Mechanisms of Social Vulnerability to Environmental Hazards

by

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ABSTRACT

Environmental hazards and disaster researchers have demonstrated strong associations between sociodemographic indicators, such as age and socio-economic status (SES), and hazard exposures and health outcomes for individuals and in certain communities. At the same time, behavioral health and risk communications research has examined how individual psychology influences adaptive strategies and behaviors in the face of hazards. However, at present, we do not understand the explanatory mechanisms that explain relationships between larger scale social structure, individual psychology, and specific behaviors that may attenuate or amplify risk. Extreme heat presents growing risks in a rapidly warming and urbanizing world. This dissertation examines the social and behavioral mechanisms that may explain inequitable health outcomes from exposure to concurrent extreme heat and electrical power failure in Phoenix, AZ and extreme heat in Detroit, MI. Exploratory analysis of 163 surveys in Phoenix, AZ showed that age, gender, and respondent's racialized group identity did not relate to thermal discomfort and self-reported heat illness, which were only predicted by SES (StdB = -0.52, $p < 0.01$). Of the explanatory mechanisms tested in the study, only relative air conditioning intensity and thermal discomfort explained self-reported heat illness. Thermal discomfort was tested as both a mechanism and outcome measure. Content analysis of 40 semi-structured interviews in Phoenix, AZ revealed that social vulnerability was associated with an increase in perceived hazard severity (StdB = 0.44, $p < 0.01$), a decrease in perceived adaptation efficacy (StdB = -0.38, $p = 0.02$), and an indirect increase (through adaptive efficacy) in maladaptive intentions (StdB = 0.18, $p = 0.01$). Structural equation modeling of 244 surveys in Phoenix, AZ and Detroit, MI revealed that relationships between previous heat illness experience, perceived heat risk, and adaptive intentions were significantly moderated by adaptive capacity: high adaptive capacity households were more likely to undertake adaptive behaviors, and those decisions were more heavily influenced by risk perceptions and previous experiences. However, high adaptive capacity households had lower risk perceptions and fewer heat illness experiences than low adaptive capacity households. A better understanding of the mechanisms that produce social vulnerability can facilitate more salient risk messaging and more targeted public health interventions. For example, public health risk messaging that provides information on the efficacy of specific adaptations may be more likely to motivate self-protective action, and ultimately protect populations.

To my grandfather, Mike Chakalian. Having spent his grade-school years a refugee in occupied Europe, Mike had close to no formal education. Nonetheless, he believed study was the most important tool for any repair. Whether he was fixing a broken refrigerator or a tangled shoe lace, Mike always taught us to “study the problem”. It is in his tradition that I have chosen to study society.

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PREFACE

What causes humanity's precarious relationship with our environment? This question follows naturally from the post-enlightenment positivist scientific endeavor to make our environment, our world, and our nature known, precisely in order to remove the precariousness of our lives in a mysterious place. So, the implicit raison d'être of this question is really, how can we reduce or eliminate pernicious effects of the environment on us, while optimally taking advantage of its forces and resources? This is a normative and a two-part question: one, how do we reduce negative effects of our environment on us, and two, how do we enhance its positive effects? To answer these questions, we first need to define negative and positive, then illuminate what our environment is, how it works, and how we interact with it. This manner of thinking accepts a dualism between human society and nature that has been critiqued (e.g. Leiss, W., 1994) however, a dualist abstraction can be useful in practice, and resonates with the lived-experience of an objective environment that exist outside of our subjective selves.

The question of understanding our precarious relationship with our environment is fundamental to the modern, positivist, scientific endeavor insofar as it seeks to explicate our natural word. For this reason, academics across disciplines have set out to answer it. Though almost the entire academic institution is involved in one way or another in answering the larger question of what our environment defined very broadly *is*, and how we interact with it, some fields focus on the question's fundamental purpose—how we can reduce or eliminate pernicious effects of the environment on us, while optimally taking advantage of its forces and resources—more than others. Specifically, studies of resource management, natural disasters, toxins, pollution, climate change, weather hazards, and agriculture deal most directly with what we typically consider the interface between people and the narrower conception of 'the environment', and specifically on the first goal of the fundamental question: eliminating negative effects of the environment on people. Researchers in fields that span the academic gamut, from chemists, biologists, epidemiologist, engineers, physical and human geographers, anthropologists, and sociologists have participated in these studies. Subfields of research have developed in several disciplines to more directly tackle this question: notably in environmental sociology and anthropology, environmental justice studies, public health, natural hazards and disasters research, political and human ecology, disaster risk reduction, risk analysis, uncertainty and decision theory, resilient infrastructure and urban design, coupled or cascading technological failures, and in science and technology studies.

As can be seen, this question is both specific—why and how the narrowly-defined 'environment' negatively impacts us—and also not far from one of, if not the single, broadest question in the scientific world: what is the fundamental nature of the world around us and how we live in it? For this reason, being both specific yet closely tied to a very broad scientific mission, answering this question requires transdisciplinary research. Unfortunately, the compartmentalized nature of the academy kept these bodies of work separated for decades. As interdisciplinarity became more fashionable within the academy, wide cross-disciplinary teams eventually bridged not only across the natural/social divide but also the basic/applied divide to answer the questions of how we can reduce or eliminate our environment's pernicious effects on us. However, over the time leading up to this cross-disciplinary collaboration, and indeed even during it, each group of researchers and the different fields of research they participated in developed separate languages, bodies of literature, and theories attempting to answer the same questions—each placing the node of importance in different places. Resilience and vulnerability, probabilistic risk and qualitative risk, physical resilience and community resilience, physical vulnerability and social vulnerability, social vulnerability and environmental justice, common pool resource problems and game theory, socioecological systems and sociotechnical assemblages, etc. Though working together in cross-disciplinary teams is helpful, without truly trans-disciplinary journals, departments, or bodies of literature these differences in language and in focus have and will continue to persist. Nonetheless, as these endeavors progressed, several fundamental sub questions emerged. To understand what negative effects our environment has on us and how we can reduce them, we needed to understand the ontological relationship between ‘people’ and the 'environment', we needed to decide how to define negative effects and what events bring them about, and why and how those events result in negative outcomes.

It was quickly realized that measuring negative effects was most easily done using quantitative measures of value: like fiat currency, or the number of lives or the years of life lost. Measuring negative outcomes using qualitative means, like senses of place, identity, or fulfillment, happens too, but is more challenging. Nonetheless, at least in the Western world, each body of literature that focused on how to reduce negative environmental effects appears to agree as to the total universe of negative outcomes—even if they focus on different specific outcomes that are measured in different ways. Modern science is also relatively capable of answering the question of what brings about negative environmental events. Physical scientists understand physical systems well, and even in a chaotic world, between past experience and probabilistic and dynamic modeling we understand fairly well why, and even with what frequency and in what places, negative environmental events are likely to occur. As for why and how negative outcomes for people follow from these events, in the most obvious sense, it's usually because the negative event or hazard occurred, i.e. people die because there was a hurricane, and there was a hurricane because of the nature of our earth's geophysical dynamics, which we mostly understand. However, it became apparent that all hurricanes wouldn’t necessarily produce negative outcomes for people, if for example, the storm never made landfall. Furthermore, the severity of negative impacts would not always correlate with the severity of a negative event, and the people most impacted were not always the ones most exposed. This led to theories of social vulnerability, sensitivity, and adaptive capacity, which attempt to explain why different people and different groups of people come to suffer worse effects from their environment than others, even with similar levels of exposure. However, we still do not have a robust understanding of the particular mechanisms that explain why and how more socially vulnerable individuals and groups suffer worse outcomes. Revealing these mechanisms will help public health practitioners, emergency managers, and policymakers more fully and more equitably reduce or eliminate pernicious environmental impacts on human societies.

CHAPTER 1

INTRODUCTION

This dissertation addresses social vulnerability to important natural and sociotechnical hazards. The risks from natural and sociotechnical hazards are increasing due to climate change, urbanization, globalization, and increasing technical complexities (Clark, Chester, Seager, Eisenburg, 2019; Krayenhoff, Moustaoui, Broadbent, Gupta, Georgescu, 2018). A better understanding of how and why some individuals and groups are more likely to suffer when exposed to hazards will enhance our ability to conduct equitable risk mitigation and build healthy, happy, and resilient communities.

It is well established that defining social vulnerability or resilience is not as easy as defining the probability of a hazard event or a community's exposure to that event. By using a combination of historical data, such as property values, unemployment claims, tax records, and hospital records, in conjunction with personal surveys and interviews, a quantifiable measure of relative vulnerability or resilience can be built (Tate, 2013; O'Brien et al., 2004; Cutter, Boruff, Shirley, 2003). However, to fully capture a community's or system's vulnerability or resilience, research is needed to better understand individual attitudes, perceptions, and behaviors, as influenced by larger social, political, and institutional structures, and their impact on dynamic hazardscapes. Neil Adger and Mick Kelly in their 1999 article "Social Vulnerability to Climate Change and the Architecture of Entitlements," propose that assessments of social vulnerability should be based on an analysis of individuals' material resources and the distribution of those resources throughout their community, while considering the political and social context that frames individuals access to those resources. While I agree with Adger and Kelly's analysis, I propose that only by understanding the mechanisms which cause those social structures to influence resource distribution and access, and how those resources create vulnerability or resilience to specific hazards in specific places, can we understand the role of social vulnerability in producing negative outcomes. Only by considering the physical risks we are exposed to, the complex social structures we are imbedded in, the capacities individuals and institutions have to adapt, and the unique attitudes, perspectives, and behaviors that individuals possess, can we fully understand, and therefore be well equipped to manage, humanity's precarious relationship with our environment.

The following pages provide a broad overview of environmental hazards and health research with a particular focus on social vulnerability and analytical sociology. I first provide a general typology of environmental hazards and health research, as well as an overview of common terms and definitions. This is followed by an in-depth discussion of social mechanism in the research tradition of analytical sociology. Following this, I go over various conceptualizations of social vulnerability theory and common sociodemographic indicators used to measure it. I then briefly discuss some practical applications of this research before finally concluding the introduction with an outline of the dissertation as a whole.

Previous work has been done to understand how environmental phenomena generate negative outcomes for people, and why and how outcomes differ for different people. This work has taken place in many sub-fields, each with its own language and particular theoretical or applied focus (Table 1, below). Broadly, the field has developed in several approaches that intersect traditional academic disciplines, which I describe as managerial/technocratic, earth systems, critical, and integrated. There are, of course, other ways to categorize the research, and efforts have been made previously to do so (e.g. Miller et al., 2010; Cutter, Emrich, Webb, Morath, 2009; Füssel, 2007; Adger 2006; Eakin & Luers, 2006; Janssen, Schoon, Ke, Börner, 2006; Gallopín, 2006; Kasperson, et al., 2005; Turner et al., 2003; Cutter, 1996). In many cases, the same authors have contributed theoretical, methodological, or empirical research in multiple approaches, however, the intellectual orientation of each research contribution has differed between approaches. Although every approach incorporates some level of interdisciplinarity, they each start from a different scientific perspective: applied, natural, or social. Managerial and technocratic studies differ from earth systems and critical approaches in that they take an applied perspective, concerned primarily with mitigating negative environmental impacts on people, rather than understanding why or how negative impacts may occur. Unlike the critical approach, earth systems studies come primarily from the natural and applied sciences, and only secondarily incorporate a social perspective. The inverse is true of the critical approach; critical scholarship stems primarily from the social sciences, and only secondarily incorporates natural or applied sciences. Integrated approaches, consisting mostly of attempts to synthesize disparate efforts, reflect a relative balance between at least two of the three other approaches. In general, research in the earth systems approach has been the most isolated from the others (Janssen, Schoon, Ke, Börner, 2006); however, review and synthesis articles have more often been written by earth systems scholars (e.g. Füssel, 2007; Janssen, Schoon, Ke, Börner, 2006; Gallopín, 2006; Turner et al., 2003) than critical scholars (e.g. Lorenz, 2013; Adger 2006), suggesting a desire on the part of the earth systems community to bridge a perceived gap in intellectual development and research activity, and a comparative unwillingness to engage on those terms by the critical community (Olsson, Jerneck, Thoren, Persson, O'Byrne, 2015).

Within each approach, scholars take varying research orientations in their work. Like the approaches themselves, the boundaries between research orientations are fluid and categories are not always mutually exclusive. While it is not necessary or advisable to provide an overview of every orientation here, there are two comments worth making. One, political ecology and environmental justice have been grouped into a single orientation in the table below. While these intellectual pursuits were largely distinct in their origins and remained relatively separate for some time, it is apparent that they have been converging in contemporary discourse (see Holifield, 2015; Sze & London, 2008). Two, many papers with a public health research orientation have strong ties to other critical approaches (and in many cases the same authors are citied in each category) however, papers with a public health research orientation have typically analyzed health disparities themselves; while they may assume that differential historical political social structures are, in whole or in part, responsible for the disparities they observe, those structures are not the analytical foci. A similar overlap, and relative distinction, exists for studies focused on measuring or mapping vulnerability.

