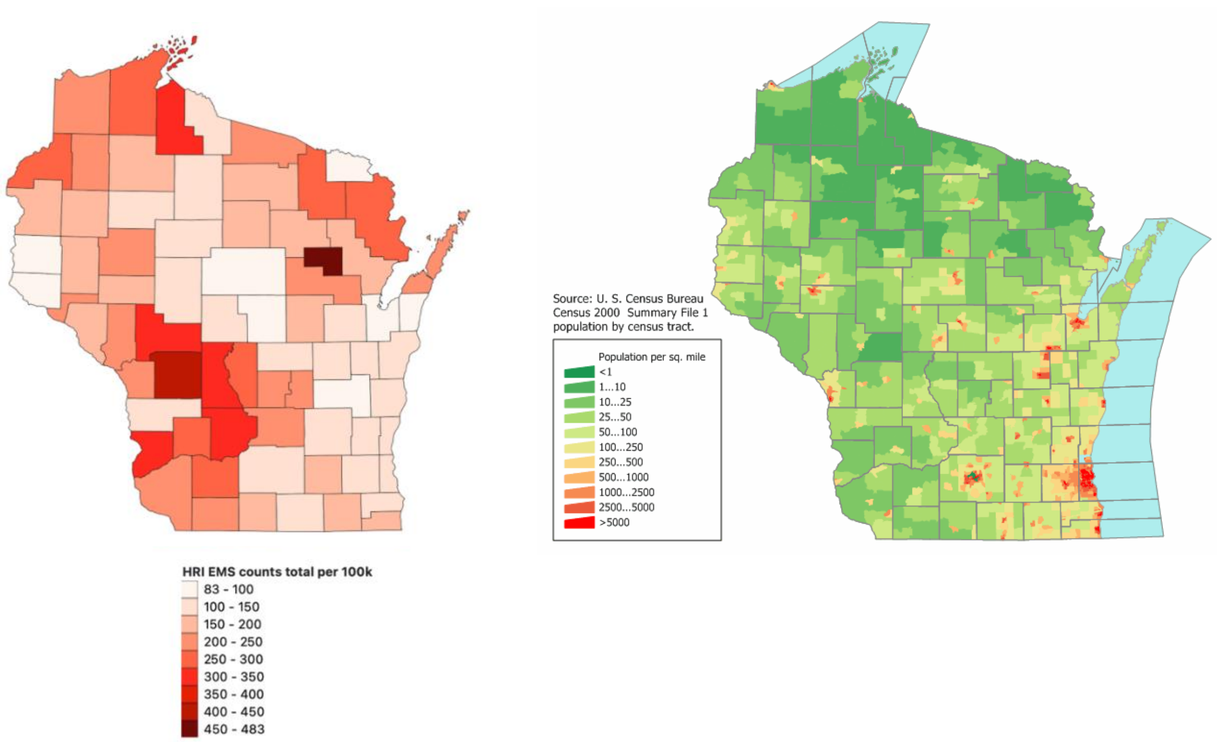


Figure 2.2: Population-adjusted total HRI EMS rates in Wisconsin 2017-2024 by county, per 100,000, alongside a population density map from Wikimedia Commons. Low-population density counties, including some in the northernmost part of the state, have high population-adjusted rates. Menominee County shows the highest risk, followed by Monroe and Juneau Counties. See Table 2.5 under Supplementary Figures for more information on county HRI EMS rates.

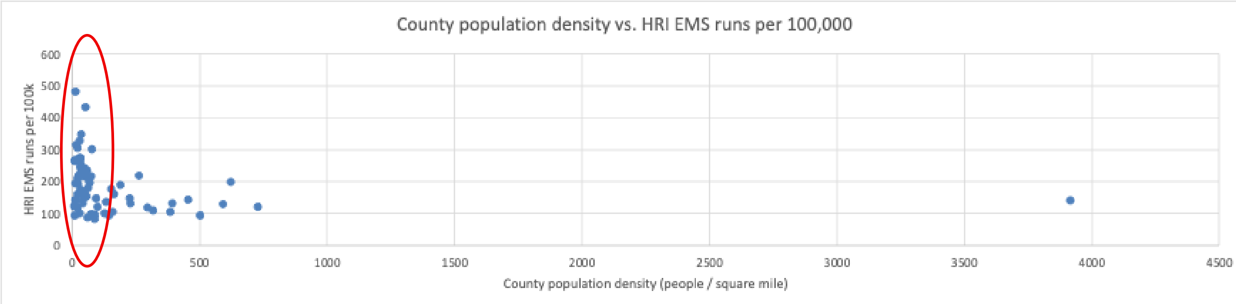


Figure 2.3: Wisconsin county population density and population-adjusted HRI EMS rates in summer months 2017-2024. The right-most point is Milwaukee County. The red circle shows where the highest EMS rates take place: all in low-population density counties.

4.2 Rates of HRI are increasing in recent years, though there is much year-to-year variability

As Figure 2.4A below shows, yearly statewide counts for HRI EMS calls are substantially rising at an average rate of 89 counts per year ($R^2 = 0.828$). This rising trend in HRI EMS calls is also shown in Figure 2.4B for both the period preceding the 2017 data dictionary change and the period afterwards, to verify that the trend persists regardless of the data dictionary. This shift does not seem to be directly attributable to steadily rising temperatures; see Figure 2.5 for general trends in temperature by year, shown via the proxy of maximum daily temperatures at Dane County Regional Airport. See section 4.4 for a more rigorous investigation of temperature and associated health outcomes. County-by-county yearly population-adjusted rates, slopes, and R^2 values are available for reference in Table 2.6 in Supplementary Figures. Among them, while R^2 values are generally quite low, out of Wisconsin's 72 counties, 57 show positive slopes and only 15 have negative slopes. In other words, HRI EMS calls are increasing in frequency across the state.

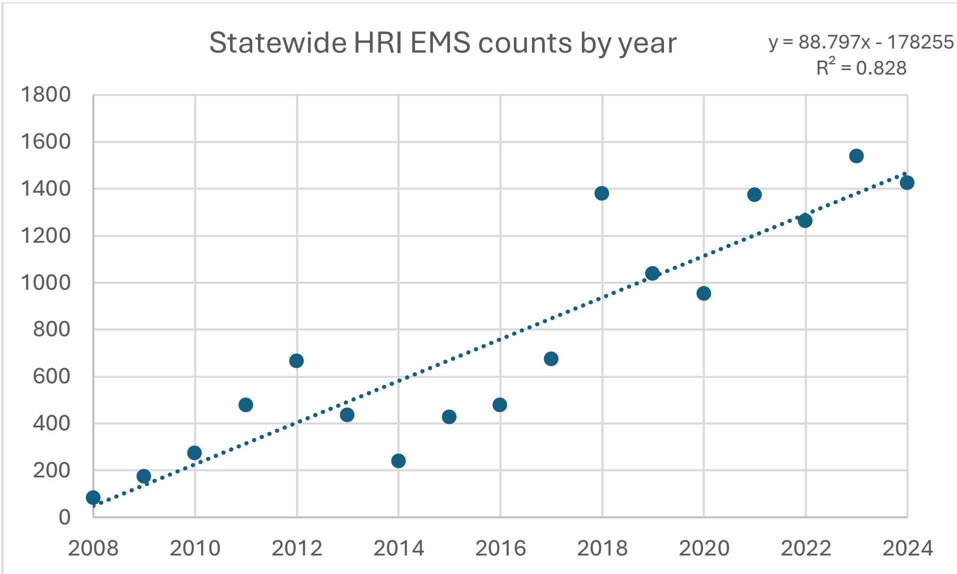
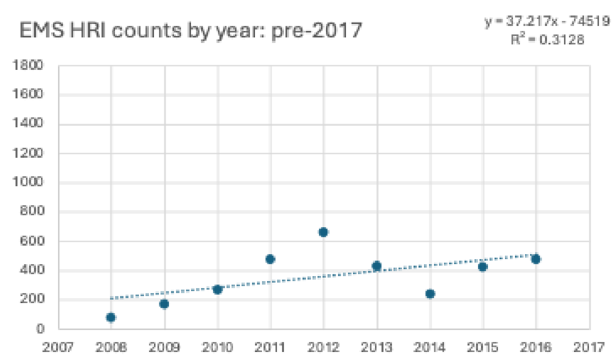


Figure 2.4A: Statewide total HRI EMS counts by year.



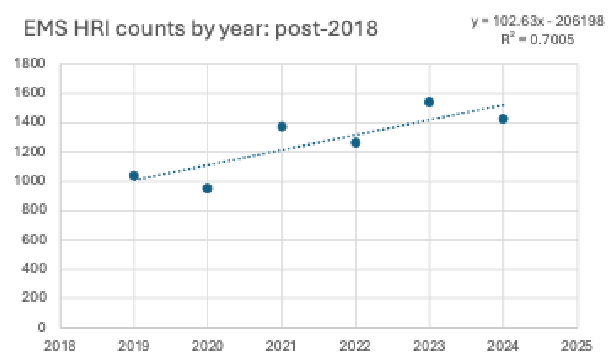


Figure 2.4B: Statewide total HRI EMS counts by year, pre- and post- data dictionary change; both have positive slopes, though post-2018 the slope is more defined.

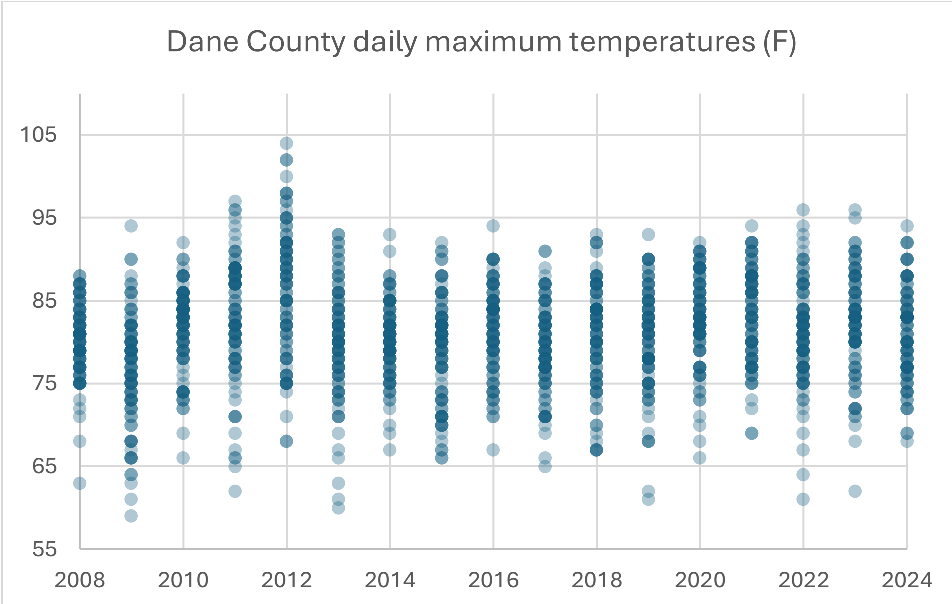


Figure 2.5: Temperature trends during the study period, shown by the proxy of daily maximum temperature in Dane County.

From further investigation, it is apparent that all-cause EMS rates are rising across the state as well (see Figure 2.6), and across the country; some studies have also noted this trend in locations across the United States and look into possible causes (Courtemanche et al., 2019; Jones, 2020).

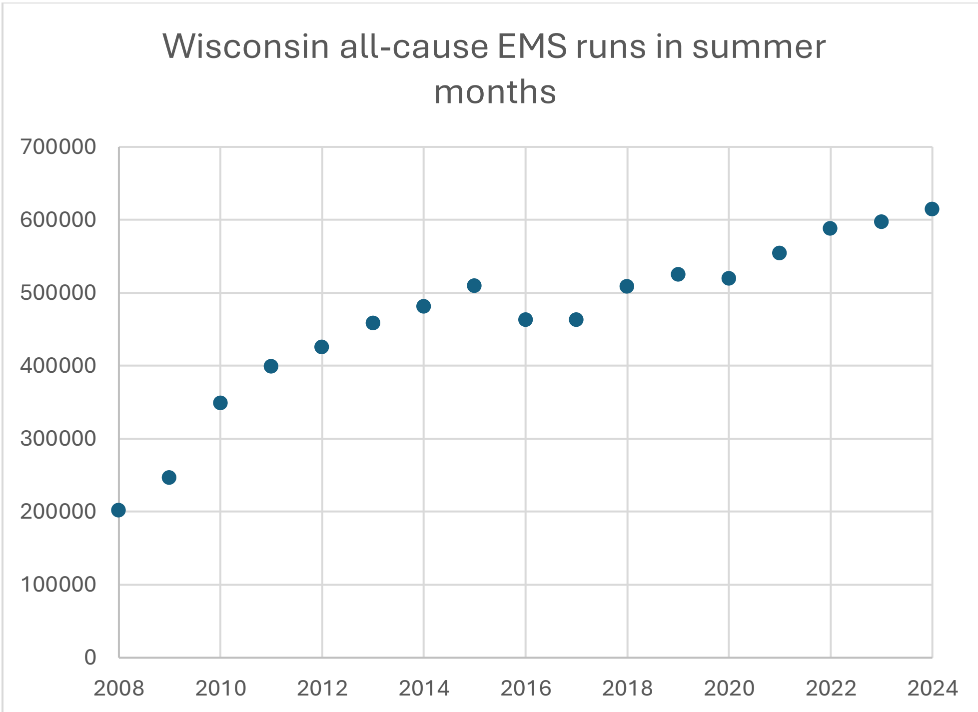


Figure 2.6 All-cause ambulance callouts in Wisconsin summer months also rise during the study period.

4.3 Meteorological conditions and county characteristics are significant in predicting health outcomes

From conducting an analysis of all counties, all weeks, and utilizing county demographic information and characteristics and meteorological conditions as outlined above, the following model was evaluated to estimate population-adjusted HRI EMS rates at the county level:

$$\text{HRI EMSp100k} = (0.04042*\text{ATmax}) + (0.0577*\text{ATacclim}) - (0.03605*\text{Week}) + (0.07381*\text{Year}) - (0.0003909*\text{CountyPopDens}) + (1.423*\text{Pct\_poverty}) + (0.07622*\text{Pct\_outdoorW}) - 151.3$$

The regression table for this model can be found below (Table 2.2).

Model	B	Std. Error	t-value	Sig.
(Intercept)	-151.3000	3.905	-3.873	***
ATmax	0.0404	0.00583	6.906	***
ATacclim	0.0577	0.01224	4.720	***
Week	-0.0360	0.01277	-2.824	**
Year	0.0738	0.01931	3.823	***
CountyPopDens	-0.0004	0.0001	-4.549	***
Pct_poverty	1.4230	0.2035	6.992	***
Pct_outdoorW	0.0762	0.02703	2.820	**

* p < 0.05, ** p < 0.01, *** p < 0.001

Table 2.2: Regression table for model predicting HRI EMS rates in Wisconsin by county from meteorological and county characteristics 2018-2024. Independent variables include maximum apparent temperature, the difference in temperature from the week of recorded HRI EMS counts and the preceding month, the number week of the year, the year, county population density, percent of families living in poverty in the county, and the county's percent outdoor workers.

All variables are significant ($p < 0.01$ for week number and percent outdoor workers, and $p < 0.001$ for the rest of the independent variables). This suggests that higher population-adjusted HRI EMS rates occur at higher temperatures, as well as when the week in question is hotter than the preceding month, which expresses that people are not acclimatized to this heat and it is a shock to their system (Langlois et al., 2013; Nairn & Fawcett, 2015). These rates are also higher earlier in the summer, when people are less acclimatized to heat than they will be later in the summer, because they have not endured as many hot days recently. More recent years have higher HRI EMS rates as well, which corroborates the findings from section 4.2. Higher illness rates are associated with counties with lower population densities, which generally corresponds to rurality, as was found in section 4.1. Finally, the county characteristics of percent of families living in poverty and percent of outdoor workers is also positively associated with HRI EMS rates, as they may contribute to increased exposure (through working outside) and lessened adaptive capacity (through economic means).

Even so, low R^2 values (multiple: 0.04; adjusted: 0.04) indicate this model explains only a small percentage of the actual variation in HRI EMS rates. Regression residuals are left-skewed and strongly deviate from normality. Squaring the temperature term and transforms on the dependent variable did not improve the fit. To further investigate, we evaluated individual counties' temperatures and corresponding health outcomes.

4.4 The hottest conditions do not necessarily result in the highest HRI rates

There is a surprisingly weak relationship between HRI EMS counts and temperature. R^2 values range between 0.006 and 0.16. As Figure 2.7 below shows, the temperature health outcome relationship is not linear; at the hottest temperatures, EMS rates decrease from their peak.

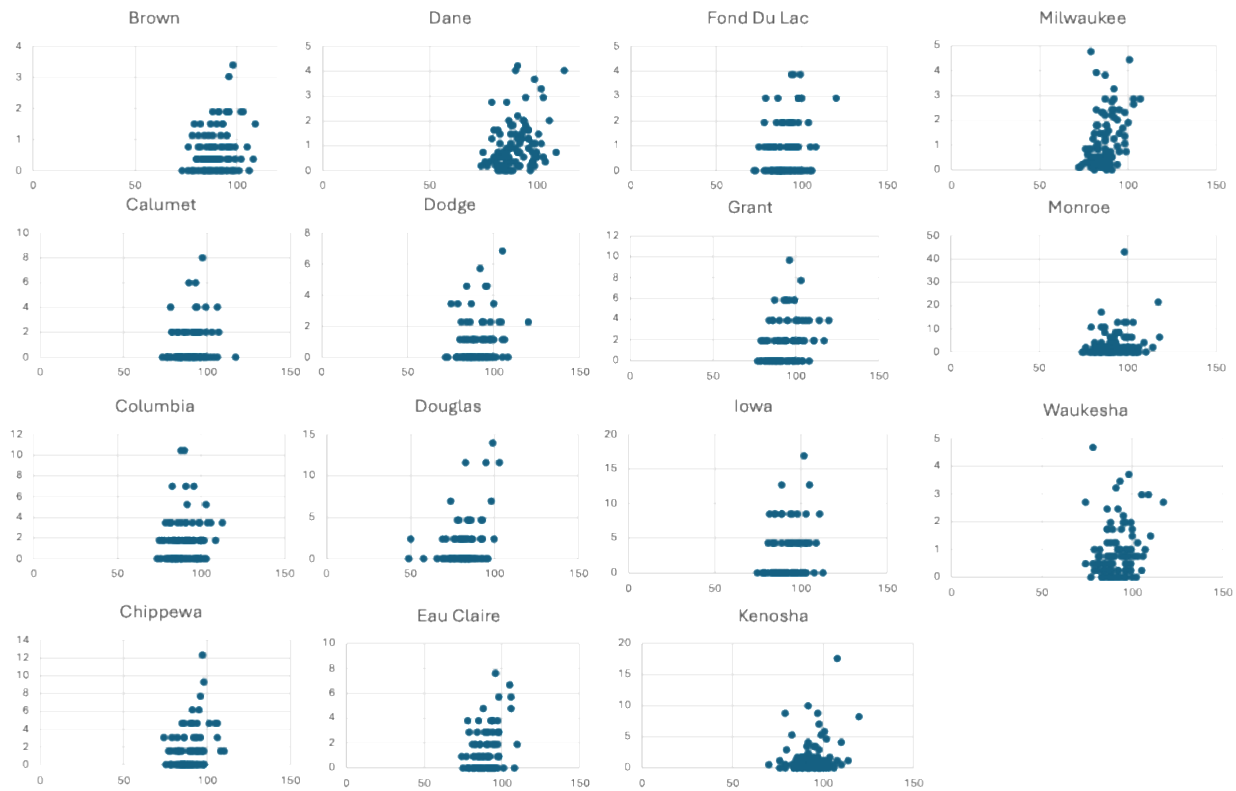


Figure 2.7: ATmax (maximum apparent temperature, °F) on the x-axis vs. HRI EMS rates (per 100,000) on the y-axis for a subset of Wisconsin counties, 2018-2024.

To consolidate and better represent this, we compared the maximum ATs experienced by each county with the maximum ATs during the weeks with the highest HRI EMS counts. For this comparison, we took the average maximum AT during the weeks with the three highest EMS counts (or including additional weeks if EMS counts were the same beyond this cutoff).[5] The ATmax of days with the highest EMS counts is consistently far lower than the actual maximum AT that the county experienced. This finding is summarized in Figure 8 below, and the full table that this figure is based upon can be found in Supplementary Figures as Table 2.7.

[5] This included additional weeks if EMS counts were the same beyond this cutoff (ex: for a county with the highest population-adjusted rates of 8, 7, 6, 6, and 5, the four highest would be chosen and averaged: the ATmax of the weeks corresponding to the 8, 7, 6, and 6.

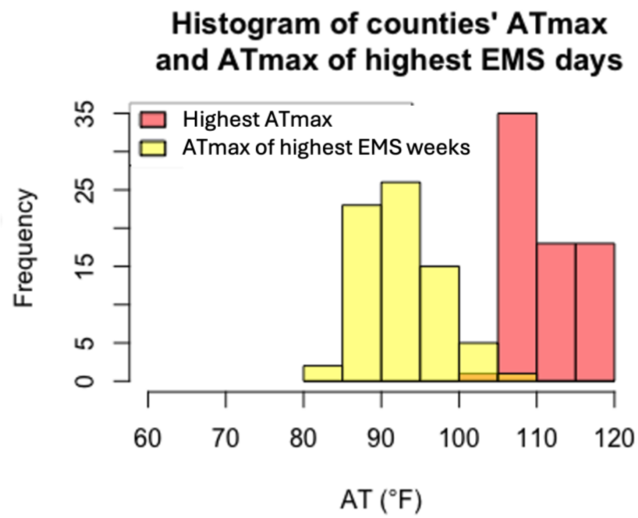


Figure 2.8: Hottest ATmax of each Wisconsin county (red) and the ATmax conditions associated with each county's highest HRI EMS counts (yellow), 2018-2024. The ATmax of days with the highest EMS counts is consistently far lower than the actual maximum AT that the county experienced.

The fact that HRI counts are not necessarily highest during the hottest periods runs counter to our understanding of the impacts of heat on health, and so other factors must be at work.

4.5 Only one third of ambulance callouts for HRI are made to residences

We find from HRI EMS patient care reports that only one in three calls are made to private residences. Fully one half are made to streets, recreation areas, and public areas combined (Figure 2.9). This has serious implications about targeted interventions because they should also consider where else people spend their time outside of their residences, including commutes, work, and recreational activities.

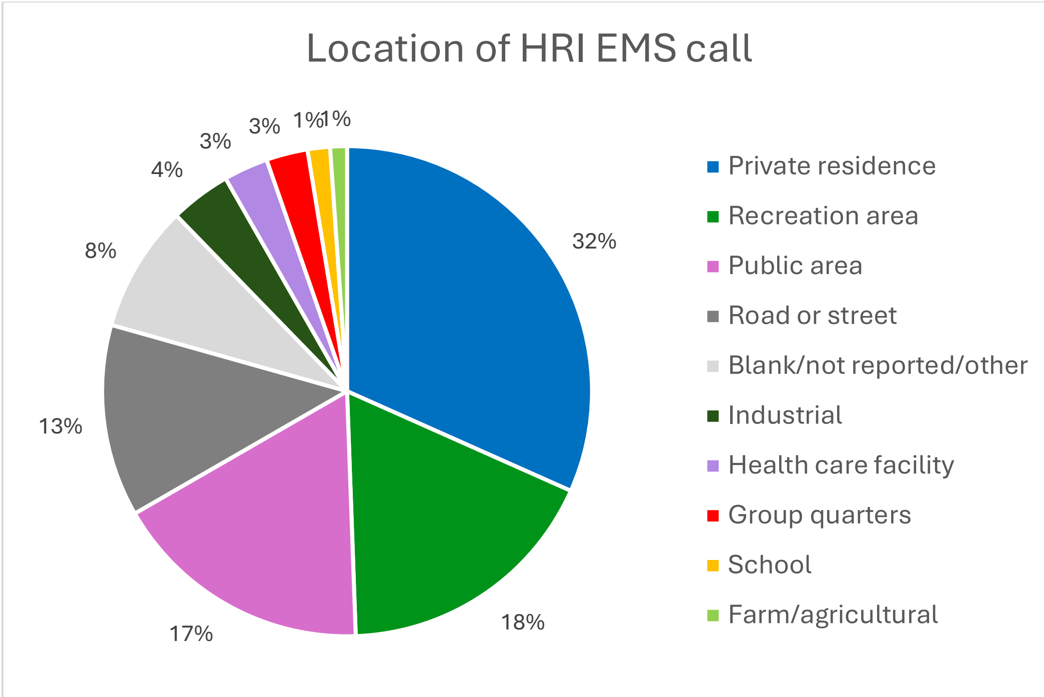


Figure 2.9: Location of HRI EMS call, where the patient was at the time of incident, for all calls made in Wisconsin from 2008-2024 during summer months.

This may also relate to when hottest temperatures occur and when most calls are made. Figure 2.10 below shows the timing of EMS calls by four-hour intervals. Most were made during the time period when daily maximum temperatures are most likely to occur, between 1-5pm local time, followed by morning and evening, with the fewest EMS calls occurring overnight. This timing of peak EMS rates and temperatures coincides with when most people may be out of the house, working, at school, doing errands, or socializing. Table 2.3 shows interactions of incident time and place; across location types, incident counts rise and fall with diurnal temperature patterns, with the vast majority occurring between 9am and 5pm.