Table 1. Research that focuses on human impacts from and on the natural environment

Approach	**Disciplines**	**Research Orientations**	**Citations**
Managerial / Technocratic (applied)	Geography, Engineering, Economics, Communications, Psychology, Epidemiology	Risk-hazard/risk-analysis & Disaster Risk Reduction (DRR)	Kasperson, 2017; Gaillard, Mercer, 2013; Solecki, Leichenko, O'Brien, 2012; Jones, Preston, 2011; Wisner, Blaikie, Blaikie, Cannon, Davis, 2004; Cutter, 2002; Comfort, et al.,1999; Kates, R.W., 1985; Burton, Kates, White, 1978; White, 1974
		Governmental reports	USGCRP, 2018; IPCC, 2014a; IPCC, 2014b; IPCC, 2012; IPCC, 2007
		Public health	Putnam, 2018; King, 2017; Harlan, Declet-Barreto, Stefanov, Petitti, 2012; Frumkin, Hess, Luber, Malilay, McGeehin, 2008; Grineski, Bolin, Boone, 2007; Ebi, Kovats, Menne, 2006; Haines, Kovats, Campbell-Lendrum, Corvalán, 2006; Patz, Balbus, 1996
		Vulnerability assessments & mapping	Watkins et al., under review; Tate, 2013; Tate, 2012; Balica, Wright, Meulen, 2012; Fekete, 2012; Reid et al., 2012; Flanagan, Gregory, Hallisey, Heitgerd, Lewis, 2011; Holand, Lujala, Rød, J2011; Reid et al., 2009; Cutter, Finch, 2008; Gall, 2007; Azar, Rain, 2007; Füssel, Klein 2006; Chakraborty, Tobin, Montz, 2005; O'Brien et al., 2004; Cutter, Boruff, Shirley, 2003
Earth Systems (natural)	Geography, Ecology, Economics	Institutions & Socio-Ecological Systems (SES)	Meerow, Newell, 2016; Collins et al., 2011; Ostrom, 2009; Berkes, Colding, Folke, 2008; Folke, 2006; Folke, Hahn, Olsson, Norberg, 2005; Adger, Hughes, Folke, Carpenter, Rockström, 2005; Anderies, Janssen, Ostrom, 2004; Walker, Holling, Carpenter, Kinzig, 2004; Folke, Carpenter, Dietz, Ostrom, Stern, 2003; Elmqvist, Gunderson, Holling, Walker, et al., 2002; Ostrom, 1990
		Land Systems/Change Sciences (LSS/LCS)	Millington, 2017; Verburg et al., 2015; Verburg, Erb, Mertz, Espindola, 2013; Turner, Robbins, 2008; Grimm et al., 2008; Turner, Lambin, Reenberg, 2007; Turner et al., 2003
Critical (social)	Sociology, Geography, Political science, Economics	Environmental justice & Political ecology	Parry, et al., 2018; Bolin, Kurtz, 2018; Bolin, Barreto, Hegmon, Meierotto, York, 2013; Smith, 2010; Bullard, 2008; Collins, 2008; Bolin, Grineski, Collins, 2008; Bolin, Stanford, 2006; Collins, 2005; Foster, 2000; Mustafa, 1998; Weinberg, 1998; Pulwarty, Riebsame, 1997; Hewitt, 1997; Sachs, 1996; Harvey, 1996; Bullard, 1993; Hewitt, 1983a; Hewitt, 1983b
		Political economy	Fraser, 2014; Adger, Kelly, 2012; Ribot, 2010; Mearns, Norton, 2009; McLaughlin, Dietz, 2008; Peet, Watts, 2004; O'Brien, Leichenko, 2000; Adger, Kelly, 1999; Adger, 1999; Bohle, Downing, Watts, 1994; Watts, Bohle, 1993; Chambers, 1989; Sen, 1981

Integrated	Trans/ Interdisciplinary	Sustainability, Climate change, Reviews & syntheses	Eakin, et al., 2017; Eakin, et al., 2016; Reed, 2013; Romero-Lankao, Qin, Dickinson, 2012; Harlan, Ruddell, 2011; Miller et al., 2010; Turner II, 2010; Adger, Eakin, Winkels, 2009; Cutter et al., 2008; Füssel, 2007; Satterthwaite, Huq, Pelling, Reid, Lankao, 2007; Harlan, 2006; Janssen, Schoon, Ke, Börner, 2006; Eakin, Luers, 2006; Schipper, Pelling, 2006; Adger, 2006; Gallopín, 2006; Pelling, High, 2005; Kasperson, Kasperson, 2005; Pelling, 2003; Cutter, 1996

Defining Common Terms

Common concepts like *hazard*, *risk*, *resilience*, *capacity*, and *vulnerability* are shared across these research approaches. These terms tend to have fuzzy definitions within each approach, often frustrating attempts at resolving cross-approach definitions (Olsson, Jerneck, Thoren, Persson, O'Byrne, 2015; Miller et al., 2010; Turner et al., 2003). In the general sense, a *hazard* is considered a source of risk, or the potential for a negative impact (Aven et al., 2018; IPCC, 2014c)." A *risk* typically refers to the possibility, and sometimes severity, of harm to something humans care about under uncertain conditions (Aven et al., 2018). *Resilience*, whether in the systems sense, a la Walker, Holling, Carpenter, Kinzig, 2004, or the community sense, a la Cutter et al., 2008, generally refers to the ability of an ontological unit akin to a system (whether or not a system per se) to continue producing or causing to effect services, circumstances, or relationships that have normatively beneficial or good outcomes when perturbed. *Capacity* is used in both earth systems and in critical approaches to refer to the ability that an individual, household, community, or system has to act to mitigate, recover from, or adapt to, a hazard or shock (Füssel, 2007). Finally, most characterizations of *vulnerability* account for some combination of: physical exposure to a hazard, the physical, social, political, economic, or bio-physiological characteristics that influence the likelihood of harm from experiencing a hazard (sometimes called *sensitivity*), and the ability of individuals, groups, or systems to influence their exposure to that hazard and recover from its potential impacts (sometimes called *adaptive capacity*) (Watkins et al., under review; Kasperson et al., 2012; Füssel, 2007; Adger, 2006, 2004).

Each of these concepts carry different nuances, making them more or less utile depending on the nature of an inquiry. For example, rather than statically withstand, resilience tends to describe an ability to dynamically recover or adapt to a shock, even if that means a system or community undergoes transformative change. So long as the post-perturbed condition of a system or community is as (or more) normatively "good" as the pre-perturbed condition, it is generally considered resilient. Because resilience scholarship tends to focus on the nature of systems themselves, e.g. feed-backs, thresholds, plateaus, and transformative changes, it is often less well-attuned to more nuanced, less measurable, or more transitory issues of equity or justice, despite efforts to engage those issues (Olsson, Jerneck, Thoren, Persson, O'Byrne, 2015; Downes, Miller, Barnett, Glaister, Ellemor, 2013; Adger, Kelly, 2012). However, resilience also largely overlaps with adaptive capacity, which is an oft defined component of vulnerability, defined in terms of an individual's capacity, or lack thereof, to access the resources necessary to be resilient to stress from a hazard, and its secondary social, political, and economic stressors—making the distinction between the two (resilience and vulnerability) perhaps more semantic than substantive (Olsson, Jerneck, Thoren, Persson, O'Byrne, 2015; Gallopín, 2006; Wisner, 2004; Adger & Kelly, 1999). For its part, vulnerability has been defined in numerous and sometimes conflicting ways (see Kasperson et al., 2012), resulting in perhaps dramatic claims about the value of the concept (see Timmerman, 1981, p. 17). At the same time, and due in part to this slippery definition, some scholars have suggested that researchers avoid the vulnerability concept entirely, in favor of "using the existing terminology of the social sciences (and extending it where needed) to describe problems and methods as specifically as possible" (Hinkel, 2011. pg. 206). Following Hinkel, the research that follows in this dissertation leans heavily on existing theory in analytical sociology, a sub-field of sociology focused on causal mechanisms and causal explanations. The general definitions of terms that have been provided above are useful for discussing human interactions with the environment, and are used in their general meanings throughout this manuscript. While this research draws inspiration from all approaches to human-environmental research, and sociological theory broadly, it leans most strongly on resource entitlements theory of the political economic tradition (e.g. Adger & Kelly, 1999).

Throughout literature concerned with human impacts from the environment, stress is a common theme. In the earth systems approach, stress is often discussed in terms of a perturbation or shock to a system (Gallopín, 2006), in the critical approach stress is typically described as a strain or difficulty that an individual or household must overcome (Füssel, 2007), however neither conceptualization is exclusive of the other (O'Brien & Leichenko, 2000). In all cases, the concept of stress is important and multidimensional. Stress can be applied to a system, for example a drought can stress the system of formal and informal political institutions that govern water use (e.g.; Wutich, York, Brewis, Stotts, Roberts, 2012), and stress the community's wellbeing more generally (e.g. Wutich et al., 2014) or stress an individual or household more directly, for example famine can stress individual or household access to food (e.g. Watts & Bohle, 1993). This stress then, can be related to myriad hazards, including, famine, pollution, power failure, or extreme heat. The general resilience of a community, or the relative distribution of vulnerability within a community, will have large effects on how these stresses impact individuals. However, this relative resilience or vulnerability is not static: systems of power and distributions of entitlements change over time, as do the nature of hazards themselves.

In the political economy and development studies orientation researchers have looked at individuals' entitlements to material and non-material resources and their capacity to call upon those resources through physical and political means (Adger & Kelly, 1999; Sen 1990; Chambers, 1989). Using this framework, social vulnerability is the product of social composition, where the exposure to risk is considered but controlled over a community or region. In addition, this orientation attempts to account for the adaptive strategies of those individuals, as well as the upstream causes, and downstream impacts of those strategies and behaviors. Therefore, borrowing ideas from the earth systems approach, it is essential to treat social composition as dynamic and attempt to anticipate how individual actors' adaptive strategies will come at the expenses or benefit of other individuals in a community subjected to a hazard (Walker et al., 2002). As an example, if during an electrical blackout in a region dependent on electricity, individuals with high incomes and access to commercial resources ran gasoline generators, those privileged individuals would increase the demand for gasoline higher than the baseline normal, the resulting price increases would reduce less privileged individuals' access to gasoline for more traditional uses, like transportation. Or in a more salient example to our own research, if a high-status community uses their social and political capital to convince an electrical utility to invest in new poles and transformers in their neighborhood, they are increasing their resilience to blackout hazards at the direct cost of increasing worse-off neighborhoods vulnerabilities, because the utility can only upgrade so many components at a time. In this way, individual vulnerabilities are dynamic and not determinable by one household's relationship with electrical resources. I argue, that to better predict these interactions researchers interested in building community resilience, or reducing social vulnerability, need to understand the *social mechanisms* that drive adaptive behaviors. (Hedström & Ylikoski, 2010; Adger, 2006, 2000; Walker et al., 2002; Hedström, Swedberg, Hernes, 1998). Most broadly, a mechanism in the sense meant here, "generates and explains an observed relationship" (Hedström, Swedberg, Hernes, 1998, p. 1), for example, between a vulnerability indicator and hazard impact or health outcome.

What are Mechanisms?

Social mechanisms are an integral component of analytical sociology, and of the chapters that follow. Analytical sociology is a particular epistemic approach to sociology that has been well defined by scholars such as Peter Hedstrom, Peter Bearman, and Jon Elster (Hedström, Bearman, Bearman, 2009). Rooted in Mertonian middle-range theory, social mechanisms help explain phenomena via causes that are smaller than the large-scale social structure—the grand theories of which traditional historical sociology was focused—and larger than the strictly psychological or, "detailed orderly descriptions of particulars that are not generalizable at all." (Merton, 1968, p. 39). While much sociological theory today would be considered middle-range by mid-century standards, insofar as it is focused on building theory that can generate hypotheses which can be empirically tested, analytical sociology has evangelized the concept. The fundamental elements of an analytical sociological perspective, which have been employed in the chapters that follow, are based on four deeply interrelated ideas. First, an analytical methodology uses an epistemology based on structural individualism, i.e. phenomena at higher levels of scale must be explainable by relations at lower levels of scale, and that to explain in a scientific sense is to identify the "entities, activities, and relations" that produce a phenomenon (Hedström & Bearman, 2009, p. 8). Fundamentally, this implies that social facts and structures are always explainable in terms of individual behaviors. Structural individualism is related to, but less restrictive than, methodological individualism in that it "emphasizes the explanatory importance of relations and relational structures" (Hedström & Ylikoski, 2010; Hedström & Bearman, 2009 pg. 8). Because this idea can often be met with resistance, especially from critical scholars, it is worth noting that methodological structural individualism is not the same as political individualism, nor does it require adherence to a particular motivational theory, e.g. rational choice theory.

The second idea is that those "entitles, activities, and relations" which explain phenomena operate mechanistically. This is not to say that all (or perhaps any) social realties can be reproduced on an engineer's schematic, but it is to say that social realties are constructed out of parts, each of which can be understood on its own, and in relation to other parts that together produce an outcome. Social mechanisms, then, consist of knowable and unique entities, or parts, that on their own and via relations with other parts cause an outcome. Thus, a social mechanism is a specific set of parts related in such a way that they predictably produce an outcome—therefore, explaining social outcomes is done by understanding the mechanism that produce them (Hedström & Ylikoski, 2010; Hedström & Bearman, 2009; Stinchcombe, 1991).

Third, analytical inquiry is fundamentally interested in "achieving causal depth", i.e. getting to the bottom of what is causing observed social phenomena. Because social phenomena are produced by individual behaviors, and individual behaviors produce relations that create social structures, which influence behaviors, a deep inquiry attempts to understand both how actors are influenced by, and produce their, social structure. Illuminating this depth not only provides a satisfying explanation for observed social phenomena, but also provides opportunity to identify dysfunctional social structures, values, or norms, and propose solutions for radical change. This feels particularly important in the face of growing global environmental risks that our social institutions have thus far failed to manage, and that are often disregarded by the U.S. public.

The fourth and final idea underpinning an analytical orientation is implicit in the first three, bridging the micro and the macro. Because social phenomena are too complex to model from purely micro interactions, and macro structures are known to have a great deal of influence on outcomes, social scientist should operationalize both micro and macro features in their analyses. A general rule to this type of analysis is that while micro features will depend on macro features, not all micro features will be equally affected by the macro, and at the same time, while macro features necessarily depend on micro features, the relationship from micro-to-macro is not causal, but rather a "parts-to-a-whole" relationship (Hedström & Bearman, 2009, p. 10). This is due to the simple tautology between the two: individual behavior does not *cause* social structure, it *constitutes* social structure. While applying these ideas to environmental hazards research is a novel contribution in itself, it more importantly presents a wealth of opportunity for future research. Hazards research conducted in the tradition of analytical sociology may yield new insights about why we often fail to manage risks, and why even when we do, protection is not distributed equitably. Because the answers provided using an analytical perspective are deep, causal, and mechanistic, they promise to be more actionable than other approaches to this work.

Social Vulnerability Theory

Across the environmental hazards literature several widely acknowledged indicators of social vulnerability have been identified (Fatemi, Ardalan, Aguirre, Mansouri, & Mohammadfam, 2017; Adger, 2006; Cutter, 1996; Cutter, Emrich, Webb, & Morath, 2009; Romero-Lankao, Qin, & Dickinson, 2012; IPCC 2014). "Generally accepted" vulnerability indicators typically represented at the neighborhood and larger scale include socioeconomic status (SES), age, gender, and racialized group affiliation (Hochman, 2017; Cutter, Boruff, & Shirley, 2003, p. 245). Though these indicators all theoretically correlate with increased harm from a hazard, each indicator bears on outcomes through different pathways (Few, 2007). In perhaps the most widely used framing of social vulnerability, the concept is broken into three pieces: sensitivity, adaptive capacity, and exposure (IPCC 2014c; Adger, 2006). As with other jargon in this space, there is ongoing debate about what, exactly, these three terms mean, and several different equally conceivable definitions for each (Kuan-Hui, Hsiang-Chieh, & Thung-Hong, 2017; IPCC 2014b,c; Lorenz, 2013; Romero-Lankao, Qin, & Dickinson, 2012;). Dependent on exact definitions, each vulnerability indicator operates on and through some combination of these three components. As an example, income is widely used as a vulnerability indicator. Theoretically, income indicates vulnerability through modification of an individual's sensitives, insofar as they may have older housing stock that is more sensitive to the force of wind or to the radiation of the sun, it will also modify adaptive capacity by affecting individuals' ability to purchase tools that will help them mitigate or recover from hazards impacts, and it will modify exposure by constraining the locations that individuals are able to afford to live. What can be seen in this example is that income is an indicator that operates through several pathways to modify several components of vulnerability. Not all indicators act this way however, some indicators, like age, may indicate vulnerability by modifying physiological sensitivity to heat, for example, while also modifying adaptive capacity by effecting an individual's social and political power. Continuing with age as an example, one would not except age to affect an individual's exposure to a hazard, though in some cases it may. For instance, being of retirement age may reduce exposure to work-related hazards.

Other differences between indicators also becomes apparent. Some indicators, like income, likely operate at different scales; wealthier neighborhoods likely have a protective effect for all residents of the neighborhood, including poorer households, through neighborhood level pathways like exposure or political capital. However, except in an extreme case (e.g. a retirement community) neighborhoods with lower or higher average ages are unlikely to have causal pathways at that scale. Finally, it may be considered reasonable to modify some indicators directly in order to modify outcomes, but for others this may not make sense. Modifying the indicator of income, for example, could very well help reduce vulnerability to all sorts of hazards through any number of pathways, including across scales. It could be reasonable 1. to provide income assistance to households to reduce vulnerability, and/or 2. to provide relocation programs or housing subsidies in order to decrease the number of poor households that are in poor neighborhoods. However, these options are not equally reasonable to suggest about age as a vulnerability indicator. It would not likely be helpful to reduce the number of old people in neighborhoods with high average ages, nor would it be reasonable, or possible, to suggest changing individuals' ages to reduce their vulnerability.

Using examples between two vulnerability indicators, income and age, I have attempted to demonstrate the heterogeneous mechanisms through which common vulnerability indicators predict negative outcomes—often confusing a traditional "vulnerability = exposure + sensitivity + adaptive capacity" framework. To date, these indicators have been widely operationalized as a homogenous suite of predictors of negative hazard-health outcomes. Indeed, in a practical sense, understanding the specific pathways through which these indicators operate may be moot in some cases, e.g. as a society we may rather provide income assistance that can be used to purchase or pay to run air conditioning than provide conditioned air directly to households. However, in other cases understanding the pathways through which these indicators operate is essential to addressing their unwanted effects (for a similar argument see Few, 2007). While we cannot change individuals' ages, we can encourage children to check on elderly relatives during heat waves, or design risk messaging targeting older individuals to overcome optimism bias (Lane et al., 2014; Sampson et al., 2013; Abrahamson et al., 2008; Weinstein, 1980). At the same time, social vulnerabilities are also intersectional, and at present, we lack an understating of the unique ways that multiple vulnerability indicators may intersect to generate unique outcomes. Ultimately, being aware of the unique pathways through which each vulnerability indicator operates will allow us to address hazard vulnerability in higher fidelity, and thus more effectively protect human lives and well-being.

However, to date, there has been little to no empirical research that establishes the explanatory mechanisms that are often implied as the underlying causes of social vulnerability to environmental hazards as a manifest phenomenon. For this reason, there is little to no documentation of any variability between the specific mechanisms that cause vulnerability across different hazards or places. At the moment, we have a limited understating of questions such as: How and why does income negatively correlate with hazard vulnerability? How and why does age positively correlate with vulnerability? Are these reasons the same in all places and for all hazards? The answers we do have to these questions often lack nuance and provide few certainties. Grand theories exist to answer these questions, and in many cases reasonable assumptions can be made about the intervening mechanisms, however little to no empirical documentation of those mechanisms exist. While answering these questions is of fundamental interest to basic social science, leaving them unanswered also presents practical applied constraints. Without a thorough understanding of the intervening mechanisms that cause social vulnerability to manifest, we do not know if emergency planers who are now using "all-hazards" risk management models are effectively, and equitably, managing risk. This will be increasingly problematic as societies face growing risks from climate change, geopolitical instability, and resource constraints.

Implications for Practice

While historically, the hazards and vulnerability community has been somewhat separated from the disaster and emergency management community, there have been pushes to better integrate those schools of thought and practice (National Research Council, 2006). To that end, environmental hazards research conducted from an analytical sociological perspective could be valuable to emergency management (EM) practice. This is especially the case as the current propagation of all-hazards emergency planning fails to address the unique causes of negative outcomes that likely differ between different hazards and places (Cutter, 1996). The traditional approach to EM may advise public health department to deploy resources to socially vulnerable neighborhoods during heat waves, but an all-hazards approach may not be suitably sensitive to the unique needs of those communities. Nor is an all-hazards approach well-suited for targeting specific interventions under specific and unique circumstances. A mechanistic approach, on the other hand, could help EM and public health practitioners identify the most effective intervention points for particular hazards in particular communities.

What Follows

The research presented in the chapters that follow attempt to fill this gap in our intellectual investigation of hazard risk and in our current risk and emergency management planning by demonstrating three novel examples of mechanism-focused social vulnerability analysis. In this framework, social vulnerability is operationalized through pathways or processes, within each of which potentially different mechanisms may generate outcomes independently or in concert. This framework requires high-resolution data from individuals and households on the causes, effects, and adaptive strategies that exist for different hazards in different places, and is directly at odds with one-size-fits-all all-hazards planning, and with shallow analyses of structural vulnerability based solely on demographic indicators. By adopting a mechanisms-oriented approach to vulnerability assessments, academics will have higher resolution data with which to understand the nuanced relationship between people and their environment, and practitioners will be better positioned to intervene in the most effective ways to equitably and sustainably protect communities.

In chapter two, I used an iterative exploratory model building technique to analyze data from household surveys in Phoenix, AZ. Exploratory factor analyses were used to specify increasingly complex structural equation models that attempted to explain the causal pathways from traditional indicators of social vulnerability to heat-illness outcomes. This chapter most saliently demonstrates a mechanisms-oriented social vulnerability analysis, and reveals surprising and often counter-intuitive findings about what does and does not matter when trying to predict negative heat-health outcomes. Social vulnerability indices and maps are now a standard public health tool used to inform both emergency response planning as well as locations for future investments in risk mitigation or capacity building. However, many social vulnerability indices may not reflect inter-household vulnerability, nor the nuanced mechanisms that create vulnerability. The most predictive model in this chapter failed to explain over half the variation in heat-health outcomes reported on the survey, suggesting that common ideas about what drives heat illness may be incomplete. More exploratory work, including inductive qualitative analysis, is needed to better understand the drivers of vulnerability to heat in Phoenix, AZ. Systematic mechanisms-oriented hypothesis testing can help us understand if those drivers are transferable to different hazards or locations.

In the third chapter, I present an analysis of household interviews about a concurrent extreme heat power failure event in Phoenix, AZ. The risks of both power failure and extreme heat are raising, as is the risk of a concurrent event (Mikellidou, Shakou, Boustras, & Dimopoulos, 2018; Vose, Easterling, Kunkel, LeGrande, & Wehner, 2017; Klinger, Owen, & Landeg, 2014). Understanding current household adaptive strategies to such an event and the relationship between those strategies, traditional vulnerability indicators, and constructed social structures will not only illuminate how vulnerability may manifest, but is of direct interest to emergency managers who may have to plan for such an event. Using the Model of Private Proactive Adaptation to Climate Change (MPPACC) this chapter focuses on the role of risk and adaptation appraisal as antecedents to protective behavioral intentions, and the role of social vulnerability (as a latent phenomenon) in moderating those relationships (Grothmann & Patt, 2005). Results suggest dependences between risk and adaption appraisal, and a significant influence from social vulnerability. This chapter helps explain why individuals with a high perception of risk may not always take the protective actions that EM practitioners would like, or expect, them to.

The fourth chapter furthers my investigation into the usefulness of risk perception as an antecedent to adaptive behavior. Using data from household surveys in Phoenix, AZ and Detroit, MI, I used structural equation modeling to test direct and mediated relationships between previous experiences with heat illness, the perceived risk of high temperatures, and heat-adaptive behaviors. Models also examined the role of adaptive capacity as a structural moderator of specified relationships. Results from this chapter challenge common assumptions about why or how risk perception sometimes corelates with adaptive behaviors, and makes a strong argument for the inclusion of social structural variables in any model of adaptive behavior. Large amounts of resources are currently spent polling American's on their risk perceptions to all number of hazards, under the belief that this information is salient for policymakers, including emergency managers and public health practitioners (Howe, Marlon, Wang, & Leiserowitz, 2019; Esplin, Marlon, Leiserowitz, & Howe, 2019; Leiserowitz, 2006). Thus, understanding if, and under what circumstances, risk perception may precede self-protective behaviors is incredibly valuable both for advancing basic social science and for designing efficient and effect risk messaging.

This dissertation finishes with a fifth and concluding chapter focused on synthesizing the lessoned learned from the previous three chapters, and suggests directions for future research on human vulnerability to environmental hazards based in an analytical sociological orientation.

CHAPTER 2

THE SOCIAL AND BEHAVIORAL MECHANICS OF HEAT VULNERABILITY IN PHOENIX, AZ

INTRODUCTION

Heat exposure is a leading cause of weather-related mortality and morbidity globally, and heat impacts on human health and wellbeing have been increasingly scrutinized (Sheridan &Allen, 2018; Petitti et al., 2016; Noelke et al., 2016; Gasparrini et al., 2015; Lee, 2014; Harlan, Declet-Barreto, Stefanov, & Petitti, 2013). There is high confidence in scientific findings that ongoing climate change and urbanization will lead to an increase in per capita heat exposure over the coming decades (IPCC, 2013; Georgescu, Moustaoui, Mahalov, & Dudhia, 2013). Overall, there is high confidence that increased warming will lead to worsening health impacts (Ebi, 2018). Though precise changes in more nuanced measures of heat exposure, which may be better correlates with specific heat-health outcomes, are harder to predict (Hondula, Georgescu, & Balling, 2014). At the same time, many studies indicate that social and behavioral factors may be better predictors of heat mortality and morbidity than exposure alone, both at present and in the future (Petitti et al., 2013; Reid et al., 2009; Stafoggia et al., 2006).

Work analyzing exactly which social and behavioral factors precede heat illness outcomes has mostly consisted either of qualitative exploration of very specific events (Semenza et al., 1996; Klinenberg, 2002), or of quantitative analysis of aggregated relationships between demographic or spatial characteristics and exposure or health outcomes (Chow, Chuang, & Gober, 2011; Reid et al., 2009; Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006). Within the latter group, heat-health research has taken various forms. The most common approach has been to compare aggregated measures of excess mortality with a suite of outdoor temperature measures to determine various temperature-response functions (e.g. Gosling et al., 2009). Some place-based studies have excluded mortality data from their analysis altogether, instead investigating or measuring social vulnerability itself (e.g. Chow, Chuang, & Gober, 2011; Wolf, Adger, Lorenzoni, Abrahamson, & Raine, 2010). Still, other studies use a combination of these techniques, for example, comparing place-specific indicators of social vulnerability with aggregated mortality estimates (e.g. Eisenman et al., 2016), or individual mortality cases (e.g. Harlan, Declet-Barreto, Stefanov, & Petitti 2013). Across these studies, many common factors have been investigated. Age, gender, and temperature are the most common variables analyzed likely due to their availability; i.e. age and gender are typically the only sociodemographic variables included in epidemiological studies because of their inclusion in medical records. The next most common variables considered are education level, income, racialized group, and acclimatization (Romero-Lankao, Qin, & Dickinson, 2012). Even fewer studies have analyzed home amenities, or considered behavioral variables (Romero-Lankao, Qin, Dickinson, 2012). In fact, I was not able to find any prior studies that comprehensively examined multiple adaptive behaviors and their effects on heat health outcomes. Understanding those behavioral pathways should help illuminate the reasons that sociodemographic and environmental indicators relate to heat-health outcomes, and in so doing expose effective public health intervention points.