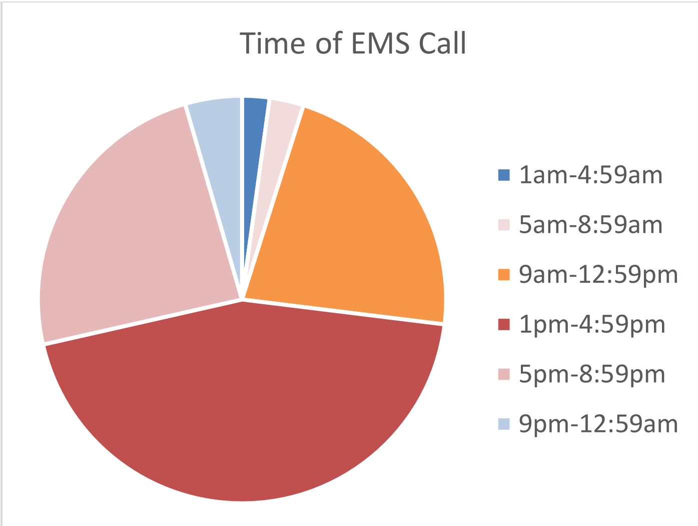


Figure 2.10: Timing of HRI EMS call by four-hour interval, for all calls made in Wisconsin from 2008-2024 during summer months.

Location Type	5am-8:59am	9am-12:59pm	1pm-4:59pm	5pm-8:59pm	9pm-12:59am	1am-4:59am	Grand Total
Farm/Agricultural Area	7	46	58	27	3	2	143
Group Quarters	16	70	147	97	15	8	353
Health Care Facility	14	69	131	102	38	23	378
Industrial Place	41	144	182	96	26	29	518
Other/not reported	5	67	137	60	16	11	295
Private Residence	127	753	1639	1099	295	159	4084
Public Area	53	492	948	604	92	33	2225
Recreation Area	25	465	1172	545	70	7	2292
Road or Street	38	435	750	344	47	19	1635
School	4	65	79	41	2	0	191
Grand Total	350	2786	5569	3208	643	311	12898

Table 2.3: Wisconsin HRI EMS calls during summer months 2008-2024: number of incidents by timestamp bucket and location type. Conditional formatting is applied to highlight the highest counts in red.

4.6 Racial disparities are apparent in EMS data, but low reporting and blank entries for race and ethnicity limit conclusions

Demographic information obtained from patient care reports indicate disproportionate health outcomes, but the dataset has considerable limitations around race. Men make up a majority of HRI EMS cases (58.2%) despite being almost exactly half of the population. This may relate to men being a larger part of the workforce for manual labor that involves exertion in the heat (Heinzerling et al., 2020). While white people make up 79.5% of the state's population, they make up only 66% of the HRI EMS counts, making them underrepresented in our reports of negative heat health outcomes. These numbers and other races are listed below in Table 2.4. At the same time, it is important to note that under the fields of race and ethnicity, "unknown" or a blank entry makes up a high proportion of these counts (23.2% and 36.8% respectively), such that we may not be able to confidently conclude much based on these numbers. One aspect that seems dubious is the apparent underrepresentation of Hispanic/Latino category in the HRI data, despite links between these groups disproportionately living in formerly redlined neighborhoods and working in jobs that expose manual labor workers more to physical activities and to increased risk to overexertion in the heat (Hesketh et al., 2020).

	Demographic	HRI EMS counts	% of HRI EMS counts	WI pop %	Notes (% of EMS counts / % pop)
Gender	Male	7511	58.2%	50.1%	Men overrepresented (1.16)
	Female	5174	40.1%	49.9%	Women underrepresented (0.82)
	Not reported/other	213	1.7%	-	
Race	White	8511	66.0%	86.4%	White underrepresented (0.83)
	Black	950	7.4%	6.6%	Black (slightly) overrepresented (1.12)
	Native American	143	1.1%	1.2%	(within 0.1%)
	Native Hawaiian/Pacific Islander	24	0.2%	0.1%	(within 0.1%)
	Asian	86	0.7%	3.3%	Asian underrepresented (0.21)
	Two or more races	7	0.1%	2.3%	Multiple races underrepresented (0.04)
	Unknown/blank	2991	23.2%	-	Unknown/blank makes up the second-highest category, behind white
	Other	186	1.4%	-	
Ethnicity	Hispanic or Latino	350	2.7%	8.1%	Hispanic or Latino underrepresented (0.33)*
	Not Hispanic or Latino	7806	60.5%	91.9%	Not Hispanic or Latino underrepresented (0.66)*
	Unknown/blank	4742	36.8%	-	Unknown/blank makes up the second-highest category, behind Not Hispanic or Latino
	Total statewide count of EMS runs	12899			

Table 2.4: Overall statewide HRI EMS counts in Wisconsin during summer months, 2008-2024, percent under demographic categories, and comparison with statewide demographics, showing which are overly and under-represented (as determined by comparing HRI rates to statewide population characteristics).

4.7 Work-related HRI reporting rates are low

There is a field in patient care reports where the EMT can record whether an incident is work-related or not, but it was mostly left empty; of those that were filled out, the vast majority were listed as not work-related (see Figure 2.11). Without a more complete record, it is very difficult to understand how much heat-related illness is truly taking place at work. Since we can access the timing of these calls, we can see that most of the counts occurred in the afternoon, during the hottest time of day, but also during work hours for many (see Figure 2.10).

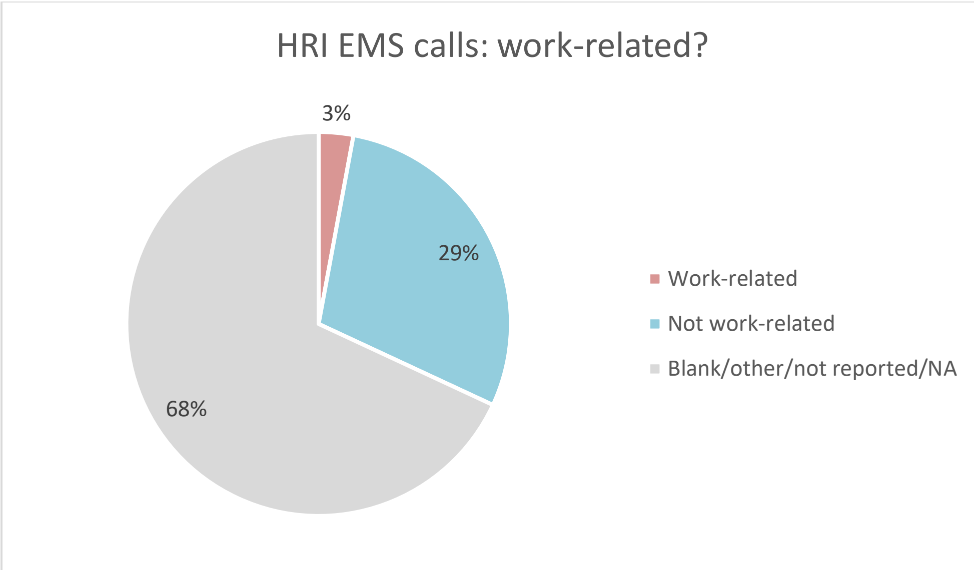


Figure 2.11: HRI EMS total counts by response to "work-related incident" for all calls made in Wisconsin from 2008-2024 during summer months. The vast majority are not conclusively filled out.

5. Discussion

These findings have a number of implications for how we understand heat, health, and disproportionate impacts. Firstly, the most vulnerable counties are not those with the most densely built-up urban centers. Milwaukee County and Dane County, which contain the two most populated cities in the state, have far lower per capita HRI rates than less densely populated, more rural counties. While there are similarities in general patterns and relative rankings of counties, those with the highest rates of HRI do not exactly match with those from the 2019 DHS report (see Figure 2.14 in the Supplementary Figures), which used emergency department admissions data. Note that the study period for that report was 2006-2015, while this study uses data since 2017, and so some differences may be due to the different time periods utilized. The datasets themselves (EMS and emergency department visit counts) may also differ because of the possibility that rather than call an ambulance, some people will get a ride to medical facilities. Ambulance response time may be longer in rural areas than urban, which may lead more people in remote locations to seek alternatives to ambulances. In general, EMS counts have been found to be a more sensitive metric than emergency department visits (see Background, section 1.2), but by omitting those who receive medical care without calling an ambulance, EMS records may underrepresent rural areas.

The rising rates of HRI seen here are in agreement with the findings of Dring et al. (2022), which illustrate that between 2008 and 2020, emergency department visits for heat-related illness (HRI) increased in the Midwest more than any other region in the country. Even as more heat waves increase the region's experience from which to plan and respond to heat, health impacts are rising, which demonstrates a need for additional action.

Meteorological conditions and county characteristics are significant in predicting health outcomes. Higher temperatures and suddenly hot conditions, associated with an inability to acclimatize, all contribute to elevated rates of HRI. Early-summer heat is more dangerous than late-summer heat, as people have not acclimatized or been impacted by previous extreme heat events yet. Regardless of temperature conditions, recent years have higher rates of HRI EMS calls, showing that people are being more impacted over time. The county characteristics of low population density, a higher percent of families living in poverty, and a higher percent of outdoor workers are all positively associated with HRI EMS rates. This points to questions around access to health infrastructure, the role of labor and work in heat exposure and illness, and other elements of lifestyle that may contribute to disproportionate vulnerability or adaptive capacity.

Even though temperature variables are significant in predicting health outcomes, the HRI EMS rates do not occur during the weeks with the highest temperatures. During the study period apparent temperatures across the state have reached the 110s and even 120°F in some cases, but counties' highest EMS counts occur when temperatures are much lower, averaging 92°F. This may imply successful forecasting, warning, messaging, adaptation measures, and/or assistance offered at the hottest extremes are in fact successful at improving health outcomes, protecting people from the worst impacts. However, then temperatures that do not merit these responses to emerge as more dangerous in terms of on-the-ground outcomes; the hottest “business as usual” days become the deadliest. Along similar lines, Keller (2012) interpreting a report by Pascal et al. (2012), reports that most heat deaths in France to take place during days that are not declared to be during heat waves; he argues that record-breaking extremes may gain the most attention, but it is steadily climbing temperatures that impose the most risk (Keller, 2024). Both sets of findings contradict the conventional understanding that the hottest conditions generate the worst health outcomes. One consideration is that some of these highest-count EMS days occur on days that seem oddly cool. One week in Door County (which was omitted from this analysis) had its highest count, 18 HRI EMS calls, during a week in August of 2017 when the highest apparent temperature was 73°F. Upon investigation, the cause appears to be a disastrous fire: "While no civilians suffered injuries, EMS personnel on scene say they treated nearly 100 firefighters for heat related illnesses. Nine firefighters had to be sent to the hospital" (Anonymous, 2017). This suggests that other results may be similarly impacted, as heat-related illness is reported as such no matter its ultimate cause, and shows a potentially impactful limitation from HRI health data and ICD codes in general.

Findings around incident location type are substantial and novel; this is the first study to my knowledge to use the category “location type” from EMS data[6] and to characterize the majority of incidents as happening outside the home, and especially in public spaces. Heat is

[6] NEMSIS data element “eScene.09 - Incident Location Type”

predominantly discussed in the literature as a matter of where someone lives (Harlan et al., 2013; Hu et al., 2022; Wilson & Chakraborty, 2019), and so this has serious implications about targeted interventions and to focus on more than solely where people live, but where they spend their time, which includes commutes, work, and recreation.

While a wealth of knowledge can be gained from HRI EMS counts and patient care reports, there are crucial limitations around fields that are blank or contain broad categories that could otherwise give us far more insight into factors of heat vulnerability. Information that would be incredibly helpful includes a more complete record of work-related incidents, including what justifications and logic go into what qualifies an incident as such, the race and ethnicity of patients (which is more available and accurate from other data sources such as hospitalizations and emergency department visits) (Kate Beardmore, Program Evaluator of the DHS Climate and Health Program, personal communication), and the different types of living situations that make up the location category of “group quarters.” This category includes nursing homes, worker dorms, and prisons, and the residents of each face very different challenges and factors that may be contributing to their risk of heat-related illness. Farmhouses, where home and work are the same place for some in rural locations, may pose a challenge in categorization; if someone falls ill while tending to their crops, will this be tagged as a residence? Will it be considered a work-related incident? There is not room for ambiguity in these categories, and so a decision is made one way or another.

The limitations inherent in trying to reconstruct the circumstances behind HRI EMS records underscore the importance of more qualitative, on-the-ground information. Expansive insights could be gained by interviewing EMTs and other medical professionals who can share their experiences working in summertime, as well as more people living and working in rural areas generally. Additionally, one important obstacle in better understanding heat-health impacts is a lack of data on air conditioning prevalence, access, and affordability in the state (Kate Beardmore, Program Evaluator of the DHS Climate and Health Program, personal communication). A concentrated effort to survey people and gain a representative sample would be incredibly useful to better understand where we stand as a state.

6. Conclusion

Analyses on EMS data on heat-related illness counts and rates in Wisconsin reveal a number of important findings. Rural, low-population density counties have disproportionately high HRI EMS calls per capita, despite the understanding that they have lower temperatures than more built-up urban areas. Reported rates of HRI are increasing statewide and across counties. Meteorological conditions and county characteristics such as prevalence of poverty and percent outdoor workers is positively and significantly associated with elevated HRI. However, the hottest conditions do not necessarily result in the highest HRI rates. Only one third of HRI EMS calls are made to people's homes, emphasizing the importance of other spaces and where else people go and what they do on hot days. Gender and racial disparities are apparent in EMS data, but low counts for some demographics and blank entries under race/ethnicity produce limitations in how much we can rely on these fields. Similarly, extremely low response rates of whether incidents were workplace-related or not constrain our understanding of how much laborers are being affected by the heat. Gaps and uncertainties in reporting, and the difficulties they pose in interpreting results, underscore the importance of accurate and complete surveillance as much as can be managed going forward, as well as supplementing findings with qualitative studies and conversations to better understand conditions on the ground.

This chapter owes its existence to the work, patience, and insights of my contacts at the DHS Office of Health Informatics, Division of Public Health, Office of Preparedness and Emergency Health Care, and the Wisconsin Hospital Association through our many back-and-forths. These datasets are incredibly valuable for being able to quantify the very elusive issue of the impacts of extreme heat on health. Numbers of occurrences, increasing rates, and hotspots of vulnerability can make a strong case for policy change and action. Similarly, the expertise, work, staffing, and funding that it takes to monitor, collate, report, and share these datasets are all vital to be able to understand these impacts and plan accordingly, and they are not to be taken for granted.

7. Works Cited

Anonymous. (2017). "Shipwrecked brew pub in Door County catches fire." NBC26. Retrieved from https://www.nbc26.com/news/shipwrecked-brew-pub-in-door-county-catches-fire

Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., ... & Tangang, F. (2022). The impact of heatwaves on mortality and morbidity and the associated vulnerability factors: a systematic review. *International journal of environmental research and public health*, *19*(23), 16356.

Barrow, M. W., & Clark, K. A. (1998). Heat-related illnesses. *American family physician*, *58*(3), 749-756.

Basu, R. (2009). High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. *Environmental health, 8,* 1-13.

Basu, R., & Samet, J. M. (2002). Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiologic reviews, 24*(2), 190-202.

Berglund, L. G., & Gonzalez, R. R. (1977). Evaporation of sweat from sedentary man in humid environments. *Journal of Applied Physiology*, *42*(5), 767-772.

Bouchama, A., & Knochel, J. P. (2002). Heat stroke. *New England journal of medicine*, *346*(25), 1978-1988.

Centers for Disease Control and Prevention. (1996). Heat-wave-related mortality--Milwaukee, Wisconsin, July 1995. *MMWR: Morbidity and mortality weekly report*, *45*(24), 505-507.

Cheng, W., & Brown, R. D. (2020). An energy budget model for estimating the thermal comfort of children. *International Journal of Biometeorology, 64*(8), 1355-1366.

Christenson, M. L., Geiger, S. D., & Anderson, H. A. (2013). Heat-related fatalities in Wisconsin during the summer of 2012. *WMJ, 112*(5), 219-223.

Courtemanche, C., Friedson, A. I., & Rees, D. I. (2019). Association of ambulance use in New York City with the implementation of the Patient Protection and Affordable Care Act. *JAMA Network Open, 2*(6), e196419-e196419.

Dalgo, E. (2023). *Socio-Spatial Vulnerability to Heat: A Study of Mortality in Washington Neighborhoods During the 2021 Western North America Heat Wave* (Master's thesis, University of Washington).

Donoghue, E. R., Graham, M. A., Jentzen, J. M., Lifschultz, B. D., Luke, J. L., & Mirchandani, H. G. (1997). Criteria for the diagnosis of heat-related deaths: National Association of Medical Examiners: position paper. *The American journal of forensic medicine and pathology*, *18*(1), 11-14.

Dring, P., Armstrong, M., Alexander, R., & Xiang, H. (2022). Emergency Department Visits for Heat-Related Emergency Conditions in the United States from 2008–2020. *International journal of environmental research and public health*, *19*(22), 14781.

Gubernot, D. M., Anderson, G. B., & Hunting, K. L. (2014). The epidemiology of occupational heat-related morbidity and mortality in the United States: a review of the literature and assessment of research needs in a changing climate. *International journal of biometeorology*, *58*(8), 1779.

Guo, Y., Gasparrini, A., Armstrong, B. G., Tawatsupa, B., Tobias, A., Lavigne, E., ... & Tong, S. (2016). Temperature variability and mortality: a multi-country study. *Environmental health perspectives*, *124*(10), 1554-1559

Hacker, K. A., Briss, P. A., Richardson, L., Wright, J., & Petersen, R. (2021). COVID-19 and chronic disease: the impact now and in the future. *Preventing chronic disease*, *18*, E62.

Harlan, S. L., Brazel, A. J., Darrel Jenerette, G., Jones, N. S., Larsen, L., Prashad, L., & Stefanov, W. L. (2007). In the shade of affluence: The inequitable distribution of the urban heat island. In *Equity and the Environment* (pp. 173-202). Emerald Group Publishing Limited.

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.

Hassinger, E. W., & Hobbs, D. J. (1992). Rural society—the environment of rural health care. *Rural health care: Innovation in a changing environment*, 178-190.

Hatvani-Kovacs, G., Belusko, M., Pockett, J., & Boland, J. (2016). Can the excess heat factor indicate heatwave-related morbidity? A case study in Adelaide, South Australia. *EcoHealth, 13*, 100-110.

Heinzerling, A., Laws, R. L., Frederick, M., Jackson, R., Windham, G., Materna, B., & Harrison, R. (2020). Risk factors for occupational heat-related illness among California workers, 2000–2017. *American journal of industrial medicine*, *63*(12), 1145-1154.

Henderson, S. B., Wan, V., & Kosatsky, T. (2013). Differences in heat-related mortality across four ecological regions with diverse urban, rural, and remote populations in British Columbia, Canada. *Health & place*, *23*, 48-53.

Hesketh, M., Wuellner, S., Robinson, A., Adams, D., Smith, C., & Bonauto, D. (2020). Heat related illness among workers in Washington State: A descriptive study using workers' compensation claims, 2006-2017. *American journal of industrial medicine*, *63*(4), 300-311.

Hicken, M. T., Gee, G. C., Morenoff, J., Connell, C. M., Snow, R. C., & Hu, H. (2012). A novel look at racial health disparities: the interaction between social disadvantage and environmental health. *American journal of public health*, *102*(12), 2344-2351.

Hondula, D. M., Davis, R. E., Leisten, M. J., Saha, M. V., Veazey, L. M., & Wegner, C. R. (2012). Fine-scale spatial variability of heat-related mortality in Philadelphia County, USA, from 1983-2008: a case-series analysis. *Environmental health*, *11*, 1-11.

Hondula, D. M., Georgescu, M., & Balling Jr, R. C. (2014a). Challenges associated with projecting urbanization-induced heat-related mortality. *Science of the total environment*, *490*, 538-544.

Hu, M., Zhang, K., Nguyen, Q. C., Tasdizen, T., & Krusche, K. U. (2022). A multistate study on housing factors influential to heat-related illness in the United States. *International Journal of Environmental Research and Public Health*, *19*(23), 15762.

Jones, J. (2020). Non-emergency utilization of EMS: Contributing factors and strategies to promote effective care with appropriate resources. https://digitalcommons.unmc.edu/coph_slce/128/

Jung, J. (2019). *Methods to Improve Existing Heat Wave Surveillance Systems* (Order No. 27543986). Available from ProQuest Dissertations & Theses Global. (2379697216).

Kalkstein, L.S., Sheridan, S. C., Martín-Olalla, J.M., Allen, M., Wellenius, G., Berg, E., Pabich, S., Rose, R. Evaluating the accuracy and effectiveness of a health-based heat wave categorization system. [Manuscript in preparation.]

Keller, R. C. (2013). Place matters: Mortality, space, and urban form in the 2003 Paris heat wave disaster. *French Historical Studies, 36*(2), 299-330.

Keller, R. C. (2024). Climate Change, COVID-19, and the End of Excess Mortality: Extreme Heat in France since 2003. *Journal of Disaster Studies*, *1*(1), 249-263.

Kilbourne, E. M., Choi, K., Jones, T. S., & Thacker, S. B. (1982). Risk factors for heatstroke: a case-control study. *Jama*, *247*(24), 3332-3336.

Klinenberg, E. (2015). *Heat wave: A social autopsy of disaster in Chicago.* University of Chicago Press.

Knochel, J. P., & Reed, G. (1994). Disorders of heat regulation. *Maxwell & Kleeman's clinical disorders of fluid and electrolyte metabolism. 5th ed. New York: McGraw-Hill*, *15*, 49-90.

Langlois, N., Herbst, J., Mason, K., Nairn, J., & Byard, R. W. (2013). Using the Excess Heat Factor (EHF) to predict the risk of heat related deaths. *Journal of forensic and legal medicine*, *20*(5), 408-411.

Lee, M., Shi, L., Zanobetti, A., & Schwartz, J. D. (2016). Study on the association between ambient temperature and mortality using spatially resolved exposure data. *Environmental research*, *151*, 610-617.

Li, B., Sain, S., Mearns, L. O., Anderson, H. A., Kovats, S., Ebi, K. L., ... & Patz, J. A. (2012). The impact of extreme heat on morbidity in Milwaukee, Wisconsin. *Climatic Change, 110*, 959-976.

Li, Y., Akkus, C., Yu, X., Joyner, A., Kmet, J., Sweat, D., & Jia, C. (2019). Heatwave events and mortality outcomes in Memphis, Tennessee: testing effect modification by socioeconomic status and urbanicity. *International journal of environmental research and public health, 16*(22), 4568.

Minnesota Department of Health and Wisconsin Department of Health Services. (2019). "Extreme heat: who's at risk? Findings from a collaborative project between Minnesota and Wisconsin." https://www.dhs.wisconsin.gov/publications/p02386.pdf

Nairn, J. R., & Fawcett, R. J. (2015). The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. *International journal of environmental research and public health*, *12*(1), 227-253.

NEMSIS. NEMSIS data dictionary version 3.5.0. National Highway Traffic Safety Administration, Office of Emergency Medical Services; 2023 Mar 17. Available from: https://www.ems.gov/assets/National_EMS_Core_Content.pdf.

Nitschke, M., Tucker, G. R., Hansen, A. L., Williams, S., Zhang, Y., & Bi, P. (2011). Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. *Environmental Health*, *10*, 1-9.

Odame, Emmanuel A. (2019). "Assessing Heat-Related Mortality and Morbidity Risks in Rural Populations and Sub-Populations" Electronic Theses and Dissertations. Paper 3637. https://dc.etsu.edu/etd/3637

Pascal, Mathilde, Alain Le Tertre, and Abdessattar Saoudi. 2012. "Quantification of the Heat Wave Effect on Mortality in Nine French Cities during Summer 2006." PLoS Currents 4. doi: 10.1371/currents.RRN1307.

San Francisco Department of Public Health Climate and Health Program. (2013). Understanding the Risk: An Assessment of San Francisco's Vulnerability to Extreme Heat Events.

Semenza, J. C., Rubin, C. H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L., & Wilhelm, J. L. (1996). Heat-related deaths during the July 1995 heat wave in Chicago. *New England journal of medicine*, *335*(2), 84-90.

Semenza, J. C., McCullough, J. E., Flanders, W. D., McGeehin, M. A., & Lumpkin, J. R. (1999). Excess hospital admissions during the July 1995 heat wave in Chicago. *American journal of preventive medicine*, *16*(4), 269-277.

Sheridan, S. C., & Kalkstein, A. J. (2010). Seasonal variability in heat-related mortality across the United States. *Natural hazards*, *55*(2), 291-305.

Smith, T. T., Zaitchik, B. F., & Gohlke, J. M. (2013). Heat waves in the United States: definitions, patterns and trends. *Climatic change*, *118*, 811-825.

Sun, S., & Cheng, W. (2025). Physical and physiological differences in thermal comfort and regulation among older adults: A systematic review. *Building and Environment*, 113424.

Tolika, K. (2019). Assessing heat waves over Greece using the excess heat factor (EHF). *Climate*, *7*(1), 9.

United States Federal Insurance Administration. (1977). *Flood Insurance Study: Door County, Wisconsin, Unincorporated Areas.* Department of Housing and Urban Development.

Urban, A., Hondula, D. M., Hanzlíková, H., & Kyselý, J. (2019). The predictability of heat-related mortality in Prague, Czech Republic, during summer 2015—A comparison of selected thermal indices. *International journal of biometeorology, 63*, 535-548.

U.S. Census Bureau, Population Division (2020). Annual Estimates of the Resident Population for Counties in Wisconsin: April 1, 2010 to July 1, 2019 (CO-EST2019-ANNRES-55).

Vaidyanathan, A., Saha, S., Vicedo-Cabrera, A. M., Gasparrini, A., Abdurehman, N., Jordan, R., ... & Elixhauser, A. (2019). Assessment of extreme heat and hospitalizations to inform early warning systems. *Proceedings of the National Academy of Sciences*, *116*(12), 5420-5427.

Wang, Q., He, Y., Hajat, S., Cheng, J., Xu, Z., Hu, W., ... & Huang, C. (2021). Temperature-sensitive morbidity indicator: consequence from the increased ambulance dispatches associated with heat and cold exposure. *International journal of biometeorology, 65*(11), 1871-1880.

Wilson, B., & Chakraborty, A. (2019). Mapping vulnerability to extreme heat events: lessons from metropolitan Chicago. *Journal of Environmental Planning and Management*, *62*(6), 1065-1088.