So far, the collective heat-health literature provides an incomplete assessment of how and why some people are more likely than others to suffer or die from exposure to high temperatures. Based on Romero-Lankao, Qin, and Dickinson’s 2012 meta-analysis, only a single variable was understood with both a high level of agreement and a high level of evidence: the magnitude of outdoor temperature, which positively related to heat vulnerability. In the same study, there was high agreement but small or medium evidence that temperature timing, duration, and variance all positively impacted vulnerability. Of measures of human exposure, there was medium agreement and small evidence that urban land use and vegetation were positively related to heat vulnerability, and that total population and open space had no relationship; there was medium evidence that population density had a positive relationship with heat vulnerability. Among sensitivity measures, there was high agreement and medium evidence that preexisting medical conditions positively related to heat vulnerability. Of adaptive capacity measures, there was high agreement and medium evidence that acclimatization and air conditioning were negatively related to heat vulnerability; identification as African American was positively related to heat vulnerability; there was slight evidence that identification as non-white had no relationship with heat vulnerability. There was medium agreement and medium evidence that poverty and deprivation were positively related to heat vulnerability, and that housing quality and social isolation had no relationship. Finally, there was medium agreement and small evidence that healthcare access was negatively related to heat vulnerability (Romero-Lankao, Qin, & Dickinson, 2012). Exact measurement of the variables reviewed in Romero-Lankao, Qin, and Dickinson's 2012 review (e.g. data sources and scales) varied between the 54 papers they analyzed. As such, their results indicate the relative importance and level agreement in the literature for generic variable categories, rather than specific measures.

On the whole, while we have an existing but limited understanding of the macro-scale indicators of heat vulnerability, we still lack a more nuanced understating of the generative causal mechanisms that underlie these relationships, despite calls for an increased focus on causal mechanisms across the social sciences broadly (Hedström & Ylikoski, 2010), and in heat-health research specifically (Gronlund, 2014). At the moment, I have found almost no empirical evidence that explains the pathways that lead from environmental and socioeconomic indicators, through individual behaviors, to potential changes in exposure, and ultimately to changes in heat-health outcomes. To address this gap, and add to the limited body of evidence accounting for heat-health vulnerability, I have conducted exploratory analysis of heat-health survey data collected from 163 households in Phoenix, AZ during summer 2016. Because the existing heat-health literature spans a wide array of methods and includes a large and variable menu of variables, I have chosen to focus on four high-level "generally accepted" social vulnerability indicators (Cutter, Boruff, & Shirley, 2003, p. 245). I hope to better explain previous findings by comparing these indicators with self-reported household level attitudinal, behavioral, and heat illness data. Accordingly, I analyzed the effects of socioeconomic status (SES), age, gender, and racialized group on heat illness outcomes, both directly as well as mediated through mechanisms suggested by the literature.

Results from this work can help guide future heat-health research by informing data collection protocols, experimental designs, or analytical procedures. This work has implications for both social determinants of health and social vulnerability theory that can be used to refine existing arguments and develop new approaches to inquiry. Several novel hypotheses are offered at the end of this chapter to help direct these endeavors.

METHODS

Data. Survey data in Phoenix comes from a multi–university NSF Hazard SEES project titled 3HEAT, which is a collaboration between The Georgia Institute of Technology, University of Michigan, and Arizona State University (NSF# 1520803). The survey instrument consisted of 148 questions that were designed to answer broad research questions on the target population's perception of, incidence of, and adaptions to, heat illness and thermal discomfort. All risk perception questions were randomized in order to mitigate ordering and anchoring biases. Surveys were administered using Kobo Toolbox open source survey software designed using the OpenDataKit (ODK) standard for mobile data collection. 163 surveys were administered between May 25 and December 15, 2016 in the City of Phoenix. Survey administrators in Phoenix relied on the 2010 US Census and 2014 American Community Survey to generate a geographically clustered and socially stratified sampling protocol. The protocol was designed to achieve a representative probability sample of 175 households across 25 Phoenix neighborhoods. At the neighborhood level, the protocol was designed to oversample vulnerable areas and capture a spectrum of distances from the urban core. Every survey was administered in person by a member of the research team in either English or Spanish. All survey participants were offered an incentive of $5 cash. Ultimately, this sampling strategy achieved a final minimum response rate of 31% (RR1) (AAPOR, 2016). Final Phoenix survey respondents generally represented the City of Phoenix based on the 2016 American Community Survey (ACS) from the US Census Bureau (See Appendix B).

Analysis. Based on the existing heat and health literature, I used an iterative exploratory approach to test several vulnerability models using structural equation modeling (SEM) to operationalize latent variables and detect both direct and indirect effects. I was interested in how several independent vulnerability indicators (i.e. SES, age, gender, racialized group), affected health outcomes based on the sample, as well as how those indicator variables related to each other with regards to their effect on outcomes. Before testing specific models, I ran several exploratory factor analyses (EFA) to understand the way that specific questions covaried within banks of questions from the survey dataset (e.g. groups of questions regarding cooling limitations or behaviors, social insulation, or perceived risk). I interpreted EFA's based on knowledge from the literature and used their results to hypothesize underlying latent factors that may explain the data. I then tested latent factors with confirmatory factor analysis (CFA). All CFA models fit well and were subsequently operationalized in the SEM's employed in this paper. Results from independent EFA's or CFA models can be made available upon request to the corresponding author. All CFA models were run in Mplus version 8 on Mac OSX using a robust estimator (WLSMV) (Byrne, 2012; Kline, 2016).

I used an iterative model-building process to explore statistical relationships present in the sample, whereby I tested several plausible pathways to ultimately specify the most parsimonious and best-fitting models possible given theoretical constraints. This process involved multiple steps. First, for each of the four social vulnerability indicators considered in the study, i.e. SES, age, gender, racialized group, I identified several hypothesized causal mechanisms based on the existing literature, or where there was no existing literature, on logical inference (e.g. one can infer that closing window shades during the summer may be related to indoor summertime thermal comfort). I then tested each hypothesized mechanism independently in several 'mechanism-models', and made re-specifications in accordance with theory, and in light of reported global and local fit indices, including x^2 difference tests, and modification indices. After each independent mechanism-model achieved the most parsimonious and most powerful specification possible, I combined them into single vulnerability ‘indicator-models’, to test multiple pathways from one vulnerability indicator to heat-health outcomes and control for effects between mechanistic pathways. Like in the previous step, I then re-specified each indicator-model using the aforementioned methods to achieve the best fit. Finally, I combined each indicator-model into a final multi-indicator-model to control for confounding effects between vulnerability indicators, and their respective mechanistic pathways, and then adjusted the final multi-indicator-model to its most parsimonious and well-fitting form, in consideration of theoretical constraints. Below, I provide a summary of the results from each single indicator-model and the detailed results from the final multi-indicator-model. Full results for all exploratory models are available upon request to the corresponding author. SEM was conducted in Mplus Version 8 using a robust estimator (WLSMV) (Byrne, 2012; Kline, 2016); all models were assessed using exact, relative, and absolute global and local indicators of fit (Thoemmes, Rosseel, & Textor, 2018; Hu & Bentler, 1999).

Variables. In total, I explored 3 outcome variables, 13 mechanism variables, and 6 vulnerability indicator variables. I operationalized 2 mechanisms as latent factors, which predicted 6 measured indicators between them, plus one latent vulnerability indicator, which predicted 3 measured indicators (Table 1). Original survey questions are included in Appendix D. Descriptions of variables are included below.

Table 1. Variables descriptions

Role	Variable	Type			Processing				Scale	
		Indi.	Exog.	Endog.	Orig.	Computed	Composite	Latent	Ord.	Cont.
Outcomes	Outdoor illness			X	X				X	
	Home illness			X	X				X	
	Frequency too hot*			X	X				X	
Mechanisms	Left home due to heat			X	X				X	
	Outdoor work			X	X				X	
	Health status			X	X				X	
	Neighborhood safety			X	X				X	
	Car			X	X				X	
	AC intensity			X		X				X
	AC hours			X		X				X
	AC limitations			X		X				X
	Long-term cooling			X		X				X
	Active cooling			X			X			X
	Passive cooling			X			X			X
	Social insulation			X				X		X
	Risk perception			X				X		X
Vulnerability Indi.	Hispanic/Latino		X		X				X	
	Black		X		X				X	
	Female		X		X				X	
	Age		X		X					X
	Over 79		X			X			X	
	SES		X					X		X
SI indi.	Number of neighbors known (Q45)	X			X				X	
	How often talk to neighbors (Q46)	X			X				X	
	Received assistance from neighbors (Q47)	X			X				X	
	Called a neighbor in an emergency (Q48)	X			X				X	
RP indi.	Risk of summer temperatures (Q05s)	X			X				X	
	Risk of heat waves (Q05h)	X			X				X	
SES indi.	Afford essentials (Q65)	X			X				X	
	Food security (Q66)	X			X				X	
	Utility assistance (Q20)	X			X				X	

Notes: Indi. = indicator; Exog. = Exogenous; Endog. = Endogenous; Orig. = Original; Ord. = Ordinal; Cont. = Continuous; SI = Social insulation; RP = Risk Perception; SES = Socioeconomic Status. *The frequency of being too hot indoors was operationalized both as an outcome and as a mechanism. Indicator variables were used to build latent factors. Exogenous variables are only independent variables. Endogenous variables are predicted by at least one other variable in the model. Original variables are used in their "raw" scored form. Computed variables were generated from two or more original variables through arithmetical manipulation (e.g. divided). Composite variables were computed from two or more original variables via arithmetical manipulation to produce a conceptually higher-level variable. Latent variables were computed from two or more original variables to produce a latent variable that controls for measurement error and is theorized to predict lower-level indicator variables. Ordinal variables are scaled with discrete integers for which distance between numbers is meaningful. Continuously scaled variables are operationalized as real numbers.

Outcome measures. I focus on three outcome measures, one of which is also operationalized as a mediator. I refer to these three outcome measures collectively as ‘heat-health outcomes’ throughout the paper. I believe these three measures reflect both varying severities of physiological distress, as well as important measures of physiological and psycho-emotional health impacts. I asked respondents to report if they had experienced medical symptoms related to heat exhaustion in the last five years, and if so, where they were located when the symptoms occurred.

Frequency too hot. Respondents’ reported how often they were hot inside their homes in the summer from 0 = never to 4 = very often.

Indoor heat illness. Indoor heat illness was coded as 1 and all other cases were coded as 0.

Outdoor heat illness. Outdoor heat illness was coded as 1 and all other cases were coded as 0.

Mechanisms. *Left home due to heat & car*. Some studies have theorized or demonstrated that the ability to transport oneself to a cooler environment may be negatively associated with heat-health outcomes (Sampson et al., 2013). In this study, I asked respondents if they had ever left their home due to being too warm, responses were binary yes/no. I also asked respondents if they had access to a car, which was also recorded as a binary yes/no variable.

Outdoor work. Previous research has demonstrated a strong and reliable effect from exposure on heat-health outcomes (Romero-Lankao, Qin, & Dickinson, 2012). Outdoor work may also be associated with other vulnerability indicators, including socioeconomic status and gender (ACS, 2016). I asked respondents how frequently they were required to work outdoors in the summer, from 0 = never to 4 = always.

Health status. It has been well documented that pre-existing medical conditions can be a reliable predictor of heat-health outcomes (Romero-Lankao, Qin, & Dickinson, 2012). Individual health status is also related to other vulnerability indicators, including SES (Pampel, Krueger, & Denney, 2010; Adler & Newman, 2002). In this study, I measured overall physiological sensitivity with a general self-reported health measure. I asked respondents to rate their health compared to people their age on a 4-point scale from 1 = poor to 4 = excellent.

Neighborhood safety. Previous research has shown that not feeling safe leaving one's home or opening doors or windows may contribute to indoor heat illness (Klinenberg, 2003; Palecki, Changnon, & Kunkel, 2011). I operationalized neighborhood safety using a single measure from the survey. I asked respondents to report how safe they felt in general in their neighborhood on a scale from 1 = very unsafe to 4 = very safe.

Air Conditioning. Previous research has shown that AC access is a highly protective factor against heat illness (Sheridan, 2007; Hansen, et. al., 2011; Banwell, Dixon, Bambrick, Edwards, & Kjellstrom, 2012). I operationalized air conditioning three ways.

- AC intensity. I computed AC intensity by subtracting respondent's self-reported ideal temperature from their self-reported average AC thermostat set temperature to derive their average relative departure from their preferred temperature. Positive values indicated an AC set temperature below their preferred temperature while negative values indicated set temperature above their preferred temperature, thus providing a relative proxy of how liberally, or intensely, AC was typically used.

- AC hours. I asked respondents about their use of air conditioning during 8 3-hour periods throughout the day. I equally summed responses to compute a 0–8 scaled AC hours variable, with 0 indicating no AC use and 8 indicating 24-hour AC use.
- AC limitations. I asked respondents about factors that may limit their use of air conditioning, including the cost of air conditioning or the cost of repairs. Participants responded on 4-point ordinal scales where 1 = not at all limiting and 4 = very limiting. I equally summed responses across 4 limitations questions to compute a 4–16 scaled AC limitations variable, with 4 indicating no AC limitations of any kind and 16 indicating substantial limitations to AC use.

Long-term cooling. I asked respondent homeowners if they had taken any actions to improve the long-term thermal comfort of their home, such as adding insulation or planting trees. I equally summed binary responses across 8 long-term cooling questions to compute a 0–8 scaled long-term cooling variable, with 0 indicating no long-term cooling behaviors and 8 indicating several long-term cooling behaviors. Renters were treated as missing cases.