Wisconsin Department of Health Services. (2014). Wisconsin heat vulnerability index. https://www.dhs.wisconsin.gov/climate/wihvi.htm

Wisconsin Department of Health Services (2022). Environmental Public Health Data Tracker. Wisconsin Environmental Public Health Tracking Program.

https://dhsgis.wi.gov/DHS/EPHTracker/ - /all/Heat and Heat Related Illness (HRI)/heatStateIndex/NOTRACT/89/438

Wisconsin Dept. of Health Services, Division of Public Health, Office of Health Informatics. Wisconsin Interactive Statistics on Health (WISH) data query system, https://www.dhs.wisconsin.gov/wish/index.htm. Population Module, accessed 6/5/2025.

Xu, Z., Watzek, J. T., Phung, D., Oberai, M., Rutherford, S., & Bach, A. J. (2023). Heat, heatwaves, and ambulance service use: a systematic review and meta-analysis of epidemiological evidence. *International Journal of Biometeorology, 67*(10), 1523-1542.

Yardley, J., Sigal, R. J., & Kenny, G. P. (2011). Heat health planning: The importance of social and community factors. *Global Environmental Change*, *21*(2), 670-679.

Zhao, Q., Li, S., Coelho, M. S., Saldiva, P. H., Hu, K., Huxley, R. R., ... & Guo, Y. (2019). The association between heatwaves and risk of hospitalization in Brazil: a nationwide time series study between 2000 and 2015. *PLoS medicine*, *16*(2), e1002753.

Zottarelli, L. K., Sharif, H. O., Xu, X., & Sunil, T. S. (2021). Effects of social vulnerability and heat index on emergency medical service incidents in San Antonio, Texas, in 2018. *J Epidemiol Community Health, 75*(3), 271-276.

8. Supplementary figures

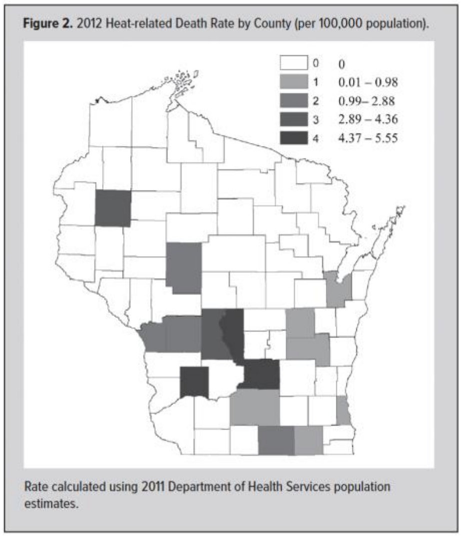


Figure 2.12: Number of deaths attributed to heat in summer 2012, population-adjusted (Christenson et al., 2013).

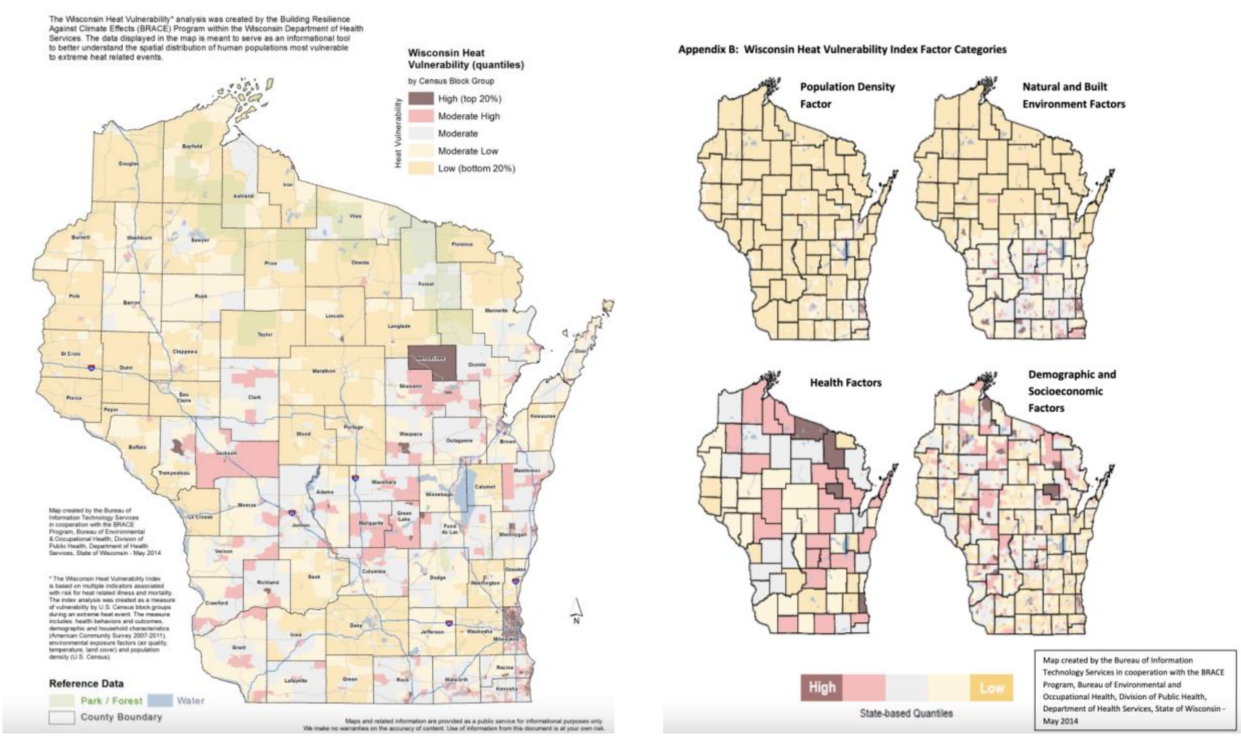


Figure 2.13: Wisconsin Heat Vulnerability Index (left) and contributing factors (Wisconsin Department of Health Services, 2014).

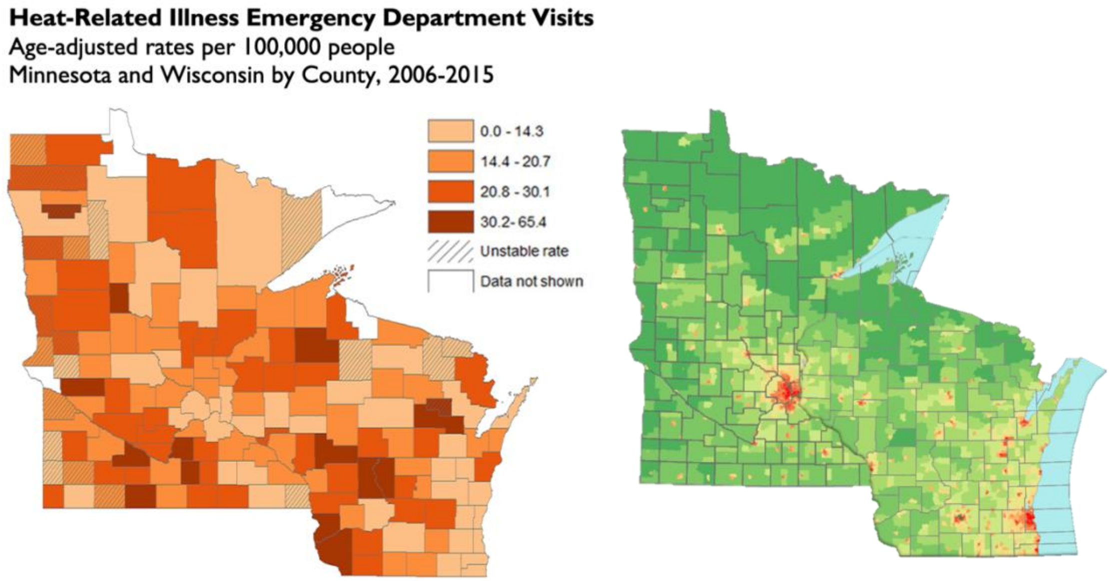


Figure 2.14. Left: Minnesota and Wisconsin county-level documented heat illness rates (Minnesota Department of Health and Wisconsin Department of Health Services, 2019). Right: Wisconsin and Minnesota population density maps adapted from Wikimedia Commons.

NEMSIS v3: Labeled as heat-related illness if one or more of the following are true:

- Narrative (eNarrative.01) or complaint (eSituation.04) contains: "feeling overheated", "heat emergency", "heat exhaustion", "heat exposure", "heatstroke", "outside in the heat", or other variants.
- Provider primary or secondary impression (eSituation.11, eSituation.12) **OR** cause of injury (eInjury.01) indicate any of the following ICD-10 codes (sub-codes included): T67.0 - T67.7.
- Protocols used (eProtocols.01) is one of the following:
  - 9914027 - Environmental-Heat Exposure/Exhaustion
  - 9914029 - Environmental-Heat Stroke/Hyperthermia

NEMSIS v2: Labeled as heat-related illness if the following is true:

- Narrative (E13_01) or chief/secondary complaint (E09_05, E09_08) contains: "feeling overheated", "heat emergency", "heat exhaustion", "heat exposure", "heatstroke", "outside in the heat", or other variants.

Figure 2.15: The process for qualifying an EMS run as being heat-related following Biospatial's definition.

County	2019 pop	People / mi2	HRI EMS runs	HRI EMS runs per 100k
Adams	20,220	31	53	262
Ashland	15,562	15	49	315
Barron	45,244	52	69	153
Bayfield	15,036	10	40	266
Brown	264,542	500	250	95
Buffalo	13,031	19	21	161
Burnett	15,414	19	41	266
Calumet	50,089	157	53	106
Chippewa	64,658	64	132	204
Clark	34,774	29	35	101
Columbia	57,532	74	124	216
Crawford	16,131	28	53	329
Dane	546,695	455	777	142
Dodge	87,839	100	106	121
Door	27,668	57	65	235
Douglas	43,150	33	105	243
Dunn	45,368	53	70	154
Eau Claire	104,646	164	169	161
Florence	4,295	9	4	93
Fond Du Lac	103,403	143	97	94
Forest	9,004	9	24	267
Grant	51,439	45	125	243
Green	36,960	63	67	181
Green Lake	18,913	53	41	217
Iowa	23,678	31	65	275
Iron	5,687	8	7	123
Jackson	20,643	21	63	305
Jefferson	84,769	152	149	176
Juneau	26,687	35	93	348
Kenosha	169,561	621	336	198
Kewaunee	20,434	60	18	88
La Crosse	118,016	261	258	219
Lafayette	16,665	26	36	216
Langlade	19,189	22	37	193
Lincoln	27,593	31	47	170
Manitowoc	78,981	134	108	137
Marathon	135,692	88	130	96
Marinette	40,350	29	111	275
Marquette	15,574	34	36	231
Menominee	4,556	13	22	483
Milwaukee	945,726	3915	1339	142
Monroe	46,253	51	200	432
Oconto	37,930	38	63	166
Oneida	35,595	32	62	174
Outagamie	187,885	293	222	118
Ozaukee	89,221	385	94	105
Pepin	7,287	31	18	247
Pierce	42,754	74	42	98
Polk	43,783	48	74	169
Portage	70,772	88	59	83
Price	13,351	11	19	142
Racine	196,311	589	255	130
Richland	17,252	29	47	272
Rock	163,354	227	215	132
Rusk	14,178	16	20	141
Sauk	64,442	77	194	301
Sawyer	16,558	13	32	193
Shawano	40,899	46	96	235
Sheboygan	115,340	225	169	147
St. Croix	90,687	126	91	100
Taylor	20,343	21	24	118
Trempealeau	29,649	40	64	216

County	2019 pop	People / mi2	HRI EMS runs	HRI EMS runs per 100k
Menominee	4,556	13	22	483
Monroe	46,253	51	200	432
Juneau	26,687	35	93	348
Crawford	16,131	28	53	329
Ashland	15,562	15	49	315
Jackson	20,643	21	63	305
Sauk	64,442	77	194	301
Marinette	40,350	29	111	275
Iowa	23,678	31	65	275
Richland	17,252	29	47	272
Forest	9,004	9	24	267
Bayfield	15,036	10	40	266
Burnett	15,414	19	41	266
Adams	20,220	31	53	262
Pepin	7,287	31	18	247
Douglas	43,150	33	105	243
Grant	51,439	45	125	243
Door	27,668	57	65	235
Shawano	40,899	46	96	235
Marquette	15,574	34	36	231
Vilas	22,195	25	49	221
La Crosse	118,016	261	258	219
Green Lake	18,913	53	41	217
Lafayette	16,665	26	36	216
Trempealeau	29,649	40	64	216
Columbia	57,532	74	124	216
Washburn	15,720	19	33	210
Chippewa	64,658	64	132	204
Kenosha	169,561	621	336	198
Waupaca	50,990	68	100	196
Sawyer	16,558	13	32	193
Langlade	19,189	22	37	193
Walworth	103,868	187	198	191
Green	36,960	63	67	181
Jefferson	84,769	152	149	176
Oneida	35,595	32	62	174
Lincoln	27,593	31	47	170
Polk	43,783	48	74	169
Oconto	37,930	38	63	166
Eau Claire	104,646	164	169	161
Buffalo	13,031	19	21	161
Dunn	45,368	53	70	154
Statewide	5,822,434	108	8913	153
Barron	45,244	52	69	153
Vernon	30,822	39	46	149
Wood	72,999	92	107	147
Sheboygan	115,340	225	169	147
Price	13,351	11	19	142
Dane	546,695	455	777	142
Milwaukee	945,726	3915	1339	142
Rusk	14,178	16	20	141
Manitowoc	78,981	134	108	137
Winnebago	171,907	392	228	133
Rock	163,354	227	215	132
Waushara	24,443	39	32	131
Racine	196,311	589	255	130
Iron	5,687	8	7	123
Dodge	87,839	100	106	121
Waukesha	404,198	728	487	120
Outagamie	187,885	293	222	118
Taylor	20,343	21	24	118
Washington	136,034	316	148	109

Vernon	30,822	39	46	149
Vilas	22,195	25	49	221
Walworth	103,868	187	198	191
Washburn	15,720	19	33	210
Washington	136,034	316	148	109
Waukesha	404,198	728	487	120
Waupaca	50,990	68	100	196
Waushara	24,443	39	32	131
Winnebago	171,907	392	228	133
Wood	72,999	92	107	147
Statewide	5,822,434	108	8913	153

Calumet	50,089	157	53	106
Ozaukee	89,221	385	94	105
Clark	34,774	29	35	101
St. Croix	90,687	126	91	100
Pierce	42,754	74	42	98
Marathon	135,692	88	130	96
Brown	264,542	500	250	95
Fond Du Lac	103,403	143	97	94
Florence	4,295	9	4	93
Kewaunee	20,434	60	18	88
Portage	70,772	88	59	83

Table 2.5: Total Wisconsin county-by-county HRI EMS runs 2017-2024 during summer months, adjusted for population (per 100,000); sorted by HRI rates on the right-hand side.

County	2019 Pop	People / mi²	2017	2018	2019	2020	2021	2022	2023	2024	Slope	R^2
Adams	20,220	31	14.84	29.67	29.67	49.46	19.78	14.84	74.18	29.67	3.0	0.13
Ashland	15,562	15	38.56	25.70	19.28	25.70	44.98	44.98	57.83	57.83	4.7	0.60
Barron	45,244	52	8.84	17.68	11.05	11.05	24.31	30.94	26.52	22.10	2.5	0.56
Bayfield	15,036	10	33.25	13.30	46.55	13.30	66.51	39.90	26.60	26.60	0.6	0.01
Brown	264,542	500	9.07	10.58	15.50	9.45	9.07	15.88	13.23	11.72	0.4	0.12
Buffalo	13,031	19	0.00	0.00	30.70	7.67	69.07	23.02	23.02	7.67	2.5	0.07
Burnett	15,414	19	12.98	45.41	12.98	19.46	19.46	58.39	71.36	25.95	4.2	0.22
Calumet	50,089	157	15.97	9.98	5.99	25.95	7.99	9.98	15.97	13.98	0.1	0.00
Chippewa	64,658	64	15.47	44.85	10.83	20.11	20.11	27.84	35.57	29.39	1.2	0.07
Clark	34,774	29	5.75	11.50	14.38	8.63	14.38	14.38	20.13	11.50	1.1	0.36
Columbia	57,532	74	8.69	34.76	24.33	19.12	31.29	34.76	39.98	22.60	2.0	0.23
Crawford	16,131	28	18.60	105.39	37.20	24.80	31.00	31.00	49.59	31.00	-2.4	0.05
Dane	546,695	455	10.61	20.67	14.27	11.52	20.85	19.76	26.52	17.93	1.3	0.33
Dodge	87,839	100	5.69	14.80	13.66	13.66	17.08	22.77	15.94	17.08	1.4	0.50
Door	27,668	57	90.36	18.07	10.84	10.84	21.69	36.14	21.69	25.30	-4.2	0.16
Douglas	43,150	33	9.27	34.76	6.95	27.81	50.98	44.03	48.67	20.86	3.4	0.24
Dunn	45,368	53	0.00	19.84	15.43	24.25	50.70	6.61	22.04	15.43	1.4	0.05
Eau Claire	104,646	164	11.47	23.89	18.16	16.25	29.62	24.85	21.98	15.29	0.6	0.06
Florence	4,295	9	0.00	0.00	23.28	0.00	23.28	46.57	0.00	0.00	1.1	0.02
Fond Du Lac	103,403	143	7.74	13.54	15.47	17.41	7.74	8.70	15.47	7.74	-0.2	0.02
Forest	9,004	9	22.21	55.53	0.00	33.32	44.42	55.53	33.32	22.21	0.8	0.01
Grant	51,439	45	9.72	38.88	27.22	25.27	27.22	46.66	46.66	21.38	2.2	0.17
Green	36,960	63	13.53	40.58	24.35	16.23	29.76	16.23	32.47	8.12	-1.1	0.06
Green Lake	18,913	53	15.86	47.59	15.86	26.44	37.01	26.44	42.30	5.29	-0.7	0.01
Iowa	23,678	31	4.22	33.79	16.89	25.34	21.12	50.68	63.35	59.13	7.5	0.74
Iron	5,687	8	0.00	17.58	0.00	0.00	17.58	17.58	17.58	52.75	5.2	0.54
Jackson	20,643	21	9.69	38.75	53.29	58.13	24.22	48.44	33.91	38.75	1.6	0.06
Jefferson	84,769	152	12.98	33.03	11.80	15.34	23.59	30.67	31.85	16.52	1.0	0.08
Juneau	26,687	35	22.48	74.94	48.71	41.22	41.22	7.49	74.94	37.47	-0.2	0.00
Kenosha	169,561	621	14.74	28.31	26.54	17.10	15.33	18.87	34.21	43.05	2.4	0.34
Kewaunee	20,434	60	4.89	29.36	4.89	4.89	4.89	19.58	4.89	14.68	-0.1	0.00
La Crosse	118,016	261	12.71	30.50	37.28	18.64	30.50	22.03	34.74	32.20	1.5	0.18
Lafayette	16,665	26	18.00	36.00	30.00	0.00	30.00	42.00	36.00	24.00	1.3	0.06
Langlade	19,189	22	5.21	20.85	10.42	26.06	41.69	41.69	26.06	20.85	2.9	0.30
Lincoln	27,593	31	0.00	14.50	28.99	18.12	32.62	18.12	18.12	39.87	3.3	0.44
Manitowoc	78,981	134	13.93	17.73	10.13	16.46	21.52	18.99	20.26	17.73	0.8	0.32
Marathon	135,692	88	5.90	16.95	8.11	11.05	15.48	9.58	16.21	12.53	0.6	0.14
Marinette	40,350	29	12.39	42.13	34.70	22.30	34.70	34.70	49.57	44.61	3.3	0.44
Marquette	15,574	34	0.00	6.42	0.00	19.26	89.89	51.37	38.53	25.68	6.7	0.29
Menominee	4,556	13	0.00	87.80	21.95	43.90	65.85	153.64	87.80	21.95	6.8	0.11
Milwaukee	945,726	3915	7.72	22.63	15.54	10.79	23.26	17.66	19.35	24.64	1.4	0.34
Monroe	46,253	51	49.73	64.86	79.99	32.43	62.70	28.11	71.35	43.24	-1.6	0.05
Oconto	37,930	38	5.27	21.09	13.18	13.18	23.73	31.64	36.91	21.09	3.0	0.52
Oneida	35,595	32	5.62	19.67	11.24	19.67	25.28	25.28	33.71	33.71	3.7	0.85
Outagamie	187,885	293	5.85	14.37	12.77	12.77	17.03	18.10	18.63	18.63	1.6	0.76
Ozaukee	89,221	385	10.09	16.81	7.85	11.21	16.81	19.05	12.33	11.21	0.3	0.03
Pepin	7,287	31	0.00	0.00	54.89	0.00	41.17	41.17	41.17	68.62	8.2	0.54
Pierce	42,754	74	16.37	4.68	4.68	7.02	30.41	4.68	16.37	14.03	0.8	0.05
Polk	43,783	48	11.42	11.42	9.14	11.42	38.83	18.27	41.11	27.41	3.8	0.50
Portage	70,772	88	5.65	7.06	7.06	5.65	18.37	9.89	18.37	11.30	1.4	0.42
Price	13,351	11	0.00	14.98	0.00	7.49	7.49	29.96	52.43	29.96	5.8	0.60
Racine	196,311	589	7.64	16.81	13.24	13.75	22.41	18.34	16.30	21.39	1.4	0.52
Richland	17,252	29	28.98	46.37	23.19	34.78	34.78	23.19	69.56	11.59	-0.1	0.00
Rock	163,354	227	5.51	17.75	19.59	14.08	15.92	22.65	22.65	13.47	1.1	0.22
Rusk	14,178	16	14.11	14.11	28.21	0.00	14.11	7.05	35.27	28.21	1.8	0.14
Sauk	64,442	77	27.93	43.45	31.04	40.35	45.00	29.48	58.97	24.83	0.7	0.02
Sawyer	16,558	13	12.08	18.12	18.12	30.20	42.28	12.08	30.20	30.20	2.2	0.24
Shawano	40,899	46	2.45	36.68	17.12	36.68	29.34	17.12	46.46	48.90	4.4	0.44
Sheboygan	115,340	225	9.54	29.48	15.61	12.14	23.41	26.01	19.94	10.40	0.0	0.00
St. Croix	90,687	126	26.46	30.88	22.05	17.64	26.46	30.88	17.64	28.67	-0.2	0.01
Taylor	20,343	21	4.92	19.66	24.58	4.92	19.66	9.83	29.49	4.92	0.2	0.00
Trempealeau	29,649	40	13.49	50.59	16.86	26.98	13.49	16.86	60.71	16.86	0.7	0.01
Vernon	30,822	39	12.98	32.44	9.73	22.71	19.47	16.22	22.71	12.98	-0.4	0.02
Vilas	22,195	25	13.52	27.03	22.53	27.03	40.55	31.54	27.03	31.54	2.0	0.39

Walworth	103,868	187	5.78	23.11	19.26	29.85	21.18	24.07	32.73	34.66	3.0	0.66
Washburn	15,720	19	12.72	31.81	12.72	25.45	25.45	25.45	31.81	44.53	3.1	0.53
Washington	136,034	316	13.23	11.03	11.03	10.29	25.73	8.82	14.70	13.97	0.4	0.03
Waukesha	404,198	728	6.93	15.09	9.90	12.37	15.59	22.76	20.78	17.07	1.7	0.60
Waupaca	50,990	68	13.73	29.42	27.46	31.38	25.50	39.22	9.81	19.61	-0.3	0.01
Waushara	24,443	39	4.09	16.36	4.09	12.27	20.46	16.36	36.82	20.46	3.1	0.53
Winnebago	171,907	392	16.87	18.03	15.71	12.22	17.45	9.31	28.50	14.54	0.3	0.01
Wood	72,999	92	15.07	9.59	9.59	16.44	17.81	16.44	28.77	32.88	2.9	0.71

Table 2.6: Yearly Wisconsin population-adjusted rates of HRI EMS counts by county, 2017-2024, with slope and R^2 values for each. Conditional formatting is applied to each difference of means to highlight steepest contrast, wherein the highest HRI-related numbers are darker red and higher populations and population densities are deeper blue.

County	Maximum ATmax (°F)	Avg ATmax of highest EMS days (°F)
Adams	111	92
Ashland	106.1	94.5
Barron	110	92
Bayfield	106.1	93.2
Brown	109	96.3
Buffalo	110	100
Burnett	110	96.25
Calumet	117	94.3
Chippewa	110	95.25
Clark	109	94.3
Columbia	113	89.6
Crawford	120	93.4
Dane	113	98
Dodge	120	94.4
Door	109	96
Douglas	103	95
Dunn	110	101.3
Eau Claire	110	101.3
Florence	107	84.5
Fond du Lac	120	96
Forest	107	87.7
Grant	120	96.3
Green	113	91.2
Green Lake	117	95.3
Iowa	113	98.7
Iron	106	87
Jackson	109	87.6
Jefferson	113	93.7
Juneau	111	95.2
Kenosha	120	94
Kewaunee	109	89.2
La Crosse	118	89
Lafayette	113	89.3
Langlade	106	87.7
Lincoln	106	92.7
Manitowoc	112	94
Marathon	107	89

Marinette	107	81.8
Marquette	111	90.4
Menominee	107	89.2
Milwaukee	117	85.7
Monroe	118	100
Oconto	109	94.75
Oneida	106	89.3
Outgamie	109	94.2
Ozaukee	112	92
Pepin	110	89.1
Pierce	110	89.2
Polk	110	96.6
Portage	111	93.6
Price	106	85.8
Racine	120	100.2
Richland	113	91.3
Rock	113	94.3
Rusk	110	85.8
Sauk	113	94.5
Sawyer	110	87.5
Shawano	109	91.9
Sheboygan	112	89.1
St. Croix	110	89.2
Taylor	109	88.9
Trempealeau	118	96
Vernon	118	103.2
Vilas	106	92.8
Walworth	120	99.2
Washburn	110	90.75
Washington	120	106.3
Waukesha	117	89.7
Waupaca	117	88.8
Waushara	111	89.1
Winnebago	117	100.3
Wood	111	91.6

Table 2.7: For each county in Wisconsin, the highest maximum AT recorded 2018-2024, and the average maximum AT during the weeks with the three highest HRI EMS counts (or including additional weeks if HRI EMS counts were the same beyond this cutoff). Conditional formatting has been applied such that the highest temperatures are darker red. The ATmax of days with the highest HRI EMS counts is consistently far lower than the actual maximum AT that the county experienced.

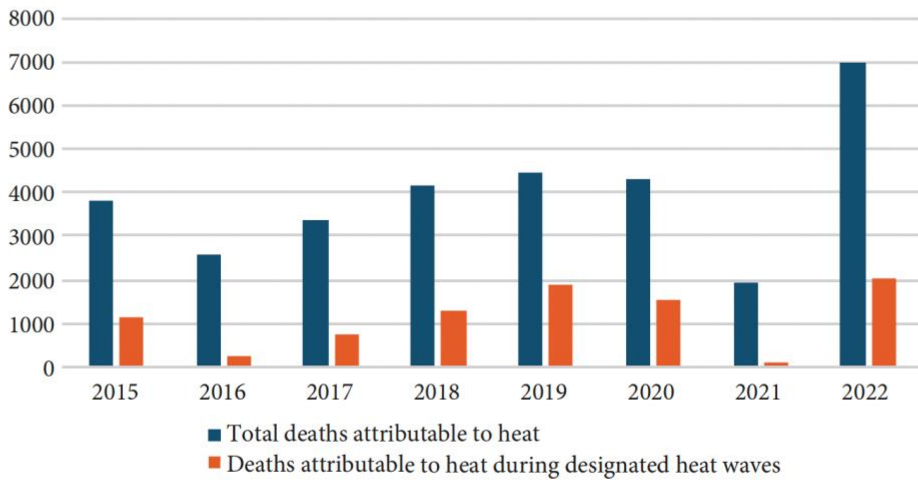


Figure 2 Heat deaths in France, 2015-2022: comparison of total deaths attributable to heat and those occurring during designated heat waves. (Source: Pascal et al. 2023.)

Figure 2.16: Heat deaths in France totaled and those occurring during heat waves. The vast majority of heat-attributed deaths occurred outside of heat waves. From Keller (2024): "Climate Change, COVID-19, and the End of Excess Mortality: Extreme Heat in France since 2003."

Chapter 3: Heat preparedness and vulnerability in Wisconsin

1. Introduction

Heat is increasingly a threat to human health as climate change makes high temperatures and other extreme weather events more frequent and intense (Union of Concerned Scientists, 2019). As risks mount and severe heat waves cause illness and death, well-informed and decisive action is critical to preserve human health and wellbeing. The deadly 1995 heat wave in the Midwest and the 2003 European heat wave have served as watershed moments: through unprecedented meteorological conditions and resulting high death tolls, they forced people to realize that heat waves like these were possible in "cold" places, that they were dangerous, and that people, their infrastructure, and their safety nets were unprepared (Keller, 2013; Klinenberg, 2015). Even as our understanding of extreme heat as a problem has improved, the hazards continue to worsen; between 2008 and 2020, emergency department visits for heat-related illness (HRI) increased in the Midwest more than any other region in the US (Dring et al., 2022).

However, there are significant knowledge gaps to overcome between climate adaptation theory and practice. There is a need for more knowledge sharing and collaboration between scientists, designers, and decision makers in climate planning (Kleerekoper et al., 2012). Multiple studies on climate adaptation call for future research to investigate how adaptation is manifesting in local contexts, what actions are taking place, and what barriers impede success (Boeckmann, 2016; Guardaro et al., 2020; Marin-Puig et al., 2022; Martinez et al., 2019; Moser & Ekstrom, 2010; Olazabal et al., 2024). Relatedly, in my own conversations with practitioners that initiated this research, those engaged in climate adaptation on the ground want to know if their interventions are having the desired effects, what is working elsewhere, if there are best practices and research results that they are not aware of, and how their contributions fit into the larger picture. Through my research in this chapter, I seek to address both sets of needs at the interface of research and action.

Loaded terms such as vulnerability, adaptation, and resilience are often referred to in climate planning but not explained (Rose & Göçmen, 2024), which can impede shared goals and understandings of the actors involved, constrain the kinds of solutions proposed, and have consequences down the line (Guardaro et al.; 2022; Olazabal et al., 2024; Ribot, 2011). Research on vulnerability to heat has largely been quantitative, focusing on indicators linked to disproportionately negative health outcomes, neglecting qualitative work that asks what processes drive some people and groups toward precarity (Jonsson & Lundgren, 2015; Romero-Lankao et al., 2012). Similarly, heat action is largely oriented towards heat mitigation measures that cool the outdoors along with reactive measures providing temporary refuge from the heat such as cooling centers. Omitted from this conversation, and from the imagined roster of solutions to help improve heat outcomes, are ways to address these underlying drivers of heat vulnerability. This kind of vulnerability, the political, economic, and social factors that affect how a person, household, or community is impacted or able to respond to a stressor, is often referred to as contextual vulnerability (O'Brien et al., 2007). In this work, I seek to bring contextual vulnerability to a heat preparedness and planning context.

Unlike states and cities that have historically had to deal with extreme heat, in Wisconsin less is known about heat preparedness and vulnerability. For instance, we know relatively little about the capacity of the state's health and emergency services or local government and communities regarding heat, the current health and economic impacts of heat, what resources are available to cope, to what level the general population is aware of available assistance, and how to improve accessibility of and effectiveness of current interventions. Any efforts to build on our collective understanding of where we stand and what needs to be done are helpful not only for acting, but also for making a persuasive case for more funding, resources, staff, and expertise to be devoted to heat vulnerability and preparedness. Given this, I focus my study on Wisconsin, conventionally thought of as a "cold" state, and specifically the cities of Milwaukee and Madison as hubs of climate action by both local governments and community-based organizations. I conduct community-engaged scholarship with practitioners, learning from people whose work interfaces with heat.

To address these gaps in the literature and bridge between research and action, I seek to answer the following questions:

1. Who are key known actors doing the work of heat resilience, and what does working towards heat resilience currently look like?
2. How can practitioners' perspectives and insights help build a more contextual understanding of heat vulnerability?
3. What challenges impede actions to meaningfully address heat vulnerability where it exists and building heat resilience across these spaces?

In interviews, I deliberately left both terms open and undefined, asking participants what contributes to heat vulnerability and what helps us build resilience, because the meaning that people assign to these terms is a key part of the story. Because terms such as vulnerability and resilience are so central to this chapter, I will provide at least a short working definition here; vulnerability in particular will be expanded on extensively in the following section and the analysis. For the time being, following the framework advanced by Turner et al. (2003) in which

vulnerability is created by **exposure** and **sensitivity** to a hazard and is reduced by **adaptive capacity**. In short, resilience is typically discussed both in general and in interviews here as being made of the different things that help individuals, communities, cities, and larger units of governance withstand hazards with minimum loss of life, health, livelihoods, or quality of life. The collective narrative is that we can all work towards resilience at these different levels (individual, community, government, etc.) by managing to physically cool spaces people spend time in, by following best practices around hydration and rest, and building communities where people check in on and take care of each other. A number of the kinds of actions or traits that contribute to resilience can also be thought of as being part of adaptive capacity.

In this chapter, I further explain contextual vulnerability and its applications to heat. Then I outline my methods of community-engaged scholarship, interviews with practitioners, and content analysis of public media that all served to address these questions. In my results and analysis section, I first outline the dimensions of contextual vulnerability to heat: how heat vulnerability manifests in home, work, and third places. I then discuss the actions that currently contribute to heat resilience, paying close attention to the specific aspects of vulnerability they address. Insights from interviewees highlight the importance of contextual vulnerability, what barriers must be overcome to truly address vulnerability to heat, and the importance of action across sectors.

2. Building a contextual understanding of heat vulnerability

Problems of extreme heat have for the most part been conceptualized as being biophysical, distributional, and approached in a quantitative fashion. This nexus of conceptualization and method shape and limit what kinds of solutions we see as being suitable to address heat problems. Studies investigate differential exposure to heat through metrics such as outdoor temperature, heat index, urban heat island magnitude. The urban heat island effect has been studied extensively; a search for academic publications about the phenomenon yields thousands of results. These include comparisons of urban to rural temperatures, cities and their UHIs to each other, and the differential greenness and temperatures of neighborhoods and blocks within a city (see review in Zhou et al., 2018). These studies provide a good understanding of differential exposure to heat but are less able to speak differential vulnerabilities and their underlying causes. Increasingly, people are now thinking of heat as an issue of health and not just exposure. Research on extreme heat and the toll it takes on people has historically been overwhelmingly quantitative; many studies investigate under what thermal conditions people become sick from the heat (Barrow & Clark, 1998; Basu & Samet, 2002; Basu, 2009; see review in Heidari et al., 2020) and disproportionate risk from individual health factors and across demographics (Arsad et al., 2022; Bouchama & Knochel, 2002; Kilbourne et al., 1982; Semenza et al., 1996; Semenza et al., 1999). Mortality is arguably the most common measure, while morbidity and hospital visits are not far behind (Basu, 2009). These studies often implicitly treat vulnerability to heat as an outcome; those negatively impacted by exposure are the vulnerable (O'Brien et al. 2007). Accordingly, dominant proposed solutions have been to mitigate outdoor heat through the built environment and vegetation (Keith & Meerow, 2022; Rose & Göçmen, 2024), and more recently, through heat management methods to reduce negative health outcomes (Hess et al., 2023; Keith & Meerow, 2022; Meerow & Keith, 2022).

It is important to understand vulnerability to a climate hazard before taking steps toward adaptation; if we do not take into consideration why some people are vulnerable to a hazard and others are not, and what processes lead to this, we cannot be sure that adaptation strategies will address the underlying causes of vulnerability (Ribot, 2011). O'Brien et al. (2007) describe climate vulnerability as a concept as being made up of two parts. Outcome vulnerability describes exposure to a hazard and its severity, understood in scientific and technical conceptualizations of the problem, which accordingly prompts scientific and technical solutions to address it. This term encompasses much of conventional heat research.

Others argue that vulnerability precedes exposure and for planning purposes we need to understand such **contextual** vulnerabilities. Contextual vulnerability is shaped by the political, economic, and social factors that affect how a person, household, or community is impacted or able to respond to a stressor. From this perspective, inequities and differences in access to resources or power are what produce vulnerability, and addressing these dynamics can reduce vulnerability. This position also posits that vulnerability is a state and a process, not an intrinsic quality (O'Brien et al., 2007).

Analyses of casualties from the deadly 1995 heat wave in Chicago and the 2003 European heat wave in Paris, while predating usage of the term "contextual vulnerability," nevertheless mirror the concept. Researchers investigated patterns of deaths and found them to be largely due to disinvestment in neighborhoods, weakened social connections, and precarious living conditions of many elderly residents (Keller, 2013; Klinenberg, 2015). According to these analyses, the two heat waves served as disruptions that pushed a flawed system to its breaking point, where some people were extremely socially vulnerable, having been left behind by society and its governing structures. Accordingly, these differential impacts and tragedies revealed a broken system with many underlying risks and faults, without which the heat wave alone would not have led to such tragedy.

While the role of redlining in inequitable distribution of heat has received notable attention in well-known news outlets in recent years (e.g., Plumer et al., 2020), we must not limit ourselves to only considering historical processes, but currently ongoing processes that create vulnerability as well. When we ask questions such as, “How can we help the homeless populations of Madison or Milwaukee become less vulnerable to heat,” the answers we hear are in the realm of outreach, communication, cooling centers, providing water and supplies, and access to resources in emergencies. All of these are essential, but rarely touched is the line of questioning: “How did these populations *become* homeless? What processes push people into this kind of precarity? How do we help people both in this situation and prevent them from reaching it in the first place?” This same question can be asked of undocumented migrant agricultural workers facing both dangerous conditions in the summer heat and fear of retaliation from raising these issues to their bosses as workers deal with language barriers, low pay, and a lack of access to healthcare. By conducting qualitative research and asking how, where, and why heat vulnerability manifests for different people and groups, we can begin to understand and address and improve the conditions that produce it. This expands our understanding of the roster of possible actions we can and should take to truly reduce heat vulnerability and build resilience.

We can gain a more grounded understanding of contextual heat vulnerability as it exists in the places we study through the practice of community-engaged scholarship. Traditional academic research, in which the research questions, methods, and sharing of results are all decided by the researcher, has historically suffered from difficulty in translating results into actions and tangible positive outcomes. In contrast, community-engaged scholarship engages with affected communities, practitioners, and/or stakeholders from the beginning. Accordingly, it is more successful in translating to effective action, especially around improving outcomes for disenfranchised populations, because there is not a gap between research and practice from the start (Faridi et al., 2007; Minkler, 2000; Ioannidis, 2004). By following this practice, conversations with practitioners can help us understand how people are thinking about heat vulnerability, how it manifests, what actions and solutions are proposed to address it. Building this understanding can then in turn aid meaningful climate action, improve health outcomes, and better prepare for extreme heat.

3. Methods

Community-engaged scholarship

As the first step of community-engaged scholarship, I have been building relationships and speaking with people whose work and/or experience tells us more about the landscape of heat preparedness in Wisconsin, both inside of and outside of government. My questions and methods have been shaped by experiences and conversations I have had with collaborators in previous heat-related work in Wisconsin, namely:

- Kate Beardmore: Program Evaluator in the Climate and Health Program at the Wisconsin Department of Health Services
- Maggie Thelen: Climate and Health Program Coordinator at the Wisconsin Department of Health Services through spring 2024, now the Environmental Health Senior Program Analyst at the Council of State and Territorial Epidemiologists
- Natalie Meier: Milwaukee County Office of Emergency Management Coordinator

We have been working with each other since summer of 2022, first through collaborating on studying heat-health relationships and warning system strategies in Wisconsin. More recently they have been partners in my community-based learning capstone course "Building Resilience to Heat" in the Nelson Institute for Environmental Studies at the University of Wisconsin-Madison Their insights and ideas have been instrumental to the existence of this research.

Semi-structured interviews

To address my research questions, I conducted semi-structured interviews with municipal and state-level government employees and leadership and staff of community-based organizations. I selected participants using a snowball sampling method, in which contacts and interviewees recommended other people to speak with, beginning with the state Department of Health Services: Climate and Health Office, Milwaukee County Emergency Management, and nonprofits working at some intersection with heat but more generally focusing on environmental justice, vulnerable populations, sustainability, conservation, and/or community health. I intentionally did not restrict myself to interviewing people dealing specifically with heat preparedness in order to hear from people in a range of positions who are aware of the issues facing vulnerable people and who could speak on how heat affects their lives and arises in their work. I conducted 26 semi-structured interviews whereby 18 of the interviewees worked with municipal or state government (such as public health, libraries, and climate planning) and 9 with community-based/nonprofit organizations (including homeless shelters, environmental justice organizations, and conservation nonprofits). Interviews were mostly conducted between May and August 2024, with the last few occurring around the summer of 2025. The duration of interviews averaged between 45 minutes and an hour. See Table 3.1 below for a more detailed breakdown of interviewee affiliations:

Number of interviewees by organization overall type / based in:	
State-level government	6
Municipal gov: Madison	6
Municipal gov: Milwaukee	6
CBO: Madison	2
CBO: Milwaukee	6

Number of interviewees by organization areas:	
Public and community health	5
Emergency management	4
EJ-focused conservation and sustainability org	4
Climate science and planning	3
Working with unhoused populations	2
Libraries	2
Workers' rights	2
Tenants' rights	1
Placemaking	1
Urban forestry	1
Energy affordability	1

Table 3.1: Organizational affiliations of interviewees.

While I did not speak to individuals personally experiencing heat vulnerability due to situations like unsecure housing, many people I spoke to in both government and non-government organizations had unique insights from working with their community members, many of whom are considered to be vulnerable to heat. Accordingly, when I discuss findings around the question of "what do people want heat resilience action to look like," the word "people" is directly referring to the organization members I spoke with. It is my sincere impression that interview participants, working in hubs of community, knowledge, resources, and services do share and represent their constituents' thoughts and needs—but do note that there may be some gaps that can only be addressed by speaking with more members of vulnerable populations themselves.

I chose the method of semi-structured interviews because it allowed me to pursue relevant lines of questioning with all participants while retaining the flexibility to dive deeper into topics (Adams, 2015; Bührle & Kimmerle, 2021). In my interviews, I asked each interviewee about what their organization does, how extreme heat comes up in their work and community, needs that have been expressed, successes or steps forward to celebrate, how the conversation around heat resilience has changed in recent years, obstacles, and what they want to see going forward. To understand the everyday experiences of residents, I also asked participants to share their understanding of what people are thinking and doing about heat, what issues they find most pressing, their awareness of heat-related programs and assistance in the city and state, and what needs and/or knowledge gaps they'd like addressed. See Appendix 1 for the full list of possible interview questions that I drew from. I analyzed the completed interviews using thematic analysis, first finding initial themes across interviews and then categorizing and fitting the themes among each other. I also investigated differences between perspectives (i.e., governmental organizations vs. community-based organizations). My analysis largely used inductive reasoning, in which I construct understanding from the substance of the interviews. At the same time, following the idea of deductive reasoning (Williams & Moser, 2019), my research questions and analysis were influenced by a political ecology framework and the driving question of what creates vulnerability.

Content analysis of public media

I performed content analysis of public media such as reports and newspaper articles to supplement interviews and follow threads named by interviewees. With them I seek to generate a working understanding of the different forces at work, where future research is needed, and potential questions that could be asked in future interviews and surveys that may interface more directly with members of vulnerable populations.

4. Results and analysis

I have three main categories of results that have emerged from interviews and content analysis: heat vulnerability, action around heat resilience, and obstacles and calls to action.

First, I discuss how heat and heat vulnerability are discussed in general, and how they are connected with many parts of society and daily life across home, work, and third places. Heat in the home is entangled with housing security and housing stock, air conditioning and energy burden, and vegetation in the neighborhood. Heat in the workplace affects sectors such as agriculture and construction, but there are many challenges to understanding its true impact when injuries and illness at work are severely underreported. Heat and third places highlight the importance of public spaces including pools, beaches, parks, and libraries, where people can cool off as well as build community and social networks that in turn contribute to resilience. It is important to note that people navigate themselves across these three spaces during their daily lives. While individuals' presence in the workplace may be required and have little flexibility or variation, people may modify the time spent at home and third places from day to day for a variety of reasons including heat exposure. Throughout these spaces, compounding hazards can strike and further increase vulnerability.

Second, I describe multiple examples of ongoing work across sectors in Wisconsin that help address heat vulnerability. Some of these are explicitly designed to deal with heat itself, but many are focused on other vulnerabilities entangled with home, work, and third places. I argue that these are all vital for heat and climate resilience and should be recognized as such. I also detail vital processes that are a part of this work, including planning and community engagement and what else shapes the current landscape of heat vulnerability and action.

Third, I conclude with specific ideas and action items that people want to see going forward that will contribute to heat resilience. Importantly, many of these have to do with addressing underlying vulnerability rather than heat exposure itself, and as a result, they have co-benefits across different types of extreme weather or general wellbeing.

Everything included in this results section was brought up in interviews, or if specified in the text, arose from public media analysis. Interviewees and their organizations are named or not named according to their preferences. I spend less time detailing more well-known facts and perspectives, such as the importance of tree canopy for shade and thermal comfort, and I expand more upon what I have seen far less of in the academic literature and heat action plans, such as access to water for swimming and the mechanisms of funding for nonprofits and emergency response.

4.1 Heat vulnerability across home, work, and third places

4.1.1 Heat vulnerability in the home

Housing arose near-universally in interviews as one of the most severe and pressing matters relating to heat. Much of what makes a person vulnerable or resilient to extreme heat is related to where they live, including matters of housing security, housing stock, air conditioning and energy burden, and nearby vegetation. Housing security is the reliability of having a roof over one's head. Housing stock is the age and quality of one's home, including weatherization and insulation, which in turn determines how well (and affordably) one can keep the temperature inside at a safe, let alone comfortable, level.

Housing security

Those with the least secure housing tend to be the most vulnerable to heat. Unhoused people are repeatedly and rightfully identified as one of the most vulnerable populations to heat and other kinds of extreme weather, most often by those affiliated with state and local government. If someone cannot escape from the elements during severe weather or extreme temperatures, they are seriously at risk of falling ill or dying as a result. A number of recent news headlines underscore the severity of problems with housing security and the essential role of shelters in extreme weather: "Madison's housing crisis is a national extreme," "Madison homeless shelters are overflowing, linked to housing shortage," "Street Angels offers Milwaukee's homeless community support during heat wave" (Robinson, 2024; Garfield, 2024; Rojas-Castillo, 2024).

However, Lindberg Chambliss, who has worked assisting unhoused people at Madison homeless shelter The Beacon, argues that no matter how much people study and contemplate how to keep people safe from the elements during extreme weather, whatever approaches they take, *the issue at its core is about housing*. He says, "People need consistent shelter that's safe, comfortable, and habitable. I think it's that simple." In other words, acting reactively in emergencies is not enough; if someone is vulnerable because they are unhoused, we need to get them housing. The national housing crisis encapsulates many co-occurring stressors and societal failures: rising price of housing, increased cost of living, stagnation of wages, and austerity policies that strip aid and welfare to the point where it can be nearly impossible for unhoused people to have enough stability and basic needs met to reach a better situation. Until they do, they are at the mercy of the elements.

Housing stock, air conditioning, and energy burden

Even for those with stable housing, the age and quality of one's dwelling substantially influence exposure to heat and other environmental harms. Older buildings are typically less weatherized, and some have been described as being like ovens in the summer. Those living in rental properties are named as being more vulnerable than homeowners, as they have less agency over changing their housing condition. Many landlords invest little in their properties to make them energy-efficient, weatherized, or thermally comfortable, as they do not directly benefit them. One reason for this is split incentives, whereby those paying the costs of upgrades are not the same people who suffer in their absence or benefit from their presence.

Extremely hot weather, humidity, and/or strong summer sunlight hitting a home can result in unaffordable energy bills, especially when paired with energy inefficiency and poor insulation. Households with a high energy burden, meaning that a high percentage of their income is spent on energy bills, may be forced to choose between paying to keep their home at a safe temperature and daily essentials such as food, medications, or gasoline. The housing crisis and rising rents already leave many in a state of financial precarity, which high energy bills exacerbate.

In extreme heat or cold, utility shutoffs in response to inability to pay the energy bill can be deadly. The general understanding among interviewees is that utilities shutoffs are not allowed in winter, when cutting someone's power in the cold can be a death sentence, but that shutoffs are fair game in summer. However, a conversation with a government employee clarified that there are indeed protections against utility shutoffs in summer: utility services *cannot* be disconnected when an excessive heat warning is in effect.[7] Even so, this is not directly comparable to the full moratorium on utility shutoffs that Wisconsin has in winter months. And importantly, if people do not know about this rule, and if a lack of knowledge impedes its enforcement, it may be doing little good.

Vegetation and tree canopy

Another characteristic of one's residence that deeply shapes their experience with heat is prevalence of vegetation and tree canopy cover in their neighborhood. The cooling power of trees and other forms of vegetation are well-documented (see review in Schmidt & Walz, 2021) and in interviews trees came up repeatedly in conversations about heat vulnerability and preparedness especially the legacies of redlining and resulting inequitable access to greenery and shade. In neighborhoods with a dearth of greenery, there is no escape from the heat. An additional challenge is for trees to recover from the damage brought by the emerald ash borer, which devastated ash trees (a common street tree) in the Midwest and eastern US (Sydnor et al., 2011).

---

[7] The Public Service Commission's Service Rules for Electrical Utilities, Subchapter III — Disconnection and Reconnection of Electric Service, PSC 113.0301 (https://docs.legis.wisconsin.gov/code/admin_code/psc/113/iii/0301c)

4.1.2 Heat vulnerability at work

There is rightfully much concern for worker safety in the context of extreme heat: both for those working outside and indoors in non-air-conditioned environments. Construction, agriculture, dairy farms, and warehouses are often named as industries and locations of concern. In addition to being more exposed to heat, people who labor in the heat are vulnerable to exertional heat stress, in which a body in motion creates more heat, which can quickly make a borderline safe situation dangerous or even deadly (Barrow & Clark, 1998; Mellion & Shelton, 1997; Knochel & Reed, 1994). The general landscape of heat and overall labor protections could be much improved.

One critical problem is that there are not enough OSHA (Occupational Safety and Health Administration) safety inspectors in the country to sufficiently motivate all workplaces to follow safety rules and regulations. Safety inspections are more feasible and efficient for large work sites where many workers are congregated in one place, but visiting and staying on top of many scattered smaller projects, like those in residential areas, is far more difficult. There are some random inspections, but they are rare enough that from a profit-motivated perspective, it makes more sense for an employer on a tight schedule to take their chances and pay the fine for violating a safety rule every few years than lose the time needed to keep workers safe. As they are, the current incentives are not enough to proactively protect workers. Safety standards developed by the federal government must be followed by all construction crews, but they are rarely checked or enforced. A death will always be investigated, but it could have been prevented through better rule enforcement. Pam Fendt, President of the Milwaukee Area Labor Council, says, “We need to have proactive safety plans and make sure that people have the information they need to work safe.”

Farm work presents many of its own challenges. Sarah Janes Ugoretz works with UW Extension as well as national coalitions,[8] and collectively they have developed the resource library "Hot Potato" (link) (Janes Ugoretz & Adalja, 2025). She takes part in running webinars to share best practices in how agricultural workers and farm owners can cultivate a safe and functional work environment. Through numerous conversations with other farmers and personal experience, they have identified a number of problems around farm safety on hot days that stem from logistics of the work itself and from the work culture.[9] Finally, many people who work on farms and are most at risk to heat are Latino; some speak little English; and immigration status can create a huge power imbalance in which it is difficult to slow down, take breaks, refuse to work in dangerous conditions, or complain to one's supervisor.