Active & passive cooling. I used EFA to reduce 19 non-central-AC cooling behaviors and account for unequal weighting between the relative importance of each variable. EFA suggested a two-factor solution, which I interpreted as active and passive cooling behaviors. The active cooling group included 6 behaviors such as using fans, swamp coolers, or window or wall air conditioners. The passive cooling group included 11 behaviors such as wetting skin, using hand fans, or wearing lighter clothes. I did not include 2 cooling behaviors in either measure (drinking alcoholic or non-alcoholic beverages), as these did not fit well in either factor. I decided to include window/room AC in the active cooling group and separately from the independent central-AC variable in part inductively, based on the results of the EFA, and in part deductively, based on literature that suggests that window/room AC does not relate to heat-health outcomes in the same way as central AC (Reid et al., 2009). Supplemental analysis of the final models showed that removing window-AC from the active composite reduced the effect sizes of parameters involving the active variable, but did not change the sign of any relationships. I did not model active or passive cooling composites as true latent factors in the full SEMs because it did not make theoretical sense to assume that each ‘factor’ explained the cooling behavior.

Social insulation/isolation. Social isolation has been regularly studied throughout the heat-health literature, though the evidence for its relevance is weak (Romero-Lankao, Qin, & Dickinson, 2012). In this study, I operationalized social isolation as a latent factor representing positive social *insulation*, predicting 4 survey questions about interactions with neighbors (Q45–Q48) (Appendix D). I use a positive inversion of social isolation in an effort to use more empowering language in social vulnerability discourse, which has been criticized for focusing on negative attributes, contributing to the disempowerment of systemically disadvantaged groups (McEvoy, Fünfgeld, Bosomworth, 2013; Lorenz, 2013; Handmer, 2003). The factor model had excellent global fit in an independent CFA (x^2 = 0.88, p = 0.65; CFI = 1.0; TLI= 1.0; RMSEA= .00, 95% C.I.= 0.00-0.12).

Risk perception. Risk perception has been analyzed as an important antecedent to many types of self-protective health behaviors (Rimal & Real, 2003), including adaptive behaviors to natural hazards—though relatively few studies have analyzed its impact on heat adaptions (Van Valkengoed & Steg 2019; Kalkstein AJ, & Sheridan, 2007). In this study, risk perception was operationalized as a latent factor that predicted two indicator measures: the perceived risk of typical summer temperatures and heat waves. I asked respondents to rate their perception of these risks to their health on a scale from 1 = not at all serious to 5 = very serious. Because the risk perception factor was locally under-identified I was not able to test it in an independent CFA, however, it performed well in full SEMs and both indicator measures were associated with the factor at $p<0.00$.

Social vulnerability indicators. *Socioeconomic status.* Previous studies have operationalized both household level (Naughton, 2002; Huisman, Kunst, & Mackenbach, 2003;) as well as city or neighborhood level SES or SES components (e.g. income) in heat mortality and morbidity research (Fletcher, Lin, Fitzgerald, Hwang, 2012; Reid et al., 2009; Harlan, et al., 2006; Vescovi, Rebetez, & Rong, 2005; Curriero, 2002). This research has generally shown a negative relationship between socioeconomic status and heat-health outcomes (Gronlund, 2014; Kim & Joh, 2006; Klinenberg, 2003). In this study, I re-processed the socioeconomic variable in light of initial results from model exploration. I removed income from the SES factor as the factor performed better without this measure. The relative importance of absolute income for different household under different circumstances may have undermined its utility; relative household income is dependent on household size and expenses (e.g. dependents, debts, medical needs, etc.). The final SES factor included a measure of household food security (Q66), the ability to afford essentials (Q65), and use of utility assistance programs (Q20) (see Appendix D). The SES factor model was just-identified (there were an equal number of free parameters and known values) and so global fit could not be assessed. However, all indicators were significant at $p<0.05$.

*Ag*e. While many studies have shown a positive relationship between age and heat mortality and morbidity (Whitman et al., 1997; Semenza et al., 1999; Naughton et al., 2002; Conti et al., 2005; Fouillet et al., 2006; Kim & Joh 2006; Medina-Ramon et al., 2006; Hutter et al., 2007; Stafoggia et al., 2008; Knowlton et al., 2009; Gronlund, 2014), others have found no association (O'Neill, Zanobetti, & Schwartz, 2003; Davis & Novicoff, 2018). In Maricopa County, within which Phoenix, AZ is located, there is a clear pattern of increased heat-related mortality among older adults. In 2017, 23% of heat-related deaths involved an individual over 75 years of age (MCDPH, 2019), though there is less evidence about patterns between age and morbidity. I explored various old-age variables based on the existing research and found that an over-79 variable best captured any non-linear effects between age and heat-illness in our sample. Thus, I operationalized age two ways in the final models: first, as linear age based on year of birth, and second, as a binary variable where 1 = over 79 and 0 = under 79.

Gender. Gender is frequently included in assessments of social vulnerability to natural hazards and is typically operationalized as a female/male binary (e.g., Cutter, Boruff, & Shirley, 2003; Enarson, Fothergill, & Peek, 2007; Fordham, 2003, Jenkins & Phillips, 2008). Public health and epidemiological studies of extreme heat morbidity and mortality have often included gender and have found generally mixed results (Harlan, et. al, 2014; Basu, 2009; Bell, et al., 2008; O'Neill, Zanobetti, & Schwartz, 2003). In the study, I gave respondents a choice to select between 3 gender options (female, male, or other) in the original survey. Because 'other' was never chosen, I have operationalized gender in the present study as a binary variable where 1 = female, and 0 = male.

Racialized group. The operationalization and conceptualization of 'race' in the modern social sciences has been thoroughly criticized. The two main criticism are: (1) that the vocabulary of 'race' itself essentializes the racial concept, reifying 'race' as an ontological entity that can be validly used in a racist social and political system—often to manifestly or latently discriminatory ends (Hochman, 2017; Omi &Winant, 1994). (2) the use of static institutional classifications of 'race' (e.g. from the most recent US Census) do not account for the dynamic historical socio-political processes of racialization, and are therefore ill-equipped to consider the unique class and cultural differences between racialized political categories, as well as the struggles over defining those categories (Bolin & Kurtz, 2018). Nonetheless, understanding the way that individuals self-identify with racialized categories and how those identities relate to unequal outcomes is an important and common research foci. In this vein, racialized group identity has been widely operationalized in environmental health research (Romero-Lankao, Qin, & Dickinson, 2012; Cutter, Boruff, & Shirley, 2003), and in heat-health research specifically (Anderson & Bell, 2009; O'Neill, Zanobetti, & Schwartzs 2005; Kalkstein & Davis, 1989). I used a broad group identity question on the survey that asked respondents to self-identify with a number of common racialized and ethnic social groups, including African American/Black, or Hispanic/Latino. In this study, I operationalize African

American/Black and Hispanic/Latino group variables as non-exclusive binary responses (i.e., respondents may have selected both African American/Black and Hispanic/Latino group affiliation).

Hypotheses. ***Socioeconomic Status.*** I tested several literature-informed socioeconomic status (SES) models to understand the unique ways that SES may influence heat-health outcomes. Based on previous heat-health research and logical inference, the relationship between SES and negative heat-health outcomes was theorized to be due to: (1) the ability to afford to own and operate air-conditioning (AC), (2) use non-central-AC means to cool oneself, (3) the ability to make long-term modifications to ones environment to make it cooler, (4) the ability to transport oneself to a cooler environment, and (5) feeling safe leaving one's home or opening doors or windows. Thus, the SES indicator-model tested several mechanistic pathways:

1. A central-AC-mechanism, hypothesizing that: heat illness experiences in the home are an extreme example of being too hot indoors, and therefore will be dependent on the frequency of being uncomfortably hot in the home. SES will independently relate to both indoor heat illness experiences and the frequency of being too hot indoors at home. The relationship between SES, and being too hot indoors, or experiencing heat illness at home, will be mediated by AC hours, AC intensity, and AC limitations.
2. A non-central-AC cooling mechanism, hypothesizing that: heat illness will be related to the frequency of being too hot indoors, that heat illness, the frequency of being too hot indoors, and the use of passive and active non-central-AC cooling

behaviors will relate to SES, and that, the relationship between SES, heat illness, and the frequency of being too hot indoors, will be mediated by active and passive non-central-AC cooling behaviors.

3. A long-term home cooling mechanism, hypothesizing that: long-term cooling will negatively relate to the frequency of being too hot indoors at home, and indoor heat illness.
4. A transportation mechanism, hypothesizing that leaving the home to go to cooler places will reduce heat-illness risk, and that having access to transportation will positively relate to leavening the home.
5. A neighborhood safety mechanism, hypothesizing that: a safe perception of neighborhood safety will positively relate to leaving the home due to being too warm indoors, and using passive cooling techniques (which includes opening doors or windows and going into the yard).
6. A health mechanism, hypothesizing that: SES will positively relate to self-reported health, and self-reported health will negatively relate to indoor and outdoor heat illness.

Each of these hypotheses were tested independently in several mechanism-models. Iterative exploration of these models, using local measures of fit and social vulnerability theory, led to the following re-specifications in the final model:

1. I hypothesized that previous heat illness experience will influence non-central-AC cooling behaviors. Thus, I added outdoor heat illness, and bi-directional effects between indoor heat illness and passive and active cooling as well as leaving the home due to being too hot indoors to the model.

2. I added the frequency of working outdoors to the model, to account for plausible outdoor heat illness antecedents for low-SES individuals' (Petitti, Harlan, Chowell-Puente, & Ruddell 2013).
3. I hypothesized that passive and active cooling would not relate to the frequency of being too hot indoors, which is consistent with operationalizing non-central-AC cooling as an effect of cooling-constraints, rather than viable cooling strategies, i.e., I theorized that non-central-AC cooling will not improve thermal comfort.

Age. Previous research has suggested that the relationship between age and heat illness, when it exists, may be due to (1) optimism bias and otherwise inaccurate perceived risk among older adults (Lane et al., 2014; Sampson et al., 2013; Abrahamson et al., 2008; Weinstein, 1980), and (2) social isolation which can prevent others from helping at-risk individuals keep cool (Reid et. al., 2009; Klinenberg, 2003; Naughton, et al., 2002; Semenza, et al., 1996). While many studies have shown elderly living alone to be at greater risk than elderly who are not alone, other studies have found that not all forms of social connections are beneficial; in particular, bonding networks may in some circumstances exacerbate the risk of heat illness (Wolf, Adger, Lorenzoni, Abrahamson, & Raine, 2010). While there are other physiological reasons that age may be associated with negative heat-health outcomes (e.g. co-morbidities), I did not use the health variable (Q60) from the survey as it was explicitly phrased to account for respondent age (see Appendix D). Likewise, I did not include feeling too warm indoors in age models because the literature suggests that a lack of thermal awareness is a risk factor associated with age (Lane, et al., 2014; Guergova & Dufour 2011; Hansen, et al., 2011; Conti, et al., 2007; Worfolk, 2000). At the same time, studies of the 1995 Chicago heat wave have suggested that the comparative health advantage among 'Hispanic' groups may have been due to increased social insulation or social capital (Klinenberg, 2002; Hansen, Saniotis, & Nitschke, 2013). Therefore, to explore relationships between age and heat-health outcomes in the sample, I hypothesized the following 2 age mechanisms:

1. A risk perception mechanism, hypothesizing that: age will be positively associated with home heat illness, and this relationship will be mediated by risk perception and the subsequent adoption non-central-AC and central AC cooling behaviors.
2. A social insulation mechanism, hypothesizing that home heat illness experiences will be related to age and social insulation directly as well as mediated by AC limitations and non-central-AC and central AC cooling behaviors.

Both of these hypotheses were tested independently in mechanism-models. Iterative exploration of the mechanism-models, using local measures of fit and heat-health theory, led to the following re-specifications in the final age indicator-model:

1. I re-specified a non-recursive model to test whether cooling behaviors fit better as a result of age, social insluation, and heat illness experiences, and if those relationships in turn related bi-directionally to indoor home heat illness.
2. Age (as a linear variable) was replaced with a binary age-over-79 variable to account for non-linear effects from age on heat-health outcomes

Gender. Sociological and anthropological analyses have demonstrated that gender identity and socialization shape hazard experiences through mechanisms such as access to resources, hazard exposure, institutional biases, social ties, and caregiving roles (Enarson, Fothergill, & Peek, 2007). Gender's potential role in shaping vulnerability to extreme heat specifically, however, has not yet been characterized. Public health and epidemiological studies of extreme heat morbidity and mortality often include gender in their analyses, although generally without proposing specific mechanisms by which gender might act on heat vulnerability (Basu, 2009). These studies show variable results on gender and heat risk, finding: higher mortality rates for women (Diaz et al., 2002; Ishigami et al., 2008; Stafoggi, et al., 2006; Yu et al., 2010); among older women (Cadot, Rodwin, & Spira, 2007; D'Ippoliti et al., 2010; Poumadere, Mays, Le Mer, & Blong, 2005); among older men (Diaz, Linares, Tobias, 2006; Donoghue et al., 1995; Robine, Michel, & Herrman, 2012); slight differences in heat-related causes of mortality but relatively similar risk ratios (Harlan et al., 2014; Monteiro, Carvalho, Oliveira, & Sousa, 2013); higher rates of emergency medical service activation in men (Uejio et al., 2016), or no substantial difference in mortality (Bell et al., 2008; O'Neill, Zanobetti, & Schwartz, 2003).