Interviewees, especially those in government positions, say that to make changes in policy to better protect workers, we need more hard data to demonstrate the current state of the problem, its costs, and where we can push next. Unfortunately, there is a shortage of data here; it is difficult to know how many people and who are getting sick on the job from heat, and what conditions are like, especially for migrant workers. Wisconsin is a federal OSHA state, which means it does not keep its own records; heat-related illness rates on the job are not tracked, and

---

[8] including Fairshare CSA Coalition, CISA (Community Involved in Sustainable Agriculture). She, Anita Adalja of Not Our Farm, and Cynthia Flores of Labor-Movement LLC, in collaboration with these organizations and many, many vegetable farmworkers across the country have worked to create Hot Potato and related trainings.

[9] Inherent in farm work is a culture of toughness where people are used to working through the pain and even take pride in it, in working in all types of weather; it is seen as part of the deal. Narrow profit margins, since prices need to be incredibly low to stay competitive, mean that to stay in business a farm can only pay its workers so much, and if employers decide to give workers a break on a hot day, produce will rot in the sun and all of that income would be lost. There is little room for error, and the ceiling of what productivity can be lost is low. The vast physical size of farms can be a daunting logistic barrier; if someone runs out of water and the refill station is a long walk or a drive away, they may go without to not lose that valuable time. The same applies to needing to use the restroom if the facilities are far. There is an inherent pressure to avoid needing to use the restroom frequently, as it cuts into efficiency, and that runs counter to the need to hydrate to stay healthy in the heat. Telling workers to hydrate will have limited effectiveness if logistical barriers and productivity incentives run counter to taking care of these human needs.

those working in labor, health departments, and OSHA agree that workplace illness and injuries in general are underreported.[10]

4.1.3 Heat vulnerability and third places

In addition to the home and workplace, public, commercial, and outdoor spaces play a significant role in heat vulnerability and resilience through providing or constraining access to relief from extreme temperatures and opportunities to build community.

Water

People have long flocked to the water for relief from the heat, and so access to water is a vital resource to cope. Madison and Milwaukee both have unique and deep connections to water: Madison is located on an isthmus between two lakes, and Milwaukee sits on the shore of Lake Michigan, with a number of rivers flowing through the city to the lake. Mandi McAlister of MKE Hummingbird says that water is not only a practical and effective way to cool down; it is also culturally significant, a deep part of Milwaukee's identity, and going to the water with

---

[10] In the absence of more complete records of on-the-job heat-related illness, one indicator that tells an important story is worker's claims. The premise of these claims is that if someone is injured on the job, they can file for compensation for days they are unable to work as a result. The recent surveillance brief reports on heat-related illness claims and their outcomes (Fall et al., 2024). Figure 3.1 in Appendix 2 shows percent denied claims over time. In the Midwest, 2011 and 2012 were very hot summers, during which some claims were denied but the majority went through. But then within a few years, most claims were denied; why might this be? The process behind claim acceptance or denial is enlightening and sobering. First, the language of our health insurance landscape: "pre-existing conditions" disqualify many heat-related illness from being properly attributed, because heat exacerbates many other health conditions rather than being identifiable as directly at fault. Second: the governor made pro-employer and pro-business appointees to the review commission that processes these claims in 2013, when we see this major shift into rejecting worker's compensation claims. To summarize: these processes of claim denial, which are pushing people back into working in unsafe conditions, are about far more than exposure and temperatures themselves. A handful of people on a decision-making board can affect the lives of so many workers; this is one example of a lever with a huge impact that we can set our sights on.

family or friends can be joyful and fun. However, even though an abundance of water exists, it is far from accessible to all.

Milwaukee is a highly segregated city with a huge disparity in access to water, especially to swimming pools. Many pools in the city stay closed because they do not have enough lifeguards on staff to safely open. These closed pools are disproportionately in neighborhoods with a high population of Black residents. While it might be possible to travel to a more distant pool in a neighborhood that does not have this problem, time and money act as constraints. If a family does not have a car, it may take them an unfeasibly long time to reach an open pool via transit. If there are several children and there is an admission cost, that cost quickly multiplies and can also become a hardship. The lifeguard shortage itself is traced both to insufficient pay and the fraught history of segregation and access to swimming pools in the 20th century, which created and still reproduces inequities in swimming ability and how much it is encultured in white vs. Black families (Wiltse, 2014). Drowning hazards are not to be understated; heat waves in the state correspond with peaking rates of drowning incidents as can be seen on Wisconsin's summer hazards dashboard (see Figure 3.2 in Appendix 2). Accordingly, suggested solutions around lifeguards and pool access include better pay lifeguards and more swim lessons and trainings to both address this gap and increase the roster of choices people can make to escape the heat.

In addition to access, water quality is a key variable affecting options to cope with the heat. Especially in warm weather or following excessive rainfall, water quality in Milwaukee can suffer from industrial processes, nutrient loads, bacteria, and backed up sewers. In Madison, agricultural runoff and excess nutrient loads combined with warm conditions can generate algae blooms, e-coli, and cyanobacteria in the water. Public Health Madison and Dane County are in charge of monitoring these levels and closing beaches and issuing warnings when conditions become unsafe (Burch, 2025; Patz et al., 2008; Reimer, 2021). On these occasions, people lose access to the lakes as a way to cool down in the heat, or they must otherwise weigh one health risk against another.

Splash pads and drinking fountains are two more public amenities. Splash pads, outdoor play areas with fountains and sprinklers without standing water, can give especially children a way to cool off, but many are closed, facing difficulties with the Milwaukee County Parks budget and maintenance costs. She also notes that the ability to access drinking fountains is also spatially uneven; they are mostly found in public spaces, especially ones with parks or outdoor sports facilities, which in turn are disproportionately located near more affluent neighborhoods. This is one less documented but still important manifestation of how spatial inequities in access to resources affect people's ability to endure the heat outside and in public spaces.

Community, isolation, and placemaking

Echoing the much-cited literature on Chicago and Paris heat wave tragedies (Keller, 2013; Klinenberg, 2015), interviewees also placed community and social isolation as central components of heat vulnerability and resilience. Many expressed that it was common for community members to be concerned about elderly neighbors living alone and staying in their homes on a hot day. Neighborhoods where people see each other coming and going, where their children play, where programming facilitates intergenerational connections and learning, are asserted to feel much more connected, safer, and more heat-resilient. In contrast, places where people do not know each other and feel unsafe impede this comradery.

4.1.4 Compounding hazards

Natalie Meier, Coordinator of the Milwaukee County Emergency Management Office, shares that compounding hazards are her worst nightmare. Risks mount when an area is struck by a storm that causes widespread power outages and is then followed by a severe heat wave. A storm that causes a widespread power outage can suddenly increase the vulnerability of an area, leaving many without refrigeration or internet let alone air conditioning, overwhelming emergency services, and greatly increasing the health risks of a heat wave.[11] Krissy Wick, Director of Public Services at Madison Public Library, is also concerned about power outages impacting libraries' many functions, including keeping the public in a safe temperature. She shares, "Our biggest concern when it comes to heat events is that we're at the same mercy as everyone else when it comes to the energy grid. If there are blackouts, our space will be worthless." Joshua Parish, Assistant Chief of the City of Milwaukee Fire Department, is also concerned about roadway access when storms or flooding make roads impassable and emergency services are blocked from providing rescue or medical services.

Heat can also compound problems of air quality and respiratory health. August M. Ball of nonprofit Cream City Conservation shared that through the organization's outdoor work, it has become quite apparent that extremely hot days could trigger asthma attacks in youth participants. High costs of inhalers make them inaccessible to many who need them, which compounds the danger. Accordingly, making inhalers more affordable is highlighted as a tangible way to reduce the harmful health effects of heat. Without prescriptions, organizations cannot order inhalers on behalf of their members, but Ball found that they could financially support parents who could in

[11] An instance of this was experienced by many, including neighborhoods in the West Side of Madison, in summer 2023 when a severe thunderstorm with high winds left hundreds without power and then heat struck.

turn purchase inhalers and EpiPens. There might be programs out there that do this kind of support, she said, but if there are, group members are not aware of them.

Co-occurring effects of climate change further exacerbate respiratory health, increasing risk and incidence of asthma as well as the frequency and severity of attacks (Han et al., 2023). Asthma itself has disproportionately high rates in Black American youth, reflecting differential exposure to pollution and irritants by neighborhood (Brown et al., 2003; Canaday et al., 2024; Mannino et al., 2002; Schuyler & Wenzel, 2022), and so both risk factors for conditions exacerbated by heat and heat exposure itself (through the UHI effect) doubly threaten the health of Black residents. Also resulting from climate change and intensifying these respiratory illnesses and risks are increased pollen in the air and wildfire smoke. At the time of interviews, the Canadian wildfires of summer 2023 were still fresh in everyone's minds. Heat, smoke, and pollen, or a subset of these can combine to make it especially difficult to breathe. When the air quality outside is hazardous, people may have to choose between safe or comfortable temperature and exposure to irritants and air pollutants when deciding whether or not to open their windows on a hot day or night, getting circulation but also letting in the PM2.5 particles. Some residents have expressed a desire to have more guidance about which hazard to weigh more heavily and at what point heat or the air is more dangerous to be exposed to.

4.1.5 Summary

Heat vulnerability is connected with many parts of society and daily life across home, work, and third places. Housing security, housing stock, energy burden, and neighborhood vegetation and tree canopy coverage all shape a person's exposure to extreme heat. In the workplace, a lack of reporting mechanisms, rare safety inspections, and under-enforcement that collectively fail to sufficiently motivate employers to put worker safety above efficiency and profits. Third places also play a large role in heat vulnerability and resilience. Swimming pools, splash pads, and natural bodies of water provide a refuge from the heat, and so access to them can be lifesaving. Neighborhood characteristics and social climates greatly impact social isolation and connections, which in turn contributes to or mitigate heat vulnerability. Compounding hazards acting across these spaces can further endanger people. Heat following blackouts or road blockages can be especially deadly, as potentially lifesaving air conditioning no longer can offer refuge, and emergency services may be impeded from assisting patients. Extreme heat exacerbates respiratory conditions, which already disproportionately impact people of color and specifically Black children, causing asthma attacks. Unaffordability of inhalers and epipens are entangled in this danger, which is further exacerbated by air pollutants from sources such as wildfire smoke and pollen. Homes, construction sites, farms, swimming pools, waterfronts, and libraries are all important sites of climate policy, even if they may not conventionally be considered as such.

4.2 Doing the work

In this section, I describe the myriad ways that people across sectors are working to address the different manifestations of heat vulnerability described above, by home, labor, and third places. I argue that despite coming from many different kinds of organizations and across different areas, it all contributes to heat and climate resilience. Then I discuss additional themes and avenues that emerged in interviews: planning, collaboration and coordination, community engagement, community-building, and heat-specific actions including forecasting, warnings, messaging and behavior change, and cooling centers. I also describe what about Wisconsin as a state shapes the context of the heat preparedness landscape and how the conversation has changed in recent years, namely that it is improving; there is more emphasis on listening to and centering community wants and needs and on justice.

4.2.1 Actors across sectors

Through my conversations and interviews, I have found that people across sectors and in unexpected places—employees across scales of government, those outside of government working within nonprofits and NGOs, and resource providers who interface with the public—all contribute to heat resilience. I have categorized the actors involved in heat action in the following ways:

Associated with government:

- State government level: the Department of Health Services (DHS), especially the Climate and Health Program; climate planning; Department of Natural Resources (DNR)
- County/municipal level: emergency management, climate planning, water management, health departments/public health offices, sustainability offices, environmental (collaboration) offices, parks, libraries
- National Weather Service; The University of Wisconsin; Extension offices

Not associated with government:

- Community-based organizations (CBOs) and nonprofits that focus on environmental justice, sustainability, environmental education, conservation, tree planting, climate action, community health, tenants' rights, and/or placemaking and community programming
- Labor unions

- Immigrants' rights organizations
- Homeless shelters
- Religious organizations and businesses that offer up their spaces and resources during extreme weather events, coordinating with or being members of networks

Coalitions and networks:

- Milwaukee Extreme Weather Task Force - an organization of at least 20 governmental, business, and nonprofit groups that meet and coordinate around winter and summer. Originally named the Extreme Heat Task Force in 2014, but renamed with a widened scope in 2022 because of the overlap in protective measures needed for both extreme heat and cold
- Wisconsin Heat Health Network – health and action-oriented group of researchers, public health professionals, and community members (2022-present)
- Wisconsin Initiative on Climate Change Impacts (WICCI) – statewide collaboration of scientists and stakeholders working to understand and prepare for climate change impacts https://wicci.wisc.edu/
- Southeast Wisconsin Citizens & Organizations Active in Disasters (SEWI COAD) – a coalition working to enhance disaster preparedness and response https://sewicoad.org/about-coad/

Additional resources/organizations:

- 211 Wisconsin – a confidential phone number people in need can call to be connected to services such as housing, food, crisis intervention, a place to cool off, etc.; review and vet cooling centers, serve as a clearinghouse for information https://211wisconsin.communityos.org/

- Red Cross – disaster relief and first aid training https://www.redcross.org/local/wisconsin.html

At a state level, the Department of Health Services is taking the initiative in coordinating around heat action in the state, getting involved in supporting other organizations. At a municipal level, emergency management and public health both are at the center of wider coordination and collaboration efforts. Essential coordination needs to include nonprofit/community-based organizations providing direct services to people, such as emergency food pantries, homeless shelters, and transit; all of these are more widely involved in emergency preparedness and response than most people realize.

4.2.2 An abundance of ongoing work

Doing the work: heat vulnerability in the home

Working towards heat resilience manifests in multiple actions associated with housing and energy. Interviewees, especially those associated with public health, emergency management, and climate planning, put much thought into running cooling and warming shelters to keep unhoused people safe from extreme temperatures, as well as how to reach hard-to-reach populations with information on where they can go and when conditions are becoming dangerous. Homeless shelters, as described above, are some people's only option to escape the elements, and so operating them and helping visitors transition to a more stable situation are accordingly an important piece.

Similarly, weatherization, increasing energy efficiency and running workshops to educate residents about how they can improve their homes, passing around toolkits, and conducting efficiency audits all contribute to reducing the energy burden of keeping one's living space at a safe temperature without financial hardship. Municipal sustainability and environmental collaboration offices are among leaders of these efforts. Tenants' rights organizations, organizing around safe housing in extreme weather, and protecting people from utility shutoffs all contribute to heat resilience. Given the entanglement of heat vulnerability and safety in housing security, housing stock, and energy burden, efforts to shelter unhoused people from the elements and to help connect them with resources and stable housing, and helping to empower people to weatherize their homes, improve their energy efficiency, and receive energy assistance are all ongoing efforts to address this side of the problem. One important note is that there are no formalized home inspections around thermal comfort and safety; insights about how hot some residences get came from personal experience of interviewees or from lead inspections or energy efficiency audits. People are not seeking to identify heat as a problem, but other work serves as a window into the issue.

Doing the work: labor

There are a number of recent and ongoing actions to build heat resilience in the workplace. Unions provide safety trainings, including heat safety, and groups such as Voces de la Frontera and UMOS work to empower workers and protect their rights, especially for migrant and seasonal farmworkers.

The Hot Potato resource library and webinars described above have guidance on practical considerations of farmworker heat safety. See an excerpt from the resource in Appendix 3**.** Some key points, paraphrased form the resource library and a webinar on its contents, are as follows:

- If telling people, "Take a break when you need it" results in everyone pushing through, then that will not actually keep people safe. You need to say something concrete such as, "It's very hot outside today, so we'll all take 10-minute breaks every 40 minutes, and I'll announce when they start and end."
- Because people acclimatize to heat each summer and de-acclimatize once the weather cools off, some farms institute a policy not to hire any new workers beginning in July, when beginning work amidst the mid-summer heat would provide a shock to their systems.
- One answer to the logistical problem of farms being so large that it may take a prohibitively long time to visit a water refill station or restroom is to have shaded water refill stations and tables that are pulled by the farm truck, and even port-o-potties towed around to remain close to the people who will need them as they move through the fields all day (see Figure 3.3 in Appendix 2).
- Finally, the Hot Potato resource library and webinars themselves prioritize language accessibility; authors and moderators implement Spanish live interpretation and translations to lower language barriers and reach Spanish-speaking participants.

In February of 2024, the Department of Workforce Development put into effect a statewide rule providing more protections for migrant workers, [12] but as is the case with

---

[12] "Wisconsin Provides Added Protections for Migrant Workers" (February 2024) https://dwd.wisconsin.gov/press/2024/240206-migrant-worker-protection.htm

workplace protections and regulations in general, implementation and enforcement are not guaranteed.

Doing the work: Third places

There have been a number of recent projects around improving public space, especially in Milwaukee and around the issue of increasing access to bodies of water. The Kinnickinnic River in Milwaukee, which runs through south side neighborhoods in the city, has recently been restored from a concrete-lined channel to its natural flow. Now green public space surrounds it, and both the changed space and programming facilitate community-building and placemaking. The water itself is cleaner with this transformation, opening more doors to swimming opportunities. While residents may feel a stigma around going to a cooling center on a hot day, Mandi McAlister of nonprofit Hummingbird MKE says, there is no such baggage for taking a walk by the water or wading in. One idea that Mandi McAlister of nonprofit Hummingbird MKE suggested in an interview, to combat the largely obsolete idea that the city's rivers are dirty and unfit for swimming, is for someone to test the water quality on hot days and announce whether it's safe to swim in. On the shores of Lake Michigan, the Milwaukee Harbor District has been organizing a summer series of social and cultural events and resource fairs to bring people together by the water, become more familiar with the space, and gain a sense of ownership and community around it. In both cases, building familiarity and ownership and congregating the public whether through changed design or programming bring people closer to the water in every way. This in turn lowers barriers around accessing natural and water features and being able to utilize them to cope with heat. Public and community gathering opportunities are also vital for building community climate resilience, as elaborated on below in the section "Doing the work:

Community engagement."

Libraries, as bastions of public space in an increasingly privatized landscape, contribute to heat resilience in many important ways. Their physical spaces keep people sheltered from the elements, their public programming educates, brings people together, and helps build community, and they provide assistance to visitors who ask to be connected with resources. A participating librarian says, "Libraries are one of the few remaining public places where you can just *be*." They serve as an important safety net and shelter; if there is nowhere else to go, the library is still there.

Plans

Milwaukee and Madison have both engaged in developing plans to prepare for extreme heat. Natalie Meier shares that an extreme heat plan for Milwaukee County was formed as a result of the 1995 heat wave. Eventually, the Extreme Heat Task Force came together, wrote Milwaukee's 2014 Excessive Heat Event Coordination Plan to develop response mechanisms to support those affected by extreme heat.[13]

Milwaukee also adopted the Milwaukee Climate and Equity Plan in 2023, which was highlighted in multiple interviews as an important centering of the connections between equity and climate action and the importance of building racial and economic justice into climate change work. This plan was created through extensive and quality community engagement. It

---

[13] This plan includes coordination with community partners who are directly providing services to unhoused and other at-risk people as well as messaging to enhance public awareness about extreme heat, when conditions become dangerous, and what illnesses are associated with it. Dane County also a similar document: The Dane County Emergency Response Handbook: Excessive Heat Events, released in May 2022. This handbook includes scientific background on meteorology and health impacts, individual risk factors, strategies around education, engagement, direct assistance, policy decisions to be made by county departments, information on response partners, and meteorological thresholds for action (Dane County, 2022).

has the explicit goals of reducing greenhouse emissions, improving racial and economic equity, paying living wages, and recruiting candidates of color, especially youth. It also feels new and exciting: Mandi McAlister of Hummingbird MKE shares, “We didn’t have an example of a climate and equity plan,” and so deciding to create one and following through is something those involved are proud of.

Tree planting

Many actors are involved in tree-planting efforts, including state and local governments, private homeowners, and nonprofits. Increasing and maintaining vegetation is also a key strategy to cope with flooding and stormwater management, and so it is supported by the efforts of groups focusing on these issues as well. Each actor may take on duties of education around tree planting and maintenance, the physical work itself, and engaging communities about their needs. Difficult questions arise around logistics, responsibility, labor, and ownership of tree planting and maintenance. Many properties are renter-occupied, and when renters are asked to put in the time and resources needed to take care of new plantings that will take years or decades to mature, who of the current residents will still be here to enjoy the benefits of a mature tree canopy?

It is important to note that more trees are not always wanted, even if they would bring shade and cooling. In Milwaukee, some residents have expressed a preference for unobstructed sightlines and the sense of safety that these generate, which more greenery would hinder. Additionally, to emergency services, trees can be hazards or obstacles, posing the risk of falling on homes and power lines during storms. The complexity of these perspectives emphasizes the importance of not applying an action such as tree-planting as a panacea, but instead meaningfully engaging with residents to understand what matters to them and how to achieve these goals together.

Heat-specific actions

While a number of actions that address heat vulnerability and build resilience are not exclusive to heat, some very important ones are. Deriving and sharing information such as forecasts, warnings, messaging about heat safety, how to recognize the signs of heat stress and act appropriately to different levels of severity, and what to do to stay cool are all essential to spur adaptive actions. Similarly, building datasets to help inform action is needed as well; little is known about rates of air conditioning usage, and when surveys are circulated, the truth is more complicated than a simple, "Do you have air conditioning, yes or no?" Complexities of use are important to know, such as whether this describes efficient central air or if there is an ancient and inefficient window unit in one room, doors remain closed at night, and the unit is too expensive to run unless the situation is dire. Other efforts to gather and visualize data include heat vulnerability indices of the state and county that incorporate socioeconomic, demographic, and meteorological data.

Kate Beardmore, Program Manager of the Department of Health Services Climate and Health Program, names the National Weather Service and local offices as an essential partner in creating tools that support decision makers. She is especially enthusiastic about the new tool HeatRisk, which forecasts heat events and takes into account health-related data and how heat can impact health in order to sound an alert, sharing:

> …folks in Wisconsin are able to use that information. That's been one of the tools that I don't know how many times I've talked to folks in the last two weeks and that's been a tool I've mentioned every time, because I think it allows for so much quick decision making. We can better understand, *Oh, we need to trigger this alert a little bit sooner,* or,

> *We need to prepare for this sooner,* because it just really it adds that that tangible human health aspect to understanding heat risk that I think is so helpful for us to see and better understand.

Messaging and behavior change are also an important part of this work. Much attention is on how to effectively circulate warnings and guidance around heat safety and resources, especially those who are both vulnerable and hard to reach. Several participants shared that they face problems with general disengagement that makes this work difficult. They cited a general cultural information overload, overstimulation, and a shortage of time as potential causes for this; many people are so busy with work and taking care of their families that they do not have time or energy to be receptive and proactive around heat guidance. Some shared best practices for effective communication and overcoming these obstacles include interfacing with trusted messengers within communities to pass along important information, details such as using the phrase “older adults” instead of “elderly,” and in order to avoid alienating potential audience members, not discussing “climate change” but the weather that we are already experiencing, health, and how businesses are impacted.

Community engagement

Community engagement emerged in virtually every interview as an essential part of any meaningful heat action. People can feel like projects are being done *to* their neighborhood, without their input. Past incidents like this have generated a sense of mistrust in the government among residents, so it is important to be thoughtful when stepping in as an outsider, no matter how well-meaning. For meaningful community engagement, one must meet people where they are at: at schools, community centers, wherever people are already spending their time. The exact phrase “Meet people where they’re at” came up in many interviews, especially those with staff of community-based organizations. The importance of trust and communication cannot be overstated. Several Milwaukee-based participants also expressed excitement around the new Community Resilience Ambassadors pilot program, in which community members are made point people around resilience action.

Community building and cultivating youth involvement

Many interviewees emphasized the importance of building community in everyday life, outside of emergencies, to be able to weather those emergencies together. Joshua Parish, Assistant Chief of the Milwaukee Fire Department, says that if people are not checking in on their neighbors as a usual practice, they will not suddenly start on a hot day or during other emergencies. Similarly, recent projects designed to address a dearth of community can help build this resilience by creating public spaces in neighborhoods to invite people to go outside, walk, see local art, explore, join community gardens, and play. This kind of work is full of co-benefits: neighborhoods and public spaces become more pleasant, fun, lovely, lively, walkable, social, and full of art, joy, and discovery, let alone improved health outcomes from climate resilience. Furthermore, peer networks, trusted sources, and known community members are found to be much more effective at sharing information and shaping people's choices than government webpages or social media. Social capital is strongly linked with better flows of information, guidance, and resources.

Getting to know neighbors and building community also happens *through* the work to improve spaces itself. August M. Ball names Cream City Conservation Corps, the Milwaukee Water Commons, other nonprofits, and green infrastructure projects as ways for involved youth and other members to get to know their neighbors and local leaders, build connections and confidence, open doors for them to check on elderly neighbors who live alone, and to see the importance of these connections across generations. Ball says:

> One of the cool things that has come out of the water equity work that MSC is doing and other organizations like Milwaukee Water Commons and other nonprofits is that as we're all collectively doing these green infrastructure projects, both on private and public lands, our students and other folks are getting to know their neighbors more. And so when we get heavy rainfall, flooding, or heat advisories, folks are now feeling more comfortable to check in on their neighbors a couple of streets down. Because they know, say, *Miss Mary lives alone. Let me go check on her. I know that person.* And so I think that neighbors who know each other, who talk to each other, are strong neighbors and community members.
>
> Especially the US, we're conditioned to be very individualistic. We're like, *Oh, I'm not gonna be nosy*. And so it’s especially important for the younger people to see that there's value in them connecting to the adults in their community. There’s a value in intergenerational exchange. In connecting with the little ones that are in their neighborhood, and engaging them, doing some plantings or helping to do the downspout disconnect or playing outside- it’s valuable.
>
> I think it builds stronger communities, and so does getting to know the local leaders within neighborhoods. And there are a lot of retirees who are really active in some of these communities. They're calling people up on the phone and making sure that they're ok, asking if they need anything from the grocery store, or more ice, and I think that's really beneficial.