Gendered patterns in heat morbidity and mortality are also present in the study area. Maricopa County, the surrounding county for the city of Phoenix, exhibits male-dominated patterns of heat mortality and illness, with men accounting for 73% of recorded heat deaths in 2006–2015 (MCDPH, 2016) and 69% of reported cases of heat illness from 2008–2012 (MCDPH, 2014). Some of these patterns may be driven by employment, as men comprise 72% of building and grounds maintenance workers, 96% of natural resource, construction, and maintenance workers, and 77% of production, transportation, and materials moving workers (ACS, 2016). Men also make up 64% of the single (i.e., non-family) homeless population in Arizona as a whole (Arizona Department of Economic Security, 2017). While men are more likely to die regardless of place of injury in Maricopa County, women are twice as likely to die indoors from heat as outdoors (MCDPH, 2016). The predominance of an indoor place of injury for women may indicate that women are less likely to experience occupational exposure and more likely to be constrained in their cooling behaviors. Indoor cooling constraints would be consistent with the higher rate of poverty among women in Maricopa County (1.15:1.00). Social or physical explanatory mechanisms for the variation in gendered patterns of heat mortality and morbidity are not conclusively known. In the United States specifically, possible explanations include the high rate of women in poverty (ACS, 2017) as well as the overrepresentation of men in outdoor labor (ACS, 2017) and unsheltered homeless populations (U.S. Bureau of Housing and Urban Development, 2017). Thus, although gendered heat-health outcomes are variable and their causes not well understood, there is one specific mechanism that I hypothesized in the gender indicator model.

1. An outdoor work mechanism, hypothesizing that: Women (men) will be more likely to report heat illness indoors (outdoors) compared to men (women) in the sample, and this effect will be mediated by the frequency of working outdoors.

Racialized group. Within social vulnerability frameworks, racialized group is frequently used as an indicator of vulnerability to environmental hazards (Bolin & Kurtz, 2018; Wisner, Blaikie, Cannon, & Davis, 2004; Cutter 2003). For example, percent African American/Black and percent Hispanic/Latino are both included in Susan Cutter's archetypal social vulnerability index (SoVI) (Cutter, 2003). However, evidence for the relationship between racialized group and heat-health outcomes is largely inconclusive. Some, mostly epidemiological studies focusing on heat hazards in the US, have shown strong associations with minority group membership and heat-health outcomes (e.g. Hansen, Saniotis, & Nitschke, 2013; White-Newsome, O'Neill Gronlund, Sunbury, Brines, & Parker, 2009; Gosling, Lowe, McGregor, Pelling, & Malamud, 2009; CDC, 2001; Kalkstein & Davis, 1989). While other epidemiological reviews have not found an association between racialized group and health outcomes at an individual or neighborhood level (Pillai et al., 2014; Madrigano, et al., 2013; Basu, Pearson, Malig, Broadwin, & Green, 2012; Green et al., 2010; Anderson & Bell, 2009).

Furthermore, evidence suggesting the precise mechanisms which may create unequal environmental health outcomes based on racialized group in the United States are largely lacking. Two exceptions being O'Neill, Zanobetti, and Schwartz's 2005 conclusion that central-AC prevalence could explain as much as 64% of the disparity in heat-health outcomes between 'blacks' and 'whites' in their study (O'Neill, Zanobetti, & Schwartz, 2005), and evidence from Phoenix, AZ which shows that 'Hispanic' groups had an increased perception of the risk of heat (Kalkstein, AJ, & Sheridan, 2007), and that individuals who identify as non-'white' are approximately twice as likely to work outdoors than those who identify as 'white' (Harlan, Chakalian, Declet-Barreto, Hondula, & Jenerette, 2019). The reality that both of these suggested mechanisms relate directly and primarily to socioeconomic status suggests that differences between studies on racialized groups and heat-health outcomes may be due to differences in the control variables included in previous analyses. It seems quite likely that the primary mechanisms that have made racialized group a meaningful vulnerability indicator are distal; minority group membership in the United States is often associated with lower-income, hotter neighborhoods, less green space, and more outdoor work (Gronlund, 2014; Harlan, Declet-Barreto, Stefanov, & Petitti 2013; Stoecklin-Marois, Hennessy-Burt, Mitchell, & Schenker, 2013; Harlan, Stefanov, Larsen, Brazel, & Prashad, 2006; O'Neill, Zanobetti, & Schwartz, 2005). While racialized group status is often operationalized as a white/non-white binary, heat and health studies have found unique—though mixed—relationships between Hispanic/Latino group identification and health outcomes. A 2013 meta review found that individuals who identified as Hispanic/Latino had a 17.5% lower all-cause mortality risk compared to other racialized groups (Ruiz, Steffen, & Smith, 2013). However, other studies in New York and Phoenix found that Hispanic/Latino identification and neighborhoods with increased Hispanic/Latino residents had increased heat illness incidence (Fletcher, Fitzgerald, & Hwang, 2012; Uejio et al., 2011; Lin et al., 2009).

In light of these mixed results, I suspected that the most fruitful use of racialized group identity in the study would be as a control variable. Nonetheless, based on the existing literature I hypothesized 1 African American/Black mechanism and 3 Hispanic/Latino mechanisms.

1. A central AC mechanism, hypothesizing that: self-identification as African American/Black would positively relate to heat illness, and that relationship would be mediated through central-AC use.
2. An outdoor heat illness mechanism, hypothesizing that: self-identification as Hispanic/Latino would positively relate to outdoor heat illness and that relationship would be mediated through outdoor work.

3. A social insulation mechanism, hypothesizing that: self-identification as Hispanic/Latino would be negatively associated with heat illness, and that relationship would be mediated through social insulation.
4. A risk perception mechanism, hypothesizing that: self-identification as Hispanic/Latino would be negatively associated with heat illness, and that relationship would be mediated through risk perception.

Combined model. Based on the results of single-indicator model exploration, I specified a multi-indicator model to test for possible confounding between social vulnerability indicators. Social outcomes are often the result of interactions between socio-demographic traits and historical social sociopolitical structures. For example, associations between racialized group identity and heat-health outcomes may be confounded by socioeconomic status, if minority groups systematically earn less than the predominate demographic; similar confounding may occur with age, and gender. The final model combined hypotheses from the previous models (above) and allowed for covariance between multiple independent variables (Figure 1). Iterative exploratory re-specifications of the multi-indicator model led to the following adjustments:

1. Paths from AC cooling behaviors and constraints to indoor home heat illness were added to test for partial mediation through the frequency of being too hot indoors at home.
2. A path from home heat illness to long-term home cooling modifications were added to account for a bidirectional relationship between heat illness experience and long-term home cooling modifications as a form of non-central-AC cooling.

3. A correlation between outdoor work and risk perception was added.

4. A correlation between SES and risk perception was added.

5. A correlation between social insulation and neighborhood safety was added.

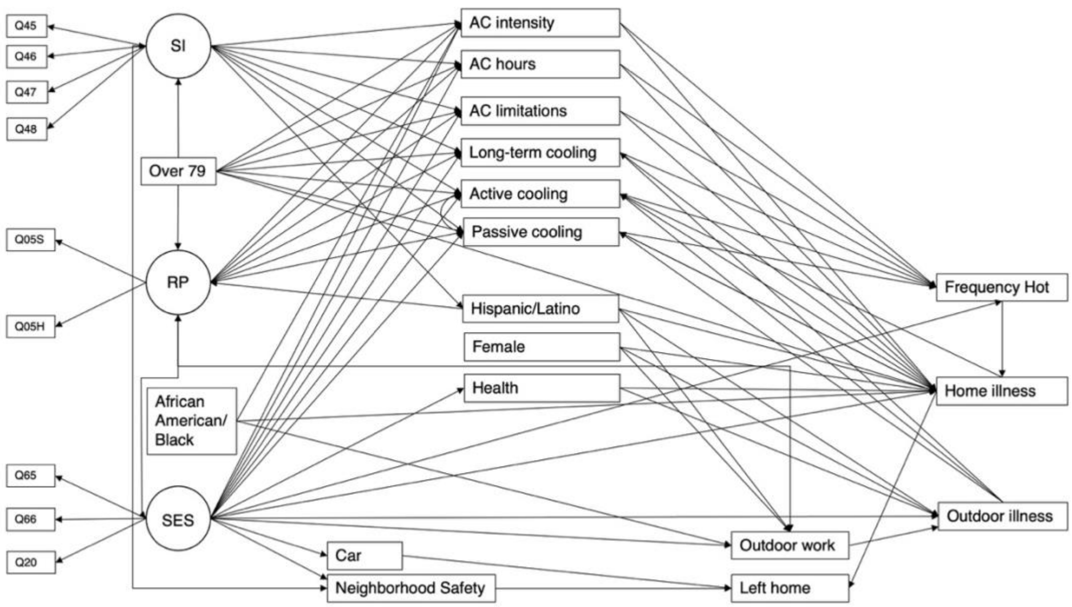

Figure 1. Combined model as specified. See Table 1 for variable descriptions.

RESULTS

Single indicator-models. ***Socioeconomic Status.*** The SES indicator model showed good global fit ($x^2 = 106.56$, $p = 0.28$; CFI = 0.97; TLI= 0.96; RMSEA= .02, 95% C.I.= 0.00-0.05). In general, SES demonstrated a moderate negative relationship with heat illness experiences. Experiencing indoor home heat illness was related to leaving the home if too hot indoors (StdB = 0.53, $p = 0.01$), and using more active non-central-AC cooling methods, including window AC and fans (StdB = 0.30, $p < 0.05$). Controlling for other effects, the frequency of being too hot indoors demonstrated the single strongest relationship with indoor home heat illness (StdB = 0.53, $p < 0.01$). While the direct effect between SES and indoor home heat illness was weaker in the mediated model, it was still present at a 94% confidence level (StdB = -0.32, $p < 0.06$). Similarly, the relationship between SES and feeling too hot indoors at home was only partially explained via the specified mediators: a medium direct effect (StdB = -0.22, $p < 0.02$) remained even after accounting for total indirect effects (StdB = -0.14, $p < 0.01$). Outdoor heat illness had a strong direct association with SES (StdB = -0.47, $p < 0.01$), however this relationship was not explained by any specified mediators. Self-reported outdoor heat illness was positively associated with both passive (StdB = 0.19, $p < 0.06$) and active (StdB = 0.19, $p = 0.06$) cooling behaviors.

Age. The age indicator-model had good global fit ($x^2 = 54.5$, $p = 0.34$; CFI = 0.99; TLI= 0.98; RMSEA= .02, 95% C.I.= 0.02-0.06). However, the majority of effects of analytical interest were inconclusive. Age-over-79 demonstrated no effect on indoor home heat illness directly or indirectly. Similarly, neither risk perception or social insulation were significantly related to the age variable, nor did they significantly mediate the relationship between age and heat illness. The only exception was the path from social insulation to long-term cooling, which affected home heat illness in the opposite than hypothesized direction, i.e. increasing (decreasing) social insulation (isolation) was associated with an increase in long-term home cooling modifications, which were in-turn associated with an increase in indoor home heat illness. Risk perception was significantly related to some home cooling behaviors; however, these relationships were most likely operating in the opposite-theorized direction (figure 1). Overall, variance in risk perception was mostly likely related to home cooling behaviors and constraints because decreasing AC intensity (StdB = -0.28, $p < 0.01$), increasing AC constraints (StdB = 0.28,

$p = 0.01$), and increasing reliance on passive cooling (StdB = 0.40, $p < 0.01$), all limit the respondents' ability to mitigate heat risks. However, I did not re-specify the model because no cooling behaviors or constraints that were related to risk perception were also related to the age variable. Finally, despite having no mediated effect on home heat illness, social insulation was significantly related to several cooling behaviors: in addition to long-term cooling, increasing (decreasing) social insulation (isolation) was related to increasing passive cooling behaviors (StdB = 0.23, $p = 0.03$), AC hours (StdB = 0.25, $p < 0.01$), and AC intensity (StdB = 0.28, $p < 0.01$).

***Gender*.** There were no effects between gender, outdoor work, or heat illness with the full survey sample. However, of only respondents who reported any heat illness experiences, those who identified as female (male) were less (more) likely to experience heat illness outdoors, at a 94% confidence level (StdB = -0.32, $p = 0.06$), however, this effect was unlikely to be mediated through the frequency of working outdoors, which was negatively associated with self-reported outdoor heat-illness (StdB = -0.42, $p = 0.11$). There were no indirect effects of gender on outdoor heat illness.

***Racialized group*.** Tests for a mediated relationship between heat illness experience, central AC use or intensity, and self-identifying with African American/Black showed no significant effects between any of the three heat-health outcome variables. Likewise, there were no significant relationships between self-identification with Hispanic/Latino, outdoor work, social insulation, or risk perception and heat illness.

Combined model. Ultimately, the multi-indicator model showed good global fit ($x^2 = 293.24$, $p = 0.07$; CFI = 0.94; TLI= 0.92; RMSEA= .03, 95% C.I.= 0.00-0.04), and largely reflected results from single-indicator models. Figure 1, below, shows paths and estimates for effects for which at least one estimate had a confidence level over 90%. Tables 2a–x show total, direct, and indirect effects from SES, age, and racialized group with indoor heat illness, indoor thermal comfort, and outdoor heat illness only for effects for which at least one standardized path estimate had a confidence level over 90%.