She also emphasizes the importance of cultivating leaders and youth empowerment. For example, the “toastmaster” is a rotating role in Cream City Conservation Corps, in which youth participants take turns as the point person making announcements, practicing public speaking, and reminding people to hydrate and take breaks in the heat. Developing and encouraging growth is a key part of building sustainability in climate, environmental, and community movements. Cultivating knowledge of and appreciation for the environment in youth, whether they take on a traditional environmental job or not, is an important part of this.

How did we get here? Background, a changing conversation, and the centering of justice

The Wisconsin landscape of heat vulnerability, action, and resilience is shaped by the state's status as a home rule state, recent leadership, and a substantial shift in the way people think about climate action which increasingly centers justice.

Wisconsin is a home rule state, which means that decision-making is up to local governments. This leaves state bodies the role of providing information and guidance but not rules or orders. In this setting, governance must be bottom-up, which grants freedom and flexibility at the local level, but can leave these different actors disconnected. In this context, it takes a concerted and sustained effort to connect and coordinate across local efforts. A broad takeaway from interviews is these efforts have indeed been occurring and are ongoing, with the state Department of Health Services and county Emergency Management offices as hubs of action.

The Walker governorship (2011–2019) greatly shaped the discourse on climate change in Wisconsin, even forbidding usage of the term. It changed the availability of resources to address social needs, and legislation that weakened unions still affects the labor bargaining rights landscape today.

However, a key part of the current landscape is a recently changing conversation. Those currently working around heat have shared feelings of hope, excitement, and activation around being able to help their communities and what they see as an exciting change in the conversation around climate towards holistic wellbeing and justice. The early COVID days have also deeply shaped current action, causing people to rethink and broaden their definitions of what disasters are, and to recenter community.

The summer of 2020, with international attention falling on the Black Lives Matter Movement, served as watershed moment that has been driving more organizations to center justice and equity in climate and environmental action. Mandi McAlister of the Milwaukee-based nonprofit Hummingbird MKE says:

> Recent changes have been encouraging. 2020 was a big year for organizations like this, for everyone to stop and think about the kind of work they're doing. Lots of statements made, lots of people are, making that commitment, missions, programs changing. People are interested and looking for environmental justice consulting. Organizations that would have been more shy talking about justice- now it's part of their mission statement that they're proudly sharing. Environmental organizations are doing environmental justice work, taking steps to be more justice-focused, and are figuring out how to shed the outdated idea of what people think we are. You might end up losing some folks in that change, some may join. You have to be willing to lose some support in order to change for the better. In past we'd want to appeal to everyone, not lose anyone, not lose any funding, but now, we feel like that's not right, this is what we need to do.
>
> We need to be building community, connecting folks to work already being done, and dismantling racism, which is at the root of the inequities we're seeing. And we need to be critical about how white supremacy is showing up in our organizations. Organizations want to diversify, but they need to ask what about their organization is making it like this, not just try to hire new people without addressing the work climate.

This sentiment was apparent across interviews, and part of this work that interviewees discussed was tackling problems within organizations themselves, taking on white supremacy cultural elements like savior complexes, where some employees feel like they know best and their job is to impose and enforce what they see as the needed solutions, and other cultural elements of perfectionism, urgency, and hyper-individualism.

An encouraging change that intersects with this trend is increasing representation. A participant working in an environmental and equity-focused nonprofit shared:

> More people of color have entered the environmental field, and I feel like that also has changed the way that we're talking about things and the way that we feel connected to things and spaces. Because when I was young and I would think of an environmentalist or a naturalist, I would think of, like, a white guy in khakis going on a hike. It seems like especially in Milwaukee, there's a growing number of BIPOC folks who are entering the environmental field. And it's all about representation, right? If you see someone who looks like you, sounds like you, and has a similar background as you, I feel like you're automatically going to be more connected to them and want to know what it is that they're working on, what it is that they're talking about, and they have more of that personal connection to it too. So I feel like that also has played a huge role.

Another change experienced in recent years is the shift from climate change being a problem of the future to one of the present, and the feeling that heat is not just a professional concern, but a personal one. Many interviewees shared that they do not have air conditioning in their homes, and summer can be a grueling time for them. Living any higher than a first-floor apartment makes their living spaces often much hotter than the surrounding outdoor air. Climate change can no longer be considered only an issue of the distant future, but it is something that is being felt now. Heat has become not just about coping with emergencies, but making major life decisions like where to move, given current climate and expected intensifying heat in the future and what the person is willing to endure. Some older adults are realizing that they are a vulnerable demographic, and they need to act more cautiously and be cognizant of their personal heat risk. When a medical condition makes someone more susceptible to overheating, decisions need to be made every day around risk tolerance, where there is little guidance given beyond “stay out of the heat” but not what exactly this means, what is a tolerable range and at what point conditions become dangerous, or how to go about it.

Similarities and differences between governmental and community-based organizations

Originally I was looking for similarities and differences between government and non-government groups as places to start, seeing them as top-down and bottom-up respectively, but it turns out that there has already been a lot of community engagement from governmental organizations and a lot of connections across different groups, both government and non-government. This is largely driven by Wisconsin's status as a home rule state: because state bodies such as the Department of Health Services can only act in an advisory position, they have been conducting outreach to community-based groups and different municipalities to find how they can best provide guidance and meet needs. As a result, perspectives from both government and non-government actors on extreme heat action are far more similar than different. Both are very interested in gathering and sharing best practices, education, and having a centralized source of information. Additionally, virtually all of them wanted to know what other actors are already doing around heat and who is interested in collaboration.

Granted, some of those working in government placed a greater emphasis on risk communication and behavior change: on how do we put together an information guide, a to-do, a checklist, a toolkit, on how do we get people to act differently during emergencies, how do we carefully discuss climate change in a way that does not alienate people on the other side of the political aisle. They are also especially interested in gathering more data. In contrast, community-based organizations more frequently brought up building connections between people, access to outdoor and public space, training future leaders within the community, especially youth, and placemaking.

Summary

Similar to how heat vulnerability manifests across the home, workplace, and third places, work to address vulnerability and build resilience takes many forms. These can include improving housing security and energy efficiency. Workplace plans that formalize frequent breaks, hydration, restroom access, illness reporting, and heat thresholds for escalating actions can help address issues at a workplace level. Social isolation contributes to heat vulnerability, and so therefore efforts to build community, public spaces, and programming to facilitate gathering are all seen as ways to help improve vulnerability and health outcomes. Writing and implementing plans, planting trees, developing and utilizing forecast tools, community engagement, community-building, are also part of this. The actions named in interviews are not necessarily *about* heat, but they all contribute.

Wisconsin's status as a home-rule state leadership and recent leadership both greatly shape the current landscape of heat action. The conversation has been changing in recent years with a greater focus on justice and equity in climate and environmental action and planning, the importance of community, and climate change as a present and personal issue.

4.3 Practitioner insights into contextual vulnerability and implications

Among interviewees, there is consensus around who the most vulnerable populations to heat are and the importance of prioritizing them during crises and in climate resilience planning. These populations are agreed to include the unhoused, very young, older adults, people who work outside or otherwise in the heat, those who have health conditions that may be exacerbated by the heat, those of low socio-economic status, racial minorities, those facing language barriers, undocumented immigrants, and the socially isolated.

Also deeply informing the conversation and current actions is the understanding of unequal exposure to heat as injustice. Far from random, the current status quo of who lives, works, and plays where and if these places are air conditioned, shaded by tree canopy, or surrounded by concrete is embedded in historical and racist processes of exclusion, extraction, disinvestment, redlining, and displacement. Given that access to air conditioning during extreme heat can be lifesaving, and that running an air conditioner can be prohibitively expensive to many, money is a key resource to be able to cope. Therefore, processes of economic exploitation and widening of economic disparities in turn contribute to extreme heat vulnerability.

Many of the points that participants raised in discussing the contributors to heat vulnerability, ways it manifests, and actions to mitigate it are facets of contextual vulnerability. People whose work intersects with heat discuss factors that go beyond our typical understanding of heat exposure. This includes the unique histories of each place that influence the present, such as lifeguard shortages in some neighborhoods in Milwaukee along lines of race and income. In interviews, people contributed and raised issues that aligned with their areas of expertise: for example, those with insights into the systemic obstacles that unhoused people face proposed housing as a way to address underlying vulnerabilities; those who work with youth of color are attentive to asthma attacks on hot days, affordability of inhalers, and racially aligned lifeguard shortages and pool closures.

Participants' unique suggestions and insights often came from their roles in their organizations, which supports the need for integration across sectors in order to share these insights with others who may be well-positioned to help address them. Correspondingly, because of intense siloing between sectors, much potential synergy is lost. This siloing is daunting because it is widespread and structural, but it also manifests at the individual level. Many interviewees initially stated that they did not feel like experts in heat, that it did not come up in their work, and wondered if they were the right person to talk to, but they all had incredible insights into these interactions, drivers of different kinds of vulnerability, and on how we can act going forward. This reveals a striking limitation: if people do not see their work as contributing to heat preparedness or being a part of climate resilience, as being something that can potentially save lives,[14] then the choices they make in this work may not carry the same weight as those made with this understanding. We are siloed on multiple scales, and therefore our understanding of how heat vulnerability manifests and how we can act to address it is limited.

However, many barriers impede addressing the many aspects of and underlying contributors to heat vulnerability and constrain heat-oriented actions to low-cost, high-impact damage reduction strategies. If we could overcome these obstacles, overcome siloing to achieve full cross-sectoral collaboration, and address underlying vulnerabilities, a much more far-reaching, holistic resilience would be achieved.

4.4 Obstacles and calls to action

Understanding what obstacles impede action can help us better overcome them going forward and respond to calls to action from those contributing to heat resilience. Obstacles and constraints arise from both the nature of heat itself and societal processes that drive people into general vulnerability, both of which are difficult for individuals and our governing structures to overcome. They include overwhelmed social safety nets, insufficient funding, staffing, and resources, limitations in how emergencies are defined and what mechanisms are in place for

---

[14] (e.g., through helping someone able to affordably cool their home, or access water to safely swim in, or building intergenerational connections between neighbors)

dealing with them, a lack of clear responsibility and leadership, the nature of heat as an ephemeral problem in a "cold" state, and tradeoffs around scale of action. Similarly, many ideas, suggestions, action items, and asks that people have involve not just heat or climate resilience itself, but ways that we as communities and a society can better take care of each other's basic needs, build community, and collaborate and share information.

Overwhelmed social safety nets

Social services that are expected to help people are overstretched and underfunded, leaving people vulnerable both in general and more specifically to extreme heat. Homeless shelters are no exception. They are meant to provide basic needs, shelter people from the elements, and help them on their way to stable housing and income, but they are facing incredible difficulties. Between our interview and this writing, Chambliss has left The Beacon for reasons stated in the WMTV piece "Former Beacon staff member calls out local leaders for inaction on homelessness crisis" (Nijhawan, 2025b). The underlying message: Staff are not being given what they need to do this work. With too little support, staffing shortages, and bureaucratic red tape that impedes larger changes, no matter how hard staff work and how many people they help, they simply cannot keep up with demand. He says:

> When you have 200 to 300 people in a tiny area, all with addiction or mental health or disability or aging issues, you need to have medical professionals there and crisis professionals there, and case workers there, and we didn't have any of those on staff. […] (Furthermore,) when you're not addressing the needs and you're not getting people stabilized and out of The Beacon, they just start to pile up, (and the situation worsens. The municipal government) …found $300 million for the new jail. They found tens of millions for this public market … they're not prioritizing housing (Nijhawan, 2025b).

Another article, “Cold weather strains Madison’s homeless shelters, with limited resources increasing tensions,” links the situation at Madison homeless shelters with extreme weather. Understaffing and burnout of staff are named as chronic problems in Madison homeless shelters. For visitors, there can be an unfeasible number of hoops to jump through to be able to stay or receive help, but they all need stability and adequate support to be able to gain stable housing. The Beacon, which was designed for a daily maximum capacity of 150 people, had an average of 243 daily visitors in 2024 (Nijhawan, 2025a).

This crisis of insufficient resources to address need is widespread and has far-reaching impacts. Wick at Madison Public Library says that librarians refer people in need to resources, but those resources are all too often tapped, leaving further action unclear:

> Librarians are information professionals. We can find out a lot of resources. But in a lot of ways, we're also like 211 (as a clearinghouse that can refer people to these resources). There's only so much capacity in the programs that we're referring people to. Often we hear that most of the programs and resources are full. They’re at capacity. There aren’t beds available, funds for things like eviction prevention have dried up, and people that just don't have other options. So we’re left in the position where we can point you towards the information, but if the resources aren't available, all we can give you for now is the space inside the library while we're open.
>
> Many of us are essentially doing a kind of social work, without the official training. The CARES program (Community Alternative Response Emergency Services) has been amazing. But it’s just that the resources aren't available. So it’s hard, telling someone there are no beds available and then going home at night, thinking, “I don't know what this person's doing tonight.”

Furthermore, as one of the last remaining public spaces, libraries serve as lifelines for people with nowhere else to go, but their ability to help is limited by the capacity of these other safety nets and services themselves. Wick says:

> We’re the safety net when all the safety nets fail. (…) The library can’t systematically solve a housing crisis or mental health crisis, but we are a social safety net to catch people when we’re open. We have childcare and story time, and we serve as a safe space. We can respond to these structural crises in a way

> that's effective on the day that we're open; we hope that when people are here, they feel safe.

Other organizations reflect on how they are forced to pick up the slack and try to fill gaps despite how daunting this task is. Meier of Milwaukee County Emergency Management says: "It's not something a food pantry of homeless shelter can solve. It's not a charity's job to solve poverty at the root." A participant who works in a nonprofit that arose in the first place to address unaddressed needs and to in gaps around community health, says: "The goal would be for us to not have to exist."

Funding

Funding, resource, and staff limitations were a near-universal theme as impeding action to address general and extreme heat vulnerability. There is a general scarcity of funds, and operations have had to make do with less. Grants sustain a vast amount of climate and heat work that both government and non-government organizations do, and the mechanisms for applying for and receiving grants greatly impact these organizations and what they can achieve. Siloed organizations with aligned missions that do not know about each other or do not collaborate are structurally forced to compete with each other for limited funds in a zero-sum game. However, if organizations do know about each other and coordinate to apply for funding, they may both benefit.

Homeless shelters, libraries, church community spaces, and other privately volunteered spaces all serve the critical need to let people in to stay cool in severe heat, but limitations around hours, staffing, staff training and preparedness for emergency situations, and getting the information out all shape their effectiveness. Wick at Madison Public Library shares that libraries are often put into a place where they have to function *as* emergency services, but they are not formally considered to have this role and do not receive the resources to respond accordingly. She shared that a new library is in the works, and early in the conversation, librarians asked if it would be possible for it to have a generator. Without one, in the event of a power failure, libraries cannot provide a safely warm or cool environment, let alone the usual services that patrons count on. However, a generator for this new building is not in the budget. Wick says:

> This doesn't make sense; this is a commitment we're making for future city facilities, to have a building standard for energy. Considering the services that this building will likely be called upon to perform in the future, it would make so much sense to have an official designation that essentially says, "You will be an official cooling center, and we will build the infrastructure so you can *be* that," (generator and all.)

She also shares how funding limitations keep people from being able to be more proactive and more effectively address large-scale problems:

> We can either address the need right in front of us, or we can try to put this small amount of money towards addressing a root cause. But there's not enough capacity, usually in terms of the staffing or the money, to really make a dent in the root cause sorts of issues. So then we get trapped in the cycle of, you know, when people talk about just putting band-aids on things. Well, yes, I know what you mean (about needing to address root causes), but also a person is bleeding in front of me, and I only have one band-aid. I'm not going to tell the person in front of me, "I'm sorry, you don't get the band-aid, I'm going to give it to someone several years in the future."
>
> The climate conversation also can feel like, "That's tomorrow's problem." And I'm doing everything I can to just survive today's problem. But we know it's just getting worse, and more problems are coming. But nobody has capacity to do things like set aside staff time, to have those discussions and really be proactive. It just takes an amount of capacity that that we don't have because we've perpetually dealt with being underfunded.

Chris Litzau, of Milwaukee-based conservation work with unhoused veterans, says on the issue of funding and capacity: “You do what you can with the resources you have, or it doesn't get done, ever.”

“That’s not an emergency as we define an emergency”

The way that emergencies are defined and that emergency services are set up to deal with them leave enormous gaps around the issue of extreme heat. Kathy Kuntz, Director of the Dane County Office of Energy & Climate Change, shares that in a heat wave following a storm that knocked out power in Madison: “911 was getting calls from people saying, ‘*My neighbor is 92 and doesn’t have power- what do I do?*’ And 911 responded, ‘*That’s not an emergency as we define an emergency*.’ This is emblematic of a wider problem where our protocols are based on narrow definitions of what qualifies as an emergency and therefore “earns” what kinds of interventions. Our funding structures in the United States are currently set up to rigorously assist with some kinds of emergencies while providing no help for others. Natalie Meier of Milwaukee County Emergency Management explains that the federal government is not designed to respond to or prepare for extreme heat; it cleans up after disasters. In order to be considered as an emergency that qualifies for federal assistance, an event needs to reach a certain threshold of physical, property damage. This process disproportionately offers assistance to those with more physical assets and neglects those who may be less wealthy, whose losses do not “count.” Heat, often referred to as a “silent killer,” does not cause the same visible and infrastructural damage as flooding or tornadoes. There have been discussions of changing the rules at the federal level to qualify heat emergencies as federal emergencies to obtain local resources. If this happens, it will be momentous. Because FEMA is largely designed to respond to disasters rather than prepare for them, it also does not support proactive measures that would save lives, such as investment in public programs along the lines of housing quality, weatherization, and energy assistance. Therefore, any change in protocol that defines these measures as lifesaving and as disaster preparedness would vastly increase the resources available to reduce vulnerability overall and to emergencies.

Extreme heat is no one's problem, so it's everyone's problem: need for collaboration and coordination

A universal theme across interviews was that extreme heat is a small part of many people's very full plates, and they have a limited amount of time, money, and resources to address their many tasks. This leaves heat on the backburner if it is an agenda item at all. Because Wisconsin is a home rule state, state-level bodies may know little about the capacities and needs of municipal rural health and emergency departments, especially ones that preside over lower populations and have less staff, funding, resources, and overall capacity. Coordinating and participating in collaborative efforts are opt-in, and given that heat historically only becomes dangerous a handful of days a year, it makes sense that overstretched offices will have their priorities elsewhere. But all of this contributes to siloing, which was named as a problem in most interviews. People need to know what harms are already being felt, what action is happening, and to share best practices in order for us all to move forward and improve the state's heat resilience. Without communication, it is difficult not to waste time reinventing the wheel, spending valuable time and resources doing what another actor or municipality or community organization has already figured out. This siloing in heat resilience work further stresses the importance of this research, sharing out results, and continuing to share what different actors are doing and opportunities for coordination between them.

Furthermore, because extreme heat is a complex problem that pervades many aspects of society and our built environment, there is a sense of diffused responsibility. Meier at Milwaukee County Emergency Management, says, “No one is owning the problem. In theory it’s FEMA’s, but at the local level it’s just being passed around.” There is no owner, and individuals feel overwhelmed and unsure where to start on the problem. Because there are so many aspects of heat preparedness and guidance, people can be uncertain about the truth of various claims and not have the capacity to look into each and every one, such as widespread uncertainty around at what point it becomes unsafe to run fans indoors with all windows closed. The labor needed to go after these threads and to become a convener, to connect and collaborate across levels of government, communities, and stakeholders, is intimidating to say the least. My own experience in reaching out and having these conversations has been exciting, activating, and full of gratitude, but the amount of time needed to at least begin to do this work “right” is truly immense (see Figure 3.4 in Appendix 2). If it is not someone’s job description to do so, the work can only take a backseat. Furthermore, many report feeling a sense of paralysis in which they do not feel like enough of an expert to take more initiative, that they are not the right person to lead something. But as Chris Litzau says in response to this vacuum of official responsibility and leadership, both to myself and to my potential audience: “You have permission [to step up and do what you can].”

“Wisconsin is a cold state” - difficulties building institutional knowledge and action for an ephemeral problem

Emergency management and public health offices are far more used to helping people cope with extreme cold than extreme heat, but the increasing frequency and severity of heat is driving people to make it more of a priority. Natalie Meier shares that in Milwaukee County, extreme heat planning gained momentum following the 1995 heat wave, but then enough years passed without a similarly severe heat event that the plan left most people's minds; institutional knowledge waned, people retired or left for other jobs, and then much of the work was undone. However, more frequent severe heat events have helped to sustain heat preparedness in recent years, as there is now more of an ingrained cultural and risk-oriented understanding that the problem is here to stay.

As heat events arise and recede, there is also a seasonal flow of capacity for many organizations: those with outdoor work or programming ramp up in summer, and so capacity to work on issues outside their main focus lessens when the heat is highest. Grant cycles determine when people are laser-focused on the task of obtaining funding to begin or continue projects. For positions and organizations that quiet down in the cold season, when there is more capacity to think about and prepare for heat, it easily vanishes from people's minds as we dream of summer heat as relief from the frigid winter.

Scale tradeoffs

Another theme that arose is that of scale tradeoffs: that one has the most control and agency at the municipal and community levels, but that resources and scalability of actions from the federal level would be able to make an immense amount of change if mobilized. Danika Hill-Paulus, Environmental Disease Control Specialist for the City of Milwaukee Health Department, and Co-Executive Director of MKE FreshAir Collective, says:

> There's a paradox where the federal government has the most funding, but the local government knows their city and county. They know the problems, and they know where funding should be prioritized. In preparedness work, the local government has to declare an emergency, then go to the state, then to the federal level, and assistance trickles back down. There are some advantages to Wisconsin being a home rule state, because people at the local level do know it in a way that the state or federal levels won't, so between that and this drawn-out process, there are pros and cons.

This scale tradeoff also manifests in implementing policies and protections. Janes Ugoretz, speaking from experience with farmworker coalitions across the country, says that people can make only so many changes on a farm-level; market pressures, state-level government, and federal government are out of an individual workplace's control, but they have such an impact on people's safety and what choices farmworkers are able to make.

Additionally, on the subject of scale and federal support: an important note is the timing of my interviews. I conducted most of them in summer 2024, when there was a great deal of excitement and positivity around IRA grants. The situation has drastically changed in 2025, and so I want to acknowledge that much of this funding has dried up, and sentiment and optimism around heat action may have greatly changed. It is important to note that research like this, into a topic so quickly changing as the current state of climate adaptation, will only ever be a snapshot; in the time it takes to write up, the situation may well have completely shifted. Therefore, if one waits and continually rewrites their findings to incorporate the latest changes, the work will never be done, and it will never be shared with those who can benefit from and build upon it. The vast difference between summer 2024 and 2025 also drives home key takeaways around scales of action and tradeoffs therein: if the federal level fails us, we can go to the state, to municipality level, community-based groups, and neighbors. Funding from the highest level of government makes all of this work so much easier and far-reaching, but we still have paths ahead of us that we can pursue in its absence.

Calls to action

In my interviews, I asked what participants want to see addressed and what kinds of futures they want to see as part of building heat resilience. Like how there are many ways that people are contributing to heat resilience and many actions that deal with underlying vulnerabilities are part of this work, many of these calls have to do with these underlying vulnerabilities as well, and some do address heat but also have co-benefits around extreme cold, financial wellbeing, and community-building. These ideas and asks are summarized below in Table 3.2:

Call to action	**Source (Sector)**
Collaboration	
▪ "The future is collaboration"	Municipal (libraries)
▪ A current organizational map of who is involved in heat action	Public health
▪ One centralized place to access resources and information on heat preparedness	(near-universal)
▪ Local responses in both climate change mitigation and adaptation, and sharing of resources across the state to help support each other	Public health
Affordable necessities	
▪ Affordable housing	Nonprofit homeless shelter
▪ Affordable inhalers/epipens; having extras on hand in case of emergency	Environmental / equity-focused nonprofits
▪ Energy assistance for cooling homes, not just for heating them	Environmental / equity-focused nonprofit
▪ Weatherization services; paid job training to engage residents	Environmental / equity-focused nonprofit

▪ Better incentives for landlords to keep homes in good condition and improve HVAC systems, thermal safety and comfort, and energy efficiency	Environmental / equity-focused nonprofit
Worker protections	
▪ Farm safety policies – see Hot Potato toolkit for examples	Farmworker coalitions, extension
▪ Increased capacity for safety inspections; incentives that better support the protection of workers than employers' profits alone	Unions
▪ Access to water and restrooms (also important to public spaces)	Farmworker coalitions, extension
Improving access to cool spaces	
▪ Test the water quality on hot days and announce whether it's safe to swim in	Environmental / equity-focused nonprofit
▪ Free transit, busses better able to serve as cooling sites; increasing awareness of the potential of transit as shelter from the elements	Emergency management
Public/general	
▪ "Being better connected with your own community, own neighbors, so you know who's in danger and can look out for one another. If you know a hot day is upcoming, can you invite a neighbor to stay with you, offer a ride? How can we each offer what we have to help out those who are most vulnerable, and how can we better know who around us is most vulnerable?"	Environmental / equity-focused nonprofit
▪ To support libraries: show up, use resources, be vocal to representatives about their importance, support your community so libraries don't have to be as stretched thin with damage control	Municipal (libraries)
▪ Share out information on local programming, government/emergency warnings and guidance, etc. to your networks; if possible, help translate these messages into more languages	Emergency management
▪ In emergencies, register as a volunteer so we better understand our numbers and can compensate people and provide worker's compensation if anyone gets hurt. Communicate with emergency management what efforts you are already doing so they do not unknowingly do the same now-redundant action	Emergency management
▪ Passive cooling and reducing the emissions from air conditioners; sustainable solutions wherein actions to address heat today do not worsen the situation in the future	Emergency management
▪ Pay people for their work. Pay people for doing what we say needs to be done. Something can start as a volunteer effort, but to be sustainable, you need full-time staff	Emergency management; public health;

	environmental / equity-focused nonprofits
▪ There is a striking lack of data on air conditioning prevalence or thermal comfort in spaces such as residences and schools. With these datasets, most likely to be acquired through surveys, we can better identify hotspots of vulnerability	Public health
▪ Communication and awareness of programs where assistance exists, such as if there are options for helping people access inhalers and epipens, and about utilities shutoffs not being allowed during extreme heat events. (as the utilities shutoffs example illustrates)	Near-universal
▪ "We need folks in all corners of all industries thinking of themselves as environmentalists, as folks who are championing this planet, the community, for generations to come in, whatever career trajectory they're going into, whether that's music, art, architecture, fashion, you name it. We need storytellers. We need data people, we need everyone."	Environmental / equity-focused nonprofits

Table 3.2: Calls to action from participants, laid out by theme and sector.

Participants also recommended resources to boost. These include general resource hubs, information and trainings from emergency- and disaster-focused organizations, and guidance on heat-specific workplace safety practices, and they are listed in Appendix 4.

4.5 Revisiting heat vulnerability and adaptation literature

In this chapter, I focus on contextual vulnerability to heat and the processes of building adaptive capacity and overall resilience. Conventional approaches to studying heat focus largely on outcome vulnerability. Many involve spatial analyses on where elevated temperatures occur and what physical environmental characteristics and what demographics are associated with those places (Jonsson & Lundgren, 2015; Romero-Lankao et al., 2012); many investigate differential health outcomes to heat and links to sociodemographic factors such as age, race, gender, and income as well as comorbidities, and place of residence (see review in Arsad et al., 2022; Basu & Samet, 2002; Basu, 2009). Correspondingly, discussions around building heat resilience, preparedness, and adaptive capacity are generally heat-specific; they are about lowering outdoor temperatures, increasing greenery in providing temporary refuge from the heat via cooling shelters, and providing guidance and resources that help people stay cool and recognize and respond appropriately to cases of heat-related illness. While this work is essential, what is missing is engaging with factors not directly tied to heat exposure and response that do shape heat vulnerability within communities exposed to heat.

The importance of actions that do not necessarily concern extreme heat itself as part of heat action has arisen in other interview-based work on climate adaptation. Conversations with residents in metropolitan Phoenix, Arizona through neighborhood design workshops "revealed deep inequities and communication/relational barriers that transcend specific urban heat issues and show how any suggested urban heat mitigation must also address issues of poverty, distribution of city services, and access to public infrastructure" (Guardaro et al., 2020). Boeckmann (2016), studying local heat action in Japan, calls actions that contribute to heat resilience without describing themselves as such "hidden adaptation practices" and reports that they are plentiful across the country (Boeckmann, 2016). Another study, gathering perspectives from local stakeholders around heat adaptation in Sweden including planners, healthcare municipal staff, and members of vulnerable populations, reported that participants revealed a vast wealth of knowledge about root causes of vulnerability and the role of social factors. They too named non-heat-related factors such as economic and livelihood as contributing to vulnerability and as being essential components of adaptation. They also emphasize the importance of contextualized knowledge and assert that it is vastly underutilized by research and in policy-making spaces (Jonsson & Lundgren, 2015).

Other shared themes across studies include difficulties with reliable government funding for heat and climate action (Boeckmann, 2016; Huang et al., 2011; White-Newsome et al., 2014). As in Wisconsin, public health departments are leading heat adaptation in Japan (Boeckmann et al., 2016). Interviews of climate adaptation scientists and practitioners across the globe reveal tensions of scale in actions around adaptation, unclear delineations of responsibility, and constraints at different scales of government. One concern is that "framing adaptation as solely a local issue can shift responsibility disproportionately onto local actors, enabling higher levels of governance to evade their obligations" (Amorim-Maia & Olazabal, 2025; Nalau et al., 2015).

Guardaro et al. (2022) emphasize the importance of qualitative data to build an understanding of adaptive capacity to heat, arguing that aggregated data does not address the processes that enable or constrain it, while talking to people about their experiences reveals a vast wealth of knowledge. As in our own study, the authors report that "participants often stated that they did not have much to say about heat. This claim ultimately proved to be untrue" (Guardaro et al., 2022). In both works, people are experts in their own experience, but too often discount this knowledge, seeing it as separate from heat rather than inextricably entwined. This can initially be a barrier to such conversations, if people dismiss their insights and do not share them; but if it is understood, we can overcome it by framing such knowledge as an indispensable part of heat vulnerability and action.

While this is not the first work to find these major themes, it is meaningful that they were independently found in Wisconsin. This research contributes to this small but vital and growing body of literature, especially through discussing the characteristics of governance, the nonprofit landscape, and legal landscape affecting heat vulnerability and action that are specific to Wisconsin.

5. Conclusion: Thousands of problems, thousands of solutions

In a 2000 essay, award-winning speculative fiction writer Octavia E. Butler shared a conversation with a student who asked about how her books seemed to predict the future. She wrote:

> "I didn't make up the problems," I pointed out. 'All I did was look around at the problems we're neglecting now and give them about 30 years to grow into full-fledged disasters.'
>
> "Okay," the young man challenged. "So what's the answer?"
>
> "There isn't one," I told him.
>
> "No answer? You mean we're just doomed?" He smiled as though he thought this might be a joke.
>
> "No," I said. "I mean there's no single answer that will solve all of our future problems. There's no magic bullet. Instead there are thousands of answers– at least. You can be one of them if you choose to be." (Butler, 2000)

This message has become very important to me personally, both as a scholar and a human being navigating the daunting reality we find ourselves in and potential futures ahead. It also resonates deeply with findings across my interviews: with the many problems that feed into heat vulnerability, with the many solutions that people are enacting, and with the need to take part and understand how our part contributes to the whole.

To summarize my results and analysis: Heat and heat vulnerability are connected with many parts of society and daily life across home, work, and third places. In Wisconsin, there is a substantial amount of ongoing work across sectors around addressing heat vulnerability and preparedness, and these many forms are apparent if one understands heat to be about more than just the physical temperature. People who do this work have a number of proposed actions to further build resilience to heat, many of which have to do with addressing underlying social and/or economic vulnerability rather than heat itself.

Narrow definitions of extreme heat vulnerability constrain our understandings of the processes that contribute to it and the solutions that we can imagine as being useful to address it. Traditionally, extreme heat has been discussed with a rather narrow definition, focusing mainly on outdoor temperatures, individual risk factors, and exposure. Heat is an episodic threat, and interventions tend to address direct health outcomes during extreme heat events rather than the broader quality of life issues that contribute to heat vulnerability. Conversely, contextual vulnerability offers a holistic understanding of what processes create heat vulnerability, and practitioners have many insights in how this manifests. Broadening the issue of heat to this perspective, we can see both many more problems and many more solutions and exciting work that is already underway. When asked about how heat touches our lives and how we can act to address it, participants' comments were not only about heat. They were about the housing crisis, youth empowerment, the importance of getting to know our communities and neighbors, supporting our libraries, and so many other parts of society and everyday life. No one I spoke with had extreme heat at the top of their job description, but everyone interacted with it, saw heat vulnerability holistically, and was taking it seriously in context. One promising manifestation of this sentiment is Milwaukee's Climate and Equity plan, in which community input drove the plan to center racial and economic inequity and improve general wellbeing alongside more conventional understandings of climate action and adaptation. The existence of this plan shows that there is a collective vision that climate action and equity must go together, and that there is will to act towards this vision.

By investigating not only outcome vulnerability—what we can see in numbers, distributions, and unequitable impacts—but also contextual vulnerability—what processes have brought us here—we can see the importance of looking beyond heat and heat-oriented action itself and into all sorts of ways that we can take care of each other and reduce underlying vulnerability. This has important implications for planners, climate experts, nonprofits, policymakers, funding providers, and more. Coordination across sectors, as well as attention to basic human needs and the systems that may either address or neglect them, will make us all better off both in general and when confronted with potential disaster. Going forward, it is essential to frame, argue for, and pursue basic needs such as housing security, financial wellbeing, social safety nets, and community as a necessary part of climate action and heat resilience. We must overcome daunting obstacles and the siloing of actors. If we do not, we will miss opportunities to address the many facets of heat vulnerability and improve human wellbeing.

Working to house people builds heat resilience. So does increasing people's access to water, nature, and community. So does understanding the pressures and regulations around labor and acting to protect workers. Many people in Wisconsin are working to address needs that one may not immediately think of as being about heat, but they absolutely do contribute to heat preparedness. Once you know to look for this, there is much good news to find, and there are many things that each of us can do. But it is essential to understand that these are all components of climate adaptation, of addressing climate vulnerability and building heat resilience.

Going forward, there is much opportunity and need for further work. This study's scope is meant to be wide in order to highlight overall patterns and interconnections, which means that there is much room to further investigate threads. I spoke with people working in hubs of communities, knowledge, and services, as they had many insights into different forms of heat resilience action, systemic problems, and the limitations of their roles. Future research can build on this by more directly engaging with residents and members of vulnerable populations about their personal experiences through methods such as surveys, focus groups, and interviews. Furthermore, because my interviews were largely based in Madison and Milwaukee, gaps in knowledge around rural heat vulnerability and action remain.

I am in the process of sharing what I have found back with collaborators and interview participants, and I aim to continue strengthening these relationships, build knowledge together, and contribute my capacity to help coordinate and connect across sectors. I am indescribably grateful for the time, expertise, and patience of everyone I spoke to over the course of this research. Thank you for doing the good work, and thank you for showing what the way forward can look like.

6. Works Cited

Adams, W. C. (2015). Conducting semi-structured interviews. *Handbook of practical program evaluation*, 492-505.

Ahmed, N. M., & Abd el Hamid Aref, A. (2019). In transitional periods how does bureaucracy work steadily?. *Review of Economics and Political Science*.

Amorim-Maia, A. T., & Olazabal, M. (2025). Beyond adjustment: A new paradigm for climate change adaptation in a complex world. *Global Environmental Change*, *93*, 103027.

Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., ... & Tangang, F. (2022). The impact of heatwaves on mortality and morbidity and the associated vulnerability factors: a systematic review. *International journal of environmental research and public health*, *19*(23), 16356.

Balvanera, P., Calderón-Contreras, R., Castro, A. J., Felipe-Lucia, M. R., Geijzendorffer, I. R., Jacobs, S., ... & Gillson, L. (2017). Interconnected place-based social–ecological research can inform global sustainability. *Current Opinion in Environmental Sustainability*, *29*, 1-7.

Barrow, M. W., & Clark, K. A. (1998). Heat-related illnesses. *American family physician*, *58*(3), 749-756.

Basu, R. (2009). High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. *Environmental health, 8,* 1-13.

Basu, R., & Samet, J. M. (2002). Relation between elevated ambient temperature and mortality: a review of the epidemiologic evidence. *Epidemiologic reviews, 24*(2), 190-202.

Boeckmann, M. (2016). Exploring the health context: A qualitative study of local heat and climate change adaptation in Japan. *Geoforum*, *73*, 1-5.

Bouchama, A., & Knochel, J. P. (2002). Heat stroke. *New England journal of medicine*, *346*(25), 1978-1988.

Burch, T. (2025, May 6). Madison officials urge cautious swimming at city beaches during summer season. *The Badger Herald (Online)*. https://badgerherald.com/news/madison/2025/05/06/madison-officials-urge-cautious-swimming-at-city-beaches-during-summer-season/

Bührle, H., & Kimmerle, J. (2021). Psychological determinants of collective action for climate justice: Insights from semi-structured interviews and content analysis. *Frontiers in Psychology*, *12*, 695365.

Brown, P., Mayer, B., Zavestoski, S., Luebke, T., Mandelbaum, J., & McCormick, S. (2003). The health politics of asthma: environmental justice and collective illness experience in the United States. *Social science & medicine*, *57*(3), 453-464.

Brown, R. H. (1995). Natural Disaster Survey Report, July 1995 Heat Wave. *National Oceanic and Atmospheric Administration*.

Butler, O. (2000). A Few Rules for Predicting the Future: An Essay. *Essence Magazine, 31*(1).

Canaday, F. T., Georas, S. N., & Croft, D. P. (2024). Examining the impact of air pollution, climate change, and social determinants of health on asthma and environmental justice. *Current Opinion in Pulmonary Medicine*, *30*(3), 276-280.

Centers for Disease Control and Prevention. (1996). Heat-wave-related mortality--Milwaukee, Wisconsin, July 1995. *MMWR: Morbidity and mortality weekly report*, *45*(24), 505-507.

Chakraborty, R., & Sherpa, P. Y. (2021). From climate adaptation to climate justice: Critical reflections on the IPCC and Himalayan climate knowledges. *Climatic Change, 167*(3-4), 49.

Christenson, M. L., Geiger, S. D., & Anderson, H. A. (2013). Heat-related fatalities in Wisconsin during the summer of 2012. *WMJ, 112*(5), 219-223.

Dane County. (2022). Dane County Emergency Response Handbook: Excessive Heat Events.

Diezmartínez, C. V., & Short Gianotti, A. G. (2022). US cities increasingly integrate justice into climate planning and create policy tools for climate justice. *Nature Communications, 13*(1), 5763.

Donoghue, E. R., Graham, M. A., Jentzen, J. M., Lifschultz, B. D., Luke, J. L., & Mirchandani, H. G. (1997). Criteria for the diagnosis of heat-related deaths: National Association of Medical Examiners: position paper. *The American journal of forensic medicine and pathology*, *18*(1), 11-14.

Dring, P., Armstrong, M., Alexander, R., & Xiang, H. (2022). Emergency department visits for heat-related emergency conditions in the United States from 2008–2020. *International journal of environmental research and public health, 19*(22), 14781.

Fall, W. et al. (2024). Heat-related illness on the job: A look at worker's compensation claims in Wisconsin (2010-2022). Surveillance brief by the Wisconsin Occupational Health and Safety Surveillance Program. https://www.dhs.wisconsin.gov/publications/p03497.pdf

Faridi, Z., Grunbaum, J. A., Gray, B. S., Franks, A., & Simoes, E. (2007). Community-based participatory research: necessary next steps. *Preventing chronic disease*, *4*(3).

Garfield, A. (2024, March 6). Madison homeless shelters are overflowing; linked to housing shortage. *The Cap Times (Online)*. https://captimes.com/news/government/madison-homeless-shelters-are-overflowing-linked-to-housing-shortage/article_a6fcc924-db16-11ee-b6f2-338a3ec6f173.html

Gelmon, S. B., Jordan, C., & Seifer, S. D. (2013). Community-engaged scholarship in the academy: An action agenda. *Change: The Magazine of Higher Learning*, *45*(4), 58-66.

Guardaro, M., Messerschmidt, M., Hondula, D. M., Grimm, N. B., & Redman, C. L. (2020). Building community heat action plans story by story: A three neighborhood case study. *Cities*, *107*, 102886.

Guardaro, M., Hondula, D. M., Ortiz, J., & Redman, C. L. (2022). Adaptive capacity to extreme urban heat: The dynamics of differing narratives. *Climate Risk Management*, *35*, 100415.

Han, A., Deng, S., Yu, J., Zhang, Y., Jalaludin, B., & Huang, C. (2023). Asthma triggered by extreme temperatures: from epidemiological evidence to biological plausibility. *Environmental research, 216*, 114489.

Harlan, S. L., Brazel, A. J., Darrel Jenerette, G., Jones, N. S., Larsen, L., Prashad, L., & Stefanov, W. L. (2007). In the shade of affluence: The inequitable distribution of the urban heat island. In *Equity and the Environment* (pp. 173-202). Emerald Group Publishing Limited.

Heidari, H., Mohammadbeigi, A., Khazaei, S., Soltanzadeh, A., Asgarian, A., & Saghafipour, A. (2020). The effects of climatic and environmental factors on heat-related illnesses: A systematic review from 2000 to 2020. *Urban Climate*, *34*, 100720.

Hess, J. J., Errett, N. A., McGregor, G., Busch Isaksen, T., Wettstein, Z. S., Wheat, S. K., & Ebi, K. L. (2023). Public health preparedness for extreme heat events. *Annual Review of Public Health*, *44*(1), 301-321.

Huang, C., Vaneckova, P., Wang, X., FitzGerald, G., Guo, Y., & Tong, S. (2011). Constraints and barriers to public health adaptation to climate change: a review of the literature. *American journal of preventive medicine*, *40*(2), 183-190.

Ioannidis, J. P. (2004). Materializing research promises: opportunities, priorities and conflicts in translational medicine. *Journal of Translational Medicine*, *2*(1), 5.

Janes Ugoretz, S., & Adalja, A. (2025). Hot potato: Heat safety where you work. Retrieved from https://docs.google.com/document/d/1b-Swh7MXEeCthQj_ihPpQjyBIvPjISCNiqmNp9Jl5sU/edit?tab=t.0

Keith, L., Meerow, S., Berke, P., DeAngelis, J., Jensen, L., Trego, S., ... & Smith, S. (2022). Plan Integration for Resilience Scorecard™(PIRS™) for Heat: Spatially evaluating networks of plans to mitigate heat (Version 1.0).

Keller, R. C. (2013). Place matters: Mortality, space, and urban form in the 2003 Paris heat wave disaster. *French Historical Studies, 36*(2), 299-330.

Kilbourne, E. M., Choi, K., Jones, T. S., & Thacker, S. B. (1982). Risk factors for heatstroke: a case-control study. *Jama*, *247*(24), 3332-3336.

Kleerekoper, L., Van Esch, M., & Salcedo, T. B. (2012). How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, *64*, 30-38.

Klinenberg, E. (2015). *Heat wave: A social autopsy of disaster in Chicago.* University of Chicago Press.

Knochel, J. P., & Reed, G. (1994). Disorders of heat regulation. *Maxwell & Kleeman's clinical disorders of fluid and electrolyte metabolism. 5th ed. New York: McGraw-Hill*, *15*, 49-90.

Mannino, D. M., Homa, D. M., Akinbami, L. J., Moorman, J. E., Gwynn, C., & Redd, S. C. (2002). Surveillance for asthma—United states, 1980–1999. *MMWR Surveill Summ*, *51*(1), 1-13.

Marin-Puig, A., Ariza, E., & Casellas, A. (2022). Unattended gap in local adaptation plans: The quality of vulnerability knowledge in climate risk management. *Climate Risk Management*, *38*, 100465.

Martinez, G. S., Linares, C., Ayuso, A., Kendrovski, V., Boeckmann, M., & Diaz, J. (2019). Heat-health action plans in Europe: Challenges ahead and how to tackle them. *Environmental Research*, *176*, 108548.

Meerow, S., & Keith, L. (2022). Planning for extreme heat: A national survey of US planners. *Journal of the American Planning Association*, *88*(3), 319-334.

Mellion, M. B., & Shelton, G. L. (1997). Safe exercise in the heat and heat injuries. *The Team Physician's Handbook. Philadelphia: Hanley and Belfus*, 151-65.

Minkler, M. (2000). Using participatory action research to build healthy communities. *Public health reports*, *115*(2-3), 191.

Minnesota Department of Health and Wisconsin Department of Health Services. (2019). "Extreme heat: who's at risk? Findings from a collaborative project between Minnesota and Wisconsin." https://www.dhs.wisconsin.gov/publications/p02386.pdf

Moser, S. C., & Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the national academy of sciences*, *107*(51), 22026-22031.

National Weather Service. n.d. July 1-7, 2012 Wisconsin Heat Wave. Retrieved from https://www.weather.gov/mkx/070112-WisconsinHeatWave

Nijhawan, S. (2025a, January 24). Cold weather strains Madison's homeless shelters, with limited resources increasing tensions. *WMTV15.com (Online)*. https://www.wmtv15news.com/2025/01/25/cold-weather-strains-madisons-homeless-shelters-with-limited-resources-increasing-tensions/

Nijhawan, S. (2025b, January 25). Former Beacon staff member calls out local leaders for inaction on homelessness crisis. *WMTV15.com (Online)*. https://www.wmtv15news.com/2025/01/26/former-beacon-staff-member-calls-out-local-leaders-inaction-homelessness-crisis/

O'Brien, Karen, Eriksen, S., Nygaard, L. P., & Schjolden, A. N. E. (2007). Why different interpretations of vulnerability matter in climate change discourses. *Climate policy*, *7*(1), 73-88.

O'Toole, T. P., Aaron, K. F., Chin, M. H., Horowitz, C., & Tyson, F. (2003). Community-based participatory research: opportunities, challenges, and the need for a common language. *Journal of general internal medicine*, *18*(7), 592.

Olazabal, M., Amorim-Maia, A. T., Alda-Vidal, C., & Goodwin, S. (2024). What is limiting how we imagine climate change adaptation?. *Current Opinion in Environmental Sustainability*, *71*, 101476.

Patz, J. A., Vavrus, S. J., Uejio, C. K., & McLellan, S. L. (2008). Climate change and waterborne disease risk in the Great Lakes region of the US. *American journal of preventive medicine*, *35*(5), 451-458.

Perea, J. F. (2011). The echoes of slavery: Recognizing the racist origins of the agricultural and domestic worker exclusion from the National Labor Relations Act. *Ohio St. LJ*, *72*, 95.

Plumer, B., Popovich, N., & Palmer, B. (2020). How decades of racist housing policy left neighborhoods sweltering. *The New York Times*. https://www.nytimes.com/interactive/2020/08/24/climate/racism-redlining-cities-global-warming.html

Ranganathan, M., & Balazs, C. (2015). Water marginalization at the urban fringe: environmental justice and urban political ecology across the North–South divide. *Urban Geography*, *36*(3), 403-423.

Reimer, J. R. (2021). *Water Quantity and Quality of the Yahara River Chain of Lakes*. The University of Wisconsin-Madison.

Ribot, J. (2011). Vulnerability before adaptation: Toward transformative climate action. *Global environmental change*, *21*(4), 1160-1162.

Roberts, J.T., Pellow, D., & Mohai, P. (2018). Environmental justice. *Environment and society: Concepts and challenges,* 233-255.

Robertson, M. (2006). The nature that capital can see: science, state, and market in the commodification of ecosystem services. *Environment and Planning D: society and space*, *24*(3), 367-387.

Robertson, M. (2007). The neoliberalization of ecosystem services. *Neoliberal Environments, London: Routledge*, 114-25.

Robinson, L. (2024, May 15). Madison's housing crisis is a national extreme. *Madison.com (Online)*. https://madison.com/news/local/business/real-estate/article_60d9d56a-d029-11ee-99f7-1f891db1746e.html

Rojas-Castillo, E. (2024, August 26). Street Angels offers Milwaukee's homeless community support during heat wave. *TMJ4.com (Online)*. https://www.tmj4.com/news/milwaukee-county/street-angels-offers-milwaukees-homeless-community-support-during-heat-wave

Rose, R. (2022). *Role of urban plan quality and land surface characteristics in urban heat island outcomes* [Unpublished master's thesis]. University of Madison-Wisconsin.

Rose, R. & Göçmen, A. (2024). Evaluating urban climate plans for heat preparedness. *Journal for Environmental Planning and Management.*

Rothstein, R. (2017). *The color of law: A forgotten history of how our government segregated America*. Liveright Publishing.

Schmidt, Katja, and Ariane Walz. (2021). "Ecosystem-based adaptation to climate change through residential urban green structures: co-benefits to thermal comfort, biodiversity, carbon storage and social interaction." *One Ecosystem 6:* e65706.

Schuyler, A. J., & Wenzel, S. E. (2022). Historical redlining impacts contemporary environmental and asthma-related outcomes in Black adults. *American Journal of Respiratory and Critical Care Medicine*, *206*(7), 824-837.

Semenza, J. C., Rubin, C. H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L., & Wilhelm, J. L. (1996). Heat-related deaths during the July 1995 heat wave in Chicago. *New England journal of medicine*, *335*(2), 84-90.

Semenza, J. C., McCullough, J. E., Flanders, W. D., McGeehin, M. A., & Lumpkin, J. R. (1999). Excess hospital admissions during the July 1995 heat wave in Chicago. *American journal of preventive medicine*, *16*(4), 269-277.

Shen, T., Howe, H. L., Alo, C., & Moolenaar, R. L. (1998). Toward a broader definition of heat-related death: comparison of mortality estimates from medical examiners' classification with those from total death differentials during the July 1995 heat wave in Chicago, Illinois. *The American journal of forensic medicine and pathology*, *19*(2), 113-118.

Sweet, E. L., & Etienne, H. F. (2011). Commentary: Diversity in urban planning education and practice. *Journal of Planning Education and Research*, *31*(3), 332-339.

Sydnor, T. D., Bumgardner, M., & Subburayalu, S. (2011). Community ash densities and economic impact potential of emerald ash bor

Tolika, K. (2019). Assessing heat waves over Greece using the excess heat factor (EHF). *Climate, 7*(1), 9.

Tschakert, P., Ellis, N. R., Anderson, C., Kelly, A., & Obeng, J. (2019). One thousand ways to experience loss: A systematic analysis of climate-related intangible harm from around the world. *Global Environmental Change, 55,* 58-72.

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., ... & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the national academy of sciences*, *100*(14), 8074-8079.

Union of Concerned Scientists. (2019). *Killer Heat in the United States: Climate Choices and the Future of Dangerously Hot Days*. Retrieved from https://www.ucsusa.org/sites/default/files/attach/2019/07/killer-heat-analysis-full-report.pdf

Watts, M.J. (1983). "On the poverty of theory: natural hazards research in context." In *Interpretations of calamity*, ed. K. Hewitt, 231-262. London: Allen and Unwin.

White-Newsome, J., O'Neill, M. S., Gronlund, C., Sunbury, T. M., Brines, S. J., Parker, E., ... & Rivera, Z. (2009). Climate change, heat waves, and environmental justice: Advancing knowledge and action. *Environmental Justice, 2*(4), 197-205.