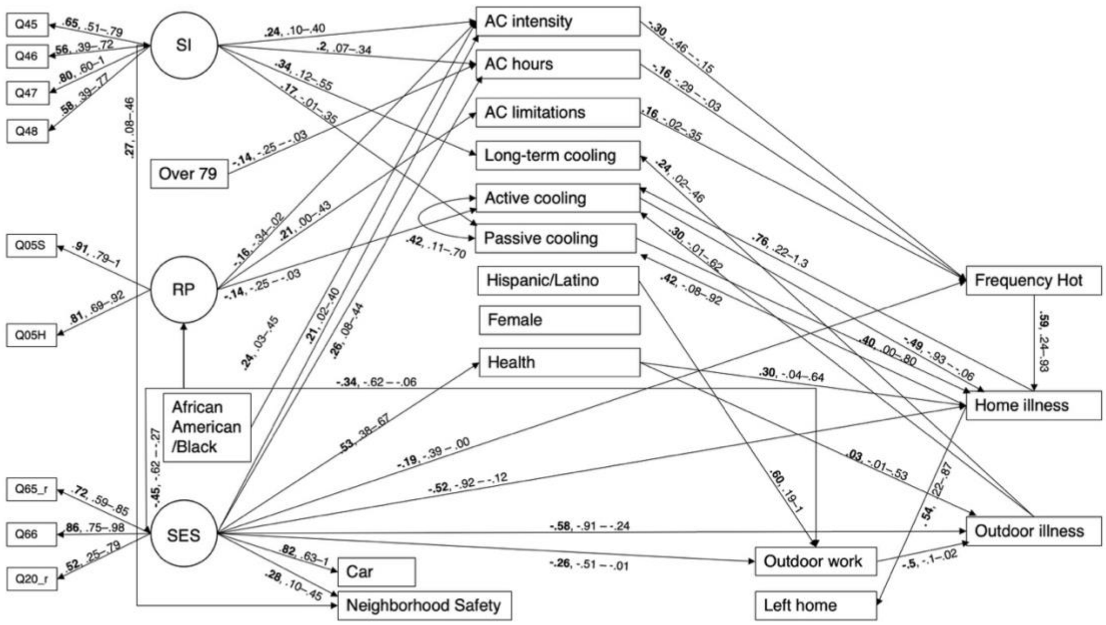

Figure 2. Final multi-indicator model showing standardized estimates and 95% CI's on paths with a standardized confidence level over 90%.

Socioeconomic Status. Considering total effects, SES demonstrated the strongest effects on heat-health outcomes, and the only effects estimated at an over 95% confidence level. This was true for effects between SES and the frequency of being too warm indoors at home in the summer (table 2b), summertime indoor home heat illness (table 2a), and summertime outdoor heat illness (table 2c). However, some indirect effects from SES were counterintuitive, specifically the indirect path from SES to home heat illness via active cooling, and the effect of SES to outdoor heat illness via outdoor work and health. In both these cases, hypothesized mediators between SES and heat-health outcomes attenuated, rather than amplified, the protective effect of SES on heat-health outcomes (tables 2a&c). Increasing SES was associated with a decrease (Std.B = -0.51, p = 0.30) in non-central-AC active cooling behaviors, including the use of window AC, swamp cooling, and fans, and therefore a reduction in the protective effect that this category of behaviors had on indoor heat illness when controlling for other factors, causing the specific indirect relationship between SES and indoor heat illness mediated by active non-central-AC cooling to be positive (table 2a) (figure 2). The frequency of working outdoors in the summer negatively related to experiencing heat illness outdoors in the summer (table 2c).

Table 2a. Total effects from SES to home heat illness *x^2 = 293.24, p>0.06*

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Direct + Indirect	-0.34**	-0.94	-0.03	0.00
Direct	-0.52*	-0.92	-0.12	0.01
Total Indirect	0.18	-0.18	0.65	0.32
Specific indirect via				
Active	0.18*	0.02	0.46	0.00
Passive	-0.04	-0.17	0.07	0.29
Health	0.10	-0.09	0.37	0.17
Frequency hot at home	-0.11*	-0.33	-0.03	0.01
Freq. hot, AC intensity	-0.03 †	-0.08	0.01	0.07
Freq. hot, AC hours	-0.02	-0.06	0.02	0.11
Freq. hot, AC limitations	-0.01	-0.05	-0.02	0.25

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Table 2b. Total effects from SES to the frequency of being too hot indoors at home in the summer *x^2 = 293.24, p>0.06*

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Direct + Indirect	-0.26**	-0.42	-0.10	0.00
Direct	-0.19†	-0.39	0.00	0.05
Total Indirect	-0.07	-0.22	0.09	0.42

Specific indirect via				
AC intensity	-0.06*	-0.12	0.00	0.04
AC hours	-0.04†	-0.08	0.00	0.07
AC limitations	-0.03	-0.08	0.02	0.23

* p < 0.5; **p < 0.01, †p < 0.10 n = 163, df = 259

Table 2c. Total effects from SES to outdoor heat illness *x^2 = 293.24, p>0.06*

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Direct + Indirect	-0.31**	-0.53	-0.08	0.00
Direct	-0.58**	-0.91	-0.24	0.00
Total Indirect	0.27*	0.03	0.50	0.03
Specific indirect via				
Good health	0.14†	-0.01	0.29	0.08
Frequency of outdoor work	0.13	-0.08	0.34	0.21

* p < 0.5; **p < 0.01, †p < 0.10 n = 163, df = 259

Age. There were no total, direct, or indirect effects from age, on heat-health outcomes at confidence levels above 81%, and in most cases, levels were well-below 50% (tables 3a–3b).

Table 3a. Total effects from Age over 79 to home heat illness *x^2 = 293.24, p>0.06*

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Direct + Indirect	0.11	-0.11	0.32	0.34
Direct	0.16	-0.0.8	0.40	0.19
Total Indirect	-0.05	-0.23	0.12	0.55
Specific indirect via				
Active	0.01	-0.07	0.08	0.84
Passive	-0.02	-0.09	0.04	0.48
AC intensity, Freq. hot	-0.02	-0.06	0.02	0.36
AC hours, Freq. hot	0.01	0.00	0.02	0.19
AC limitations, Freq. hot	0.00	-0.02	0.01	0.42
Social insulation, Active	0.00	-0.01	0.01	0.57
Social insulation, Passive	0.01	-0.01	0.02	0.43
Social insulation, AC intensity	-0.01	-0.02	0.01	0.38
Social insulation, AC hours	0.00	-0.01	0.00	0.52

Social insulation, Long-term cooling	0.00	-0.01	0.01	0.80
Social insulation, AC intensity, Freq. hot	0.00	-0.01	0.00	0.38
Social insulation, AC hours, Freq. hot	0.00	-0.01	0.00	0.40
Social insulation, AC limitations, Freq. hot	0.00	0.00	0.00	0.54
Risk perception, Active	0.00	-0.03	0.02	0.71
Risk perception, Passive	0.00	-0.02	0.01	0.71
Risk perception, AC intensity	0.00	-0.01	0.00	0.72
Risk perception, AC limitations	0.00	0.00	0.00	0.87
Risk perception, AC intensity, Freq. hot	0.00	0.00	0.00	0.72
Risk perception, AC hours, Freq. hot	0.00	0.00	0.00	0.74
Risk perception, AC limitations, Freq. hot	0.00	0.00	0.00	0.73

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Table 3b. Total effects from Age over 79 to the frequency of being too hot indoors at home in the summer $x^2 = 293.24, p>0.06$

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Indirect	-0.04	-0.144	0.07	0.50
Specific indirect via				
AC intensity	-0.04	-0.13	0.04	0.33
AC hours	0.02	-0.01	0.04	0.16
AC limitations	-0.01	-0.04	0.02	0.41
Social insulation, Passive	0.00	-0.01	0.01	0.62
Social insulation, AC intensity	-0.01	-0.03	0.01	0.35
Social insulation, AC hours	0.00	-0.01	0.01	0.37
Social insulation, AC limitations	0.00	0.00	0.01	0.54
Risk perception, Active	0.00	-0.01	0.01	0.71
Risk perception, AC intensity	0.00	-0.01	0.01	0.71
Risk perception, AC hours	0.00	0.00	0.00	0.73
Risk perception, AC limitations	0.00	-0.01	0.01	0.72

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Gender. Gender demonstrated no relationships to any other variables specified in the model at better than a 65% confidence level.

Racialized group. There were no total or direct effects from racialized group with heat-health outcomes, however there were 2 specific indirect effects involving racialized group that had estimates with confidence levels above 90%. Self-identification with African American/Black was associated with a decrease in the frequency of being too hot indoors mediated by AC intensity (table 4b), and with home heat illness, mediated by the frequency of being too hot indoors and ac intensity (table 4a). Self-identification with the Hispanic/Latino group was associated with an increase in working outdoors during the summer at a better than 99% confidence level, but not with risk perception or social insulation (figure 4c–4e), nor directly or indirectly with any heat-health outcomes.

Table 4a. Total effects from self-identification with 'black' to home heat illness *$x^2 = 293.24, p>0.06$*

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Direct + Indirect	-0.03	-0.21	0.14	0.70
Direct	0.00	-0.23	0.22	0.98
Total Indirect	-0.03	-0.11	0.05	0.45
Specific indirect via				
Freq. hot, AC intensity	-0.03†	-0.06	0.00	0.09
Freq. hot, AC hours	0.01	-0.01	0.02	0.26

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Table 4b. Total effects from self-identification with 'black' to the frequency of being too hot indoors at home in the summer *$x^2 = 293.24, p>0.06$*

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Indirect	-0.05	-0.31	0.06	0.18
Specific indirect via				
Freq. hot, AC intensity	-0.07*	-0.34	0.00	0.05
Freq. hot, AC hours	0.02	-0.03	0.11	0.24

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Table 4c. Total effects from self-identification with 'Hispanic / Latino' to home heat illness *x^2 = 293.24, p>0.06*

Paths	Std B	Lower 95% CI	Upper 95% CI	p
Total Direct + Indirect	0.12	-1.42	1.66	0.88
Direct	0.10	-1.90	2.10	0.92
Total Indirect	0.03	-0.44	0.49	0.91
Specific indirect via				
Social insulation, Active	0.00	-0.01	0.01	0.55
Social insulation, Passive	0.01	-0.01	0.02	0.41
Social insulation, AC intensity, Freq. hot	0.00	-0.01	0.00	0.31
Social insulation, AC hours, Freq. hot	0.00	0.00	0.00	0.31
Social insulation, AC limitations, Freq. hot	0.00	0.00	0.00	0.56
Risk perception, Active	0.01	-0.04	0.06	0.69
Risk perception, Passive	0.01	-0.03	0.04	0.69
Risk perception, AC intensity, Freq. hot	0.00	-0.01	0.01	0.70
Risk perception, AC hours, Freq. hot	0.00	0.00	0.00	0.72
Risk perception, AC limitations, Freq. hot	0.00	-0.01	0.01	0.69

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Table 4d. Total effects from self-identification with 'Hispanic / Latino' to the frequency of being too hot indoors at home in the summer *x^2 = 293.24, p>0.06*

Paths	Std B	Lower 95% CI	Upper 95% CI	p
Total Indirect	0.00	-0.21	0.20	0.97
Specific indirect via				
Social insulation, Passive	0.00	-0.01	0.01	0.59
Social insulation, AC intensity	-0.01	-0.02	0.01	0.29
Social insulation, AC hours	0.00	-0.01	0.00	0.30
Social insulation, AC limitations	0.00	0.00	0.01	0.57
Risk perception, AC intensity	0.00	-0.01	0.02	0.69
Risk perception, AC hours	0.00	-0.01	0.00	0.72
Risk perception, AC limitations	0.00	-0.01	0.02	0.68

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Table 4e. Total effects from self-identification with 'Hispanic / Latino' to outdoor heat illness *x^2 = 293.24, p>0.06*

Paths	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Total Direct + Indirect	-0.20	-1.88	1.50	0.82
Direct	0.10	-1.80	2.01	0.92
Total Indirect	-0.30	-0.74	0.14	0.18
Specific indirect via				
Frequency work outdoors	-0.30	-0.74	0.14	0.18

* p < 0.5; **p < 0.01, †p < 0.01 n = 163, df = 259

Cooling behaviors. All relationships between central-AC variables (AC intensity, hours, and limitations) and indoor home heat illness were fully mediated by the frequency of being too warm indoors, while non-central-AC passive and active cooling behaviors were unmediated by this variable (figure 2). Active non-central-AC cooling had the single strongest total relationship on indoor heat illness (Std.B = -0.45, p < 0.01), after AC intensity (Std.B = -0.16, p < 0.05), of any meditator besides the frequency of being too hot indoors. Both active and passive non-central-AC cooling behaviors were bi-directionally associated with home and outdoor heat illness. However, only active cooling had a negative effect on home heat illness; passive cooling was positively related to home heat illness in both directions (figure 2). Outdoor heat illness was a positive predictor of long-term and active non-central-AC cooling behaviors, but only active non-central-AC cooling was subsequently negatively related to indoor heat illness (figure 2).

Social insulation & Risk perception. Increasing social insulation was associated with increased cooling capacity even when controlling for SES, while risk perception was associated with a decrease in cooling capacity and an increase in cooling constraints (figure 2). However, there were no indirect effects from age, gender, or racialized group through social insulation or risk perception on heat-health outcomes based on this sample (tables 3a & 3b, 4a–4e).

DISCUSSION

While distal indicators may be able to tell researchers and practitioners where social vulnerability exists in space (e.g. Reid et al., 2009; Cutter, Boruff, & Shirley, 2003), or how it changes over time (e.g. Chow, Chuang, & Gober, 2011), without a comprehensive understanding of the mechanisms that generate vulnerability it is difficult to turn spatiotemporal insight into programmatic action. While there are many reasons individuals experience negative health and wellbeing impacts that can never be fully reflected in an empirical model, I have attempted to increase our understating of these pathways by conducting a mechanism-oriented analysis of social vulnerability in the context of extreme heat in Phoenix, AZ.

In general, the self-reported frequency of being too hot indoors was the best predictor of indoor heat illness when controlling for other independent variables. This suggests that individuals' intrinsic sense of comfort may be closely linked to their personal risk of heat illness. Thus, self-reported thermal comfort may be a skillful predictor of heat illness risk for public health outreach. Suggesting that risk messaging could be designed to encourage individuals to trust their feelings, e.g., "*Trust your gut, if you feel too warm you are at increased risk for heat illness—go to a cool place and avoid strenuous activity*."