Williams, M., & Moser, T. (2019). The art of coding and thematic exploration in qualitative research. *International management review*, *15*(1), 45-55.

Wilson, B. (2020). Urban heat management and the legacy of redlining. *Journal of the American Planning Association*, *86*(4), 443-457.

Wiltse, J. (2014). The Black–White swimming disparity in America: a deadly legacy of swimming pool discrimination. *Journal of Sport and Social Issues*, *38*(4), 366-389.

Zhou, D., Xiao, J., Bonafoni, S., Berger, C., Deilami, K., Zhou, Y., ... & Sobrino, J. A. (2018). Satellite remote sensing of surface urban heat islands: Progress, challenges, and perspectives. *Remote Sensing*, *11*(1), 48.

7. Appendices

Appendix 1: Semi-structured interviews on heat planning and preparedness in Wisconsin

General topics:

- Progress and successes in heat planning and preparedness
- Intended next steps and what the interviewee wants to see happen
- Barriers and potential ways to overcome them

Examples of questions to help guide conversation:

1. How has extreme heat been discussed as an issue in your circles? What does vulnerability to heat mean in this context?

2. What are other people/offices/organizations you have been collaborating with regarding this issue? What are some you know of that are doing similar work but have not directly worked with?

3. Have you found that the conversation around how heat impacts people, and necessary steps to address vulnerability to heat, has changed in recent years? If so, how?

4. What is the current capacity to better understand and address vulnerability to heat? Who, how many people, full-time staff, knowledge/skillsets (community leader buy-in, mapping and GIS, etc.)

5. If designing survey or interview questions to the general public, what sort of information would be most useful to know in order to plan accordingly?

6. What mapping/fact gathering has been done or is in the works? (Ex: tree canopy coverage, remotely sensed land surface temperature to identify the urban heat island, bus routes and cooling centers, vulnerable populations defined by income, age, and/or race and proximity cooling centers, etc.) When has this begun, and is it completed or ongoing?

7. What mapping/fact gathering has not been done to your knowledge but would be useful?

8. What solutions, resources, and/or services have been provided to help people better cope with heat? When were they first instituted?

9. What solutions, resources, and/or services are in the works to help? When may they formally begin?

10. What solutions, resources, and/or services have been brought up as ideas but have not yet been acted on?

11. Have any been dismissed, deemed not a good fit for the city/your operations, deemed too costly, or for some other reason? If so, why?

12. Is there a particular direction or way forward you would like heat planning efforts to take?

13. What are some successes to celebrate, progress made, or steps completed in understanding and addressing heat vulnerability?

14. What are some barriers or constraints that have impeded or prevented success?

15. What are some ways those barriers might be overcome? What would help in these efforts?

16. In what ways do the different responsibilities, abilities, funding, and/or resources of different levels of government (municipality vs. county vs. state vs. federal) affect the ability of your organization to address heat vulnerability?

17. Is there anything else you would like to share?

Appendix 2: Supplementary figures

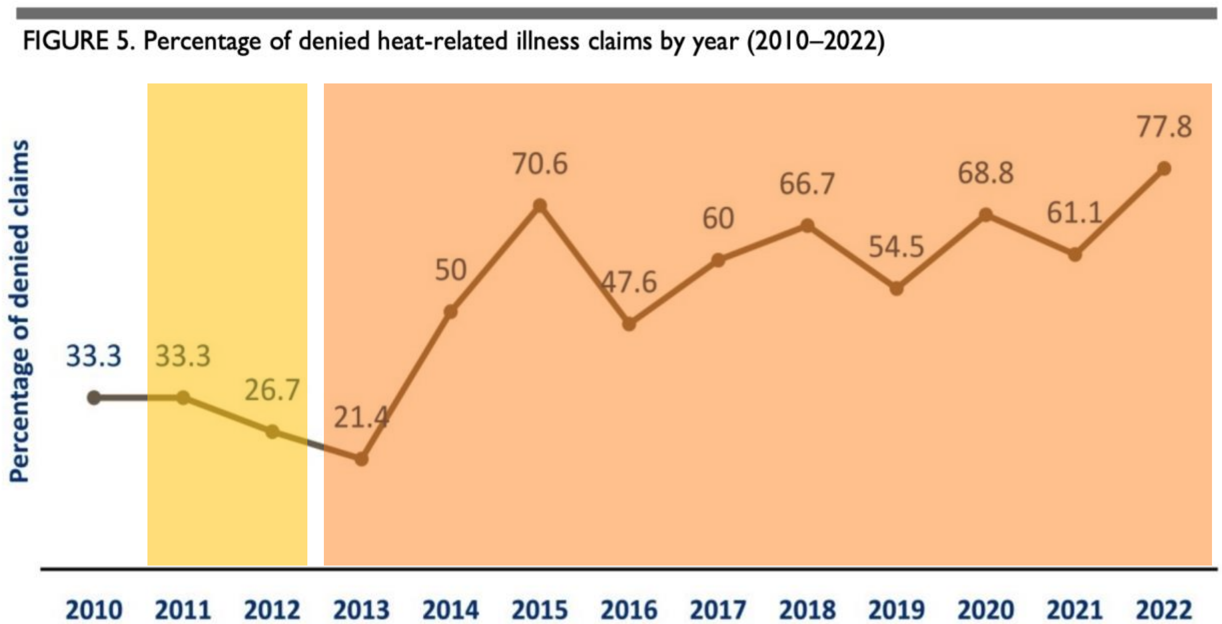


Figure 3.1: Percentage of denied heat-related illness claims in Wisconsin by year in the report "Heat-related illness on the job: A look at worker's compensation claims in Wisconsin (2010-2022)." I have added yellow highlights two especially hot summers, and orange shows higher rates of claim denial under the governor Walker-appointed commission (Fall, W. et al., 2024).

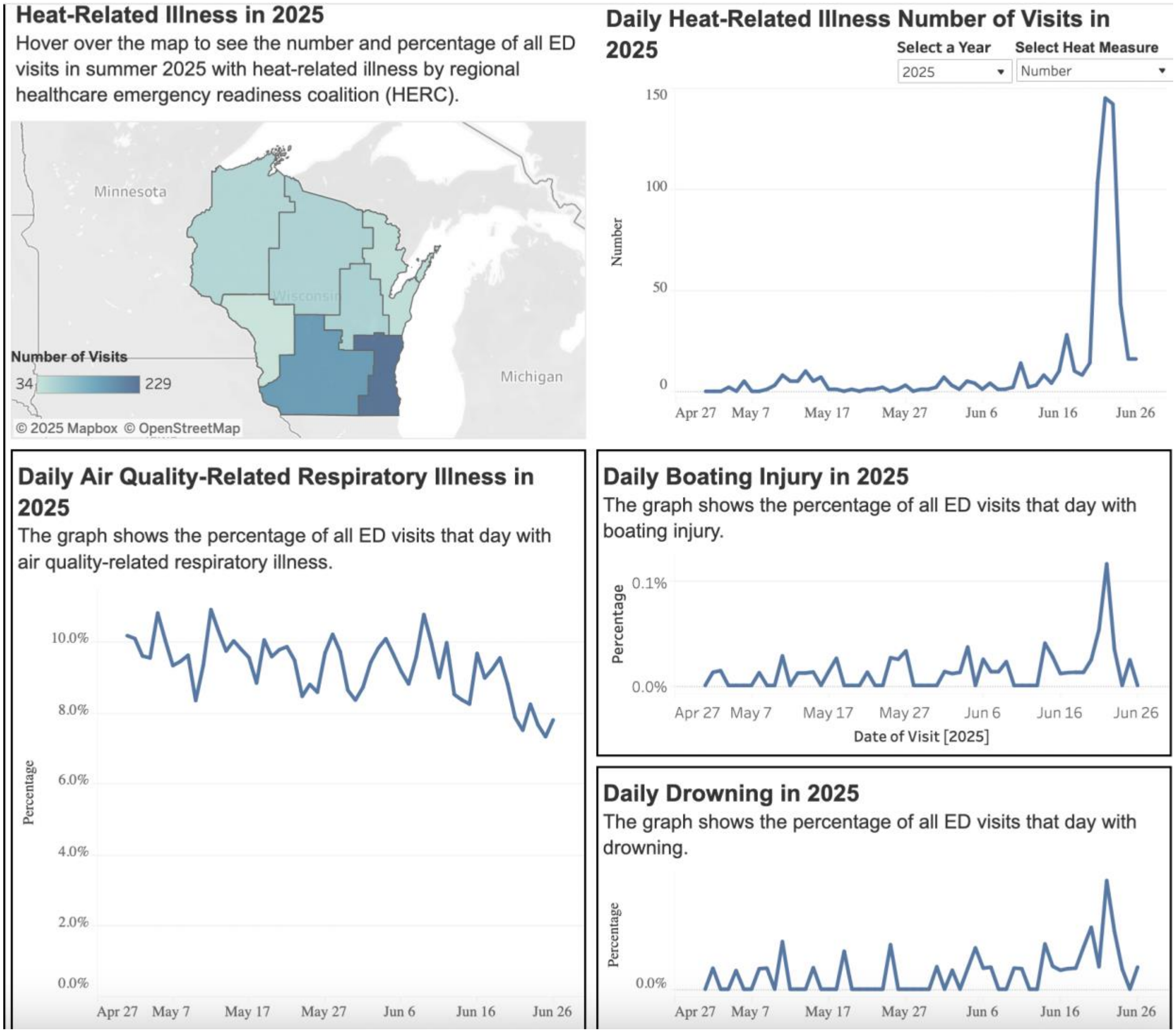


Figure 3.2: Wisconsin Summer Hazards Dashboard, screenshotted on June 27, 2025, showing a peak in heat-related illness emergency department visits, boating injuries, and drownings on June 22. Retrieved from: https://www.dhs.wisconsin.gov/climate/summer-hazards.htm

Figure 3.3: Portable shade structure with drinking water and picnic table; port-o-potties on wheels for greater restroom accessibility for farmworkers, at Paicines Ranch in Paicines, California. P/C Sarah Janes Ugoretz.

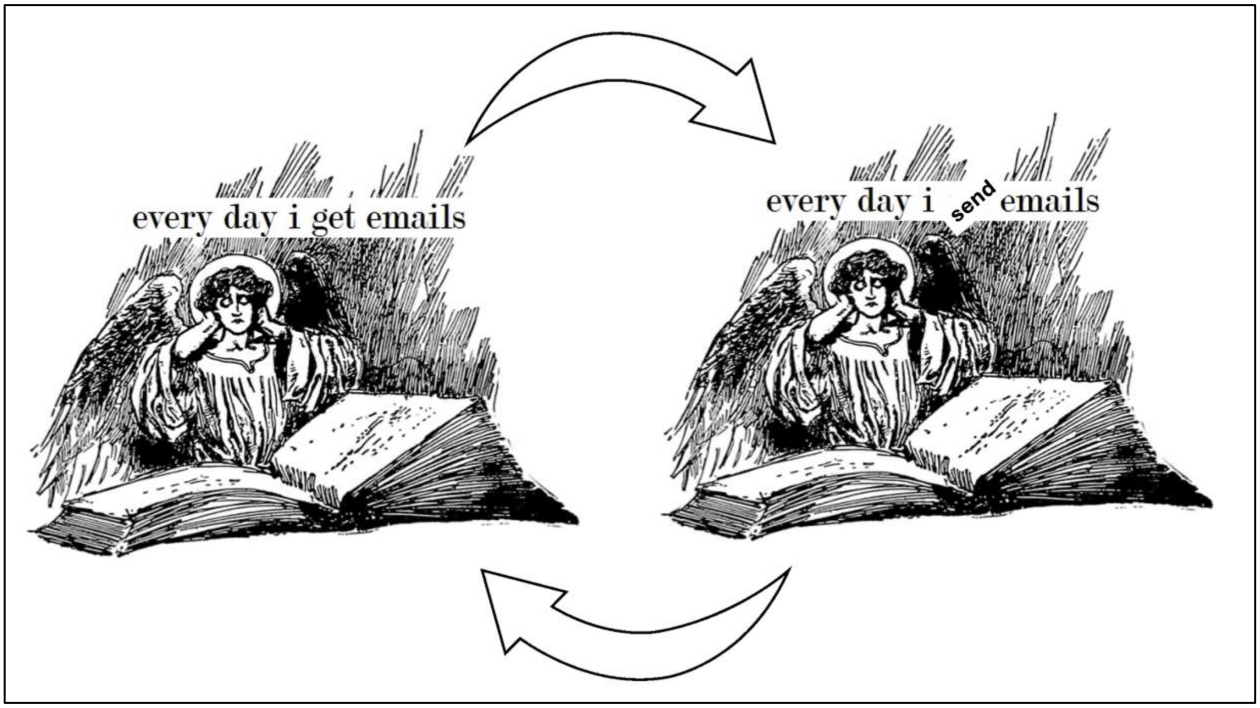


Figure 3.4: Conceptual diagram of the labor that goes into communication and coordination around heat resilience efforts and research. Original image modified from (link); original post removed, next-oldest image found at (link).

Appendix 3: Excerpts from Hot Potato resource library showing some farms' temperature-dependent work-break schedules and standard operating procedures (SOP)

Example of work-break schedule and tasks

*should be adjusted for humidity, drought conditions, comfortability of worker, etc.

Temperature	Light work	Moderate work	Heavy work
20-25	Usual	50 min work/5 min break	40 min work/10 min break
25-30	40 min work/5 min break	30 min work/5 or 10 min break	20 min work/10 min break
30-35	20 min work/5 min break	15 min work/5 or 10 min break	15 min work/10 min break
35-40	15 min work/10 min break	10 min work/5 min break	10 min work/10 min break
40+	Maybe go home?	Go home	Definitely just go home

Light work task examples: light weeding, seed saving, fixing irrigation

Moderate work task examples: transplanting, seeding, harvesting

Heavy work task examples: digging, moving equipment/machinery, putting up fence

Broadturn Farm's Hot Work Day SOP

Broadturn Farm | Scarborough, Maine | Flowers + Vegetables

Purpose: To protect farm employees from changing weather conditions, specifically high temperatures and humid environments, that can lead to dehydrations and heat-related illnesses, including heat exhaustion and heat stroke.

Conditions:

- If high temperature (or heat index) is above 90 degrees **and/or**
- There are local heat advisories **and/or**
- There are air quality warnings **and/or**
- Farm owners/managers deem conditions too extreme for working

Norms:

- Owners/managers will notify the team of earlier start and end times by the end of the previous work day (or by Sunday evening if the earlier start will be on Monday) in order to avoid the hottest part of the day
- The team will take a mandatory break, including a 30 minute breakfast break mid-morning. Employees are encouraged to self-monitor and take breaks outside of scheduled mid-morning break when needed.
- Breaks will be out of direct sun, ideally in the air-conditioned Silver Barn. Breaks will be no more than 3 hours between.
- Electrolytes are provided by the farm and are located in the break area of the Silver Barn. Staff is educated and encouraged to use electrolytes as they see fit.
- Work in high tunnels and greenhouses is avoided on hot work days if possible. If critical work is necessary, such as harvesting, in the high tunnels or greenhouses, it is prioritized for the morning to avoid working in the hottest part of the day.
- Extra sun protection measures encouraged:
    - Ball caps or wide brimmed hats
    - Sunscreen
    - Sun-shirts/long sleeves
    - Sunglasses
- Check-ins within groups working together will be frequent
- Lone workers will have walkie for communication, or cell phones. Employees will be encouraged to assess the needs of their bodies and take additional breaks of their own volition, when needed.
- Employees will be encouraged to understand their physical and medical history and how they may be affected by extreme weather conditions, which may include adverse reactions for some who take medications.
- Refer to CDC "Heat Related Illness" flier for signs and symptoms of heat stress.

Appendix 4: Resources to boost

One question I asked in interviews was, are there any resources you would like to boost, that you wish more people knew about? I include those here and on public-facing platforms for more accessible circulation. This includes a reiteration of resources originally listed above under "key actors."

- 211 Wisconsin – a confidential phone number people in need can call to be connected to services such as housing, food, crisis intervention, a place to cool off, etc.; review and vet cooling centers, serve as a clearinghouse for information https://211wisconsin.communityos.org/
- Wisconsin Department of Health Services Climate and Health program extreme heat toolkits https://www.dhs.wisconsin.gov/climate/toolkits.htm
- Ready – national public service campaign for emergency preparedness and response www.ready.gov; www.ready.gov/kit
- ReadyWisconsin – public safety information by emergency management for disaster preparedness and response https://readywisconsin.wi.gov/
- Red Cross – disaster relief and first aid training https://www.redcross.org/local/wisconsin.html
- Hot Potato – resource library on policies and practices people can use to keep their farmworkers safe in the heat (link)

Conclusion

Even the Upper Midwest, which is sometimes referred to as a "climate haven," faces daunting impacts of climate change, including increasingly common and dangerous heat waves. As risks mount and severe heat waves cause illness and death, well-informed and decisive action is critical to preserve human health and wellbeing.

To return to the framework of vulnerability introduced in this dissertation's introduction: **vulnerability** can be thought of as being created by **exposure** and **sensitivity** to a hazard and is reduced by **adaptive capacity** (Turner et al., 2003). Drawing from definitions elaborated on by Smit & Wandel (2006) and the glossary for the 2018 IPCC (Intergovernmental Panel on Climate Change) report (Matthews, 2018), my working definitions of these concepts as applied to heat are:

1) **Exposure** – the severity, extent, or frequency of the stressor which people, livelihoods, ecosystems, and assets are exposed to; the presence of both a hazard and potentially impacted people or systems.
2) **Sensitivity** – the degree to which people or a system are impacted by a hazard
3) **Adaptive capacity** - the ability of systems, institutions, humans and other organisms to adjust or cope to potential damage; can also include the ability of the system to act to prevent future damage

In my first chapter, I explored **exposure** to heat by utilizing Dane County's urban heat island (UHI) sensor network to examine the climatology of apparent temperature and the role of climate and soil moisture extremes on the UHI effect, vapor pressure, apparent temperature, and how much apparent temperature is elevated above temperature. I found that apparent temperature and temperature behave differently from each other across moisture extremes, landcover types, and times of day, which indicates contrasting mechanisms at work. Importantly, rural areas may be exposed to hotter conditions than previously thought and than would be indicated by temperature alone when accounting for apparent temperature and elevated humidity due to greater amounts of evapotranspirating vegetation. The slightest difference in temperature or apparent temperature can make a difference in whether an extreme heat warning is issued and whether heat exposure reaches injurious or life-threatening levels.

In my second chapter, I explored **sensitivity** to extreme heat by conducting an analysis of EMS data on heat-related illness counts and rates in Wisconsin. I found that rural, low-population density counties have disproportionately high HRI EMS calls per capita, despite the understanding that they have lower temperatures than areas with more urban, built-up area. Reported rates of HRI are increasing statewide and across counties. Meteorological conditions and county characteristics such as prevalence of poverty and percent outdoor workers is positively and significantly associated with elevated HRI. However, the hottest conditions do not necessarily result in the highest HRI rates. Only one third of HRI EMS calls are made to people's homes, emphasizing the importance of other spaces and where else people go and what they do on hot days. Gender and racial disparities are apparent in EMS data, but low counts for some demographics and blank entries under race/ethnicity produce limitations in how much we can rely on these fields. Similarly, extremely low response rates of whether incidents were workplace-related or not constrain our understanding of how much laborers are being affected by the heat. Gaps and uncertainties in reporting, and the difficulties they pose in interpreting results, underscore the importance of accurate and complete surveillance as much as can be managed going forward, as well as supplementing findings with qualitative studies and conversations to better understand conditions on the ground.

The fact that the hottest days do not result in the highest number of EMS calls is promising. It suggests that during the period of record, since 2017, our forecasting, warning, messaging, adaptations, and behavior change may be successfully averting negative health outcomes on the most dangerous days. Where these actions are occurring, they are working; this means it is vital to keep them going, see where they are not, and prioritize those areas.

In my third chapter, exploring conceptions of both **adaptive capacity** and **vulnerability** as a whole**,** I conducted interviews with people whose work intersects with heat, both those working in government positions and in community-based groups, in order to better understand the landscape of heat preparedness and vulnerability in the state. I found heat and heat vulnerability are connected with many parts of society and daily life across home, work, and third places. In Wisconsin, there is a substantial amount of ongoing work across sectors around addressing heat vulnerability and building adaptive capacity at individual, community, city, and statewide scales, and these many forms are apparent if one understands heat to be about more than just the physical temperature. People who do this work have a number of proposed actions to further build resilience to heat, many of which have to do with addressing underlying social and/or economic vulnerability rather than heat itself. Narrow definitions of extreme heat vulnerability constrain our understandings of the processes that contribute to it and the solutions that we can imagine as being useful to address it. Conversely, **contextual vulnerability** offers a holistic understanding of what processes create heat vulnerability, and practitioners have many insights in how this manifests. Broadening the issue of heat to this perspective, we can see both many more problems and many more solutions and exciting work that is already underway.

When asked about how heat touches our lives and how we can act to address it, participants' comments were not only about heat. They were about the housing crisis, youth empowerment, the importance of getting to know our communities and neighbors, supporting our libraries, and so many other parts of society and everyday life. No one I spoke with had extreme heat at the top of their job description, but everyone interacted with it, saw heat vulnerability holistically, was taking it seriously in context, and had ideas about how to better address it.

By investigating not only outcome vulnerability—what we can see in numbers, distributions, and unequitable impacts—but also contextual vulnerability—what processes have brought us here—alongside what kinds of action contribute to adaptive capacity at individual, community, local, and statewide levels, we can see the importance of looking beyond heat and heat-oriented action itself and into all sorts of ways that we can take care of each other and reduce underlying vulnerability. This has important implications for planners, climate experts, nonprofits, policymakers, funding providers, and more. Coordination across sectors, as well as attention to basic human needs and the systems that may either address or neglect them, will make us all better off both in general and when confronted with potential disaster. Going forward, it is essential to frame, argue for, and pursue basic needs such as housing security, financial wellbeing, social safety nets, and community as a necessary part of climate action and heat resilience. We must overcome daunting obstacles and the siloing of actors. If we do not, we will miss opportunities to address the many facets of heat vulnerability and improve human wellbeing.

Contextual vulnerability encompasses the processes through which people are exposed to heat, can be at least partly measured by disproportionate sensitivity, and are limited in what adaptive capacity they have. An unhoused person, with a severely constrained ability to escape the heat (adaptive capacity) will be exposed to more dangerous conditions, is more likely to have negative health outcomes (sensitivity), and is overall considered very vulnerable to extreme heat overall due to these three factors. Pressures of the housing market, wages vs. the cost of living, limited social safety nets, and rising temperatures all encompass elements of their contextual vulnerability to heat. Places they can find refuge from the heat, including cooling centers, homeless shelters, and libraries, especially if publicized, accessible, and welcoming, can address current exposure to the heat and reduce negative health outcomes, though they do not address the root causes that have caused the person to experience homelessness (contextual vulnerability). The person's personal adaptive capacity is improved by access to this temporary shelter, and a jurisdiction's adaptive capacity is improved by providing these resources to protect its most vulnerable populations. This in turn reduces instances of negative health outcomes, which can also be expressed as sensitivity or outcome vulnerability. At the same time, a jurisdiction's work to address the processes that create homelessness, whether through governance or community-based work, reduces contextual vulnerability and improves its overall adaptive capacity and overall vulnerability.

When brought together, the findings from these three chapters reveal previously under-appreciated factors that shape vulnerability in rural environments and the role of labor in heat exposure, vulnerability, and negative health outcomes. The feels-like temperatures of rural areas may be underestimated compared to urban areas, especially during the daytime; most ambulance calls for heat-related illness occur during the daytime which coincides with typical working hours; only one in three of these ambulance calls are made for people who fell ill in their homes; population-adjusted heat-related illness rates are positively associated with counties with lower population densities and more outdoor workers; and instances of work-related heat illness are underreported through metrics such as worker's compensation claims, completion of the "work-related" field in EMS patient reports, and insufficient inspections and enforcement of safety standards, which all contribute to a lack of understanding of the true scope of dangerous conditions in the workplace. Questions of access to health infrastructure and the fact that it may be impractical to call an ambulance in remote locations, further support the notion that our counts of heat-related illness, especially in rural areas, are underestimates. In turn, this lack of data and complete counts makes it difficult to make a compelling argument for policy change. Best practices and standard operating procedures collected by farmworkers and worker coalitions provide some answers of conditions and pressures faced as well as strategies to stay safe in the heat, but much remains unknown. Future studies should continue to delve into the processes and dynamics surrounding heat exposure, sensitivity, and adaptive capacity in rural areas and through labor that exposes workers to dangerous levels of heat.

Within this interdisciplinary, mixed-methods work, there is tension: insights from practitioner interviews, as well as limitations from the quantitative studies, emphasize the importance of that which cannot easily be measured. At the same time, what *can* be measured can support decision making, drive future research questions, and provide a persuasive case for policy change and funding. From interviews that shared a need for more data on variables such as air conditioning prevalence, the qualitative asserts the need for the quantitative. Limitations of the quantitative can be at least partly addressed by the qualitative. Each informs the other, and through iterative work between the two, research can be better resigned, with refined questions, and deliberately chosen datasets that can better answer questions and address needs.

This work has also underscored to me the importance of community-engaged scholarship and community-based learning as ways for researchers and students to ground their approaches in reality, build meaningful and reciprocal relationships with community partners, and lend their capacities to climate adaptation efforts. Research relationships can help with the much-needed coordination that can help us overcome siloing.

The broad scope of the problems we face around extreme heat means that a broad scope of solutions is needed, and that contributions to any of these are helping: we need quantitative research, we need qualitative research, we need to better understand heat itself, and we need to better understand the social environments and pressures that shape vulnerability in order to address those directly. Researchers must, as much as possible, ground their work in community and practitioner relationships to stay informed of what is relevant, wanted, and impactful. Many people in Wisconsin are working to address needs that one may not immediately think of as being about heat, but they absolutely do contribute to heat preparedness. Once you know to look for this, there is much good news to find, and there are many things that each of us can do.