In all models, SES retained a moderate negative effect on both indoor and outdoor heat-health outcomes even when controlling for possible mediating or confounding variables. This is particularly interesting for the relationship between SES and thermal comfort, for which specified mediators most closely reflected probable causal pathways. SES may impact heat-health outcomes through risk perception, suggested by the correlation between those two variables, however this was not tested as there was little theoretical basis to do so. Future research should explore alternative explanations for the relationship between SES and heat-health outcomes, including other forms of personal health (e.g. mental or emotional) as possible mediators.

While SES positively related to self-reported health status, health positively, rather than negatively, related to heat illness. This result was surprising and was opposite the uncontrolled bivariate relationship between the personal health and heat illness measures. Thus, the counterintuitive relationship between health and heat illness is likely due to controlling variables in the model, which may confound the typical relationship between health and heat illness (e.g. SES). Also surprising, the frequency of working outdoors in the summer was negatively related to self-reported outdoor heat illness. This may be due either to outdoor workers under-reporting heat-illness symptoms, or alternatively, because outdoor workers may take extra precautions against heat risks.

Previous research shows a relationship between past experience and risk perception, and suggests that increasing perceived risk can increase the likelihood that an individual engages in self-protective behaviors, therefore reducing their vulnerability. Bi-directional results from this study show that while previous experience with both indoor and outdoor heat illness may correlate with an increased use of protective cooling behaviors, it may not always result in reduced vulnerability; i.e. not all protective behaviors result in actual protection. Households that employed high levels of passive (e.g. wet clothing) cooling behaviors were hotter and experienced more heat illness. Individual level longitudinal research is needed to better understand the circumstances in which self-protective behaviors do and do not result in decreased risk. Ultimately, risk communication and public health interventions will need to be based on an understanding of not only typical indicators of vulnerability (e.g. age and risk perception), but on the particular behaviors that do and do not decrease vulnerability and constraints on those behaviors. For example, the significant protective effect of active non-central-AC cooling vs. central cooling is likely due to the compounded bi-directional effect between active cooling and heat illness. Typically, central-AC has a stronger negative effect on heat illness than window or room AC (Reid et al., 2009), and this was true in the single SES-indicator model, suggesting that individuals who experienced heat illness may have increased their use of *supplemental* room-cooling behaviors when controlling for other vulnerability indicators.

Results from this chapter may be used to build a base of evidence documenting the mechanisms of heat vulnerability, which can be referenced when making decisions about how to best prevent negative heat-health outcomes now and in the future. That is, each significant path could be a possible public health intervention point. However, the goal of this study is primarily to orient a discussion on the need for such research, and suggest novel ways to formulate and analyze hypotheses in-line with a mechanism-based epistemological orientation. The statistical integrity of this study was limited for several important reasons. First, all paths in all models should be interpreted correlationally, i.e. standardized estimates from cross-sectional observational data in mediated SEM represent essentially either bivariate or partial correlation coefficients (Fairchild, &

McDaniel, 2017). Second, while the sample was generally proportionally representative of the City of Phoenix, it was not of sufficient size to be statistically representative. Thus, while this study demonstrates a novel method for answering causal questions, it cannot itself answer causal questions using the data available today. Furthermore, reported global fit indices should be interpreted with the understanding that they may mask important local under-fitting, and were largely inflated by measurement models that were pre-fitted using theory-driven EFA outside of this analysis. While all attempts were made to specify globally-identified, theoretically reasonable and parsimonious models, sufficient conditions do not equal ideal conditions, and all models would have benefited from a larger sample. Nonetheless, all modes had sufficient degrees of freedom to completely converge and were free from estimation errors including negative residual variances, or correlations larger than 1. While falling short of common sample size rules of thumb (e.g. 5 cases per free parameter), such rules of thumb have been recently scrutinized as unreliable, and samples of the size used in this study have been shown to be stable in simulated analysis (Wolf, Harrington, Clark, & Miller, 2013). Though this sample is smaller than desired, I believe it is sufficient to justify an exploratory analysis. Due to these limitations, I conclude by offering the following evidence-based propositions that I believe warrant attention from researchers and public health practitioners alike.

Socioeconomic Status.

- SES may be related to indoor home heat illness for reasons besides air conditioning access or capacity.

- Passive non-central-ac cooling behaviors may be an outcome of heat illness experiences and may not reduce heat illness.
- Active non-central-AC cooling behaviors may be driven by previous experience and may help reduce future indoor heat illness risk, but may not decrease indoor thermal discomfort.
- SES may confound the relationship between health status and heat illness; there may be no relationship between health status and heat illness when controlling for SES.
- Risk perception may mediate the relationship between SES and heat-health outcomes.

Age.

- Age may not be related to self-reported heat illness or thermal comfort. While age appears to be related to heat mortality, more research is needed to determine if age is related to heat morbidity, and if so, why.
- To the extent that age is related to the perceived risk of heat, perceived risk may be an outcome of past heat illness and not a driver of future heat illness risk.
- To the extent that age is related to social insulation, age may increase social insulation; social insulation may have no effect on heat illness or thermal comfort.

Gender.

- If gender is related to heat illness or thermal comfort, the effects may not be discernible from broad closed-ended samples. More research is needed to discern if gender relates to heat-health outcomes in specific high-risk contexts, including for example, in workplaces or in transient communities.

Racialized group.

- If racialized group identity is related to heat illness or thermal comfort, the effects may not be discernible from broad closed-ended samples. More research is needed to discern what, if any, role racialized group identity plays in heat-health vulnerability. Effects from racialized group identity are likely to be intersectional (i.e. confounded with other demographic and identity traits), and tied to historical sociopolitical and social structural processes that may be hard to measure with traditional survey instruments.

Outdoor work.

- Outdoor workers may have an attenuated perception of the risk of heat and under-report heat-health symptoms.
- Outdoor workers may have an amplified perception of the risk of heat and take increased adaptive precautions.
- Outdoor workers are more likely to be socially vulnerable to heat and other hazards due in part to their increased environmental exposure and in part to the intersection of outdoor work with other indicators of relative social (dis)advantage (e.g. socioeconomic status, gender, and racialized group identity). More research is needed to understand the interactions between these vulnerabilities.

CONCLUSION

I used an iterative exploratory process to test mediating variables that may explain theory-suggested relationships between sociodemographic indicators of social vulnerability and heat-health outcome measures. This study demonstrated the novel use of SEM for environmental social science research. SEM is well-suited for this type of research because it is compatible with small non-normal samples that are common in the social sciences, and can operationalize typical survey variable data types, including nominal and ordinal scales. Furthermore, SEM supports a mechanisms-oriented analysis, which I have argued is needed to advance environmental social science research.

Through this process, I discovered three important findings. First, individuals' self-perception of thermal comfort may be a good predictor of their heat illness risk, and this has implications for risk communication and public health monitoring. Second, money matters. Socioeconomic status was the only sociodemographic variable associated with heat-health outcomes when controlling for age, gender, and racialized group. Suggesting that public health programs and policies designed to mitigate heat risk need to address their constituents economic needs to reduce risk. Third, non-AC passive cooling techniques, like using hand fans or wearing wet clothes, did not have a protective effect on heat illness outcomes based on the sample. These passive cooling behaviors were used in greater proportion by socially vulnerable individuals', suggesting that they may be used as stop-gap measures, to little effect. This suggests that risk communication should focus on air conditioning over passive cooling behaviors and that public health practice and policy should focus on building economically stable communities. Together, results from this study strongly suggest that decreasing poverty would decrease heat health risks.

While this chapter has identified plausible mechanisms to explain relationships between social vulnerability indicators and heat-health outcome in Phoenix, AZ, more work is needed to determine if these mechanisms operate in other places, and for other hazards. This chapter makes a compelling argument that common assumptions about, if, how, and why social vulnerability manifests may be unclear or misleading. Both professional stakeholders and academics interested in social vulnerability to environmental hazards will benefit by understanding the specific pathways that lead some people to negative health outcomes more than others. A mechanisms-oriented approach to environmental social science research paired with causal empirical methods, like SEM, can help fill this research gap. While it is unlikely that large-scale social structure will radically change in the near term, it is plausible that specific causal mechanisms leading to specific inequitable outcomes can be addressed, but to do so we need to continue to identify and validate the mechanisms in play.

CHAPTER 3

PERCEIVED ADAPTATION EFFICACY KEY TO ADAPTIVE INTENTION FOR HAZARD CASCADE IN PHOENIX, AZ

INTRODUCTION

Understanding how and why some households and individuals are more or less resilient to climate change related hazards is of fundamental interest to multiple social and interdisciplinary sciences, as well as to state and local practitioners charged with protecting public health and safety. To date, the hazards geography and sociology literature has established a robust empirical and theoretical understanding of the spatial (e.g., neighborhood location) and social structural features (e.g., socioeconomic status) that create differential vulnerability to hazards (Cutter, Boruff, & Shirley, 2003; Adger, 2006; Bolin & Kurtz, 2018). At the same time, a somewhat overlapping but largely disconnected body of literature in psychology and communication has established a robust understanding of the role of risk attitudes and personal dispositions in predicting self-protective behaviors that could mitigate hazard risks, and help adapt to impacts (Wachinger, Renn, Begg,& Kuhlicke, 2013; Bubeck, Botzen, & Aertz, 2012; O’connor, Bard, & Fisher, 1999; Renn, 2011; Vos et al., 2018).

Due in part to a warming climate, the risks of extreme heat and electrical power failure are both growing in the US, and so is the risk of a concurrent heat wave power failure event (Vos et al., 2018; Myint, Wentz, Brazel, & Quattrochi, 2013; Byrd & Mattweman, 2014; Vose, Easterling, Kunkel, LeGrande, & Wehner, 2017; Krayenhoff, Moustaoui, Broadbent, Gupta, & Georgescu, 2018; Mikellidou, Shakou, Boustras, & Dimopoulos, 2018; Klinger& Landeg, 2014; Miller, Hayhoe, Jin, & Auffhammer, 2008;

Pescaroli & Alexander, 2018; Chakalian, Kurtz, & Hondula, 2019). Extreme heat in power-out conditions is particularly dangerous, especially since air conditioning has been repeatedly established as one of the most protective factors against heat-related mortality and morbidity (Semenza et al., 1996; Basu, Rupa, & Samet, 2002; Naughton et al., 2002; Kamp, Evans, & Campos-Flores, 2017; Altavena, 2017). Individual risk perception may be an important predictor of individual risk mitigation and adaptation behavior in some contexts (Esplin, Marlon, Leiserowitz, & Howe, 2019; Van Valkengoed, Anne, Steg, & Linda, 2019). Yet, individuals less able to adapt may have increased perceived risk (Wachinger et al., 2013). While research on risk perception to extreme heat shows evidence of an optimism bias for some vulnerable individuals (Weinstein, 1980; Sheridan, 2007), and especially for seniors (Lane et al., 2014; Abrahamson et al., 2008; Sampson et al., 2013; Ruddell, Harlan, Grossman-Clarke, & Buyantuyev, 2009), the available evidence shows that vulnerable populations (excluding the elderly) exposed to heat hazards tend to have an increased perception of risk (Ruddell, Harlan, Grossman-Clarke, & Chowell, 2012; Semenza, et al., 2008; Kalkstein & Sheridan, 2007). This is in-line with results from a systematic review by Wachinger et al., who showed that high risk perception did not necessarily lead to more mitigatory or adaptive action for resource-constrained individuals (Wachinger et al., 2013).

Social vulnerability, a concept that captures the differential social, political, economic, and bio-physiological features that generate disparate hazard outcomes, may help explain this discrepancy (Cutter et al., 2003; Adger, 2006; Bolin & Kurtz, 2018). Hazard scholars are increasingly interested in understanding the motivational factors that explain adaptive intentions. In a recent meta-analysis, Valkengoed & Steg (2019) found that in addition to risk perception, self-efficacy and outcome efficacy were important antecedents to protective action (Van Valkengoed et al., 2019). I suggest that socially vulnerable households may perceive themselves and their adaptive options as less efficacious. Valkengoed and Steg's meta-review of 106 different studies explicitly called for more case research to establish the impacts of risk perception, self-efficacy, and outcome efficacy on adaptive intentions to heatwaves and multi-hazard scenarios (Van Valkengoed et al., 2019).

To fill this gap, and to improve the understanding of the role of social vulnerability in individual adaptive behaviors to climate change hazards, I conducted content analysis on 40 interview transcripts following the Model of Private Proactive Adaptation to Climate Change (MPPACC)(Grothmann & Patt, 2005). The study was designed to capture subjects' risk and adaptation appraisal to a hypothetical concurrent metro-wide heatwave and power failure event in Phoenix, AZ. The MPPACC framework is an enhancement of widely-used protection motivation theory, which considers prior risk experience, appraised future risk—including the perceived probability of an event and its anticipated severity—and appraised adaptation—including the perceived efficacy of an adaptation, an individuals' perceived efficacy of themselves as agents, and the perceived cost of an adaptation(Grothmann & Patt, 2005; Rogers, 1975; Rogers, 1983; Rogers & Prentice-Dunn, 1997; Floyd, Prentice-Dunn, & Rogers, 2000). The MPPACC framework suggests two opposed outcomes from this decision-making process: adaptive or maladaptive intentions. Maladaptive intentions are based on wishful or magical thinking, denial of the risk, or fatalism (see Appendix C). Four hypotheses guided this study (Figure 1): (H1) Subjects with low risk appraisal would report higher adaptation appraisal, and vice-versa; (H2) More vulnerable subjects would have increased risk appraisal and decreased adaptation appraisal; (H3) The relationship between a subject's risk appraisal and adaptation appraisal would be moderated by vulnerability, such that less vulnerable subjects would report increased adaptation appraisal, when controlling for risk appraisal; and (H4) Subjects who are more vulnerable would be more likely to indicate a maladaptive adaptation intention.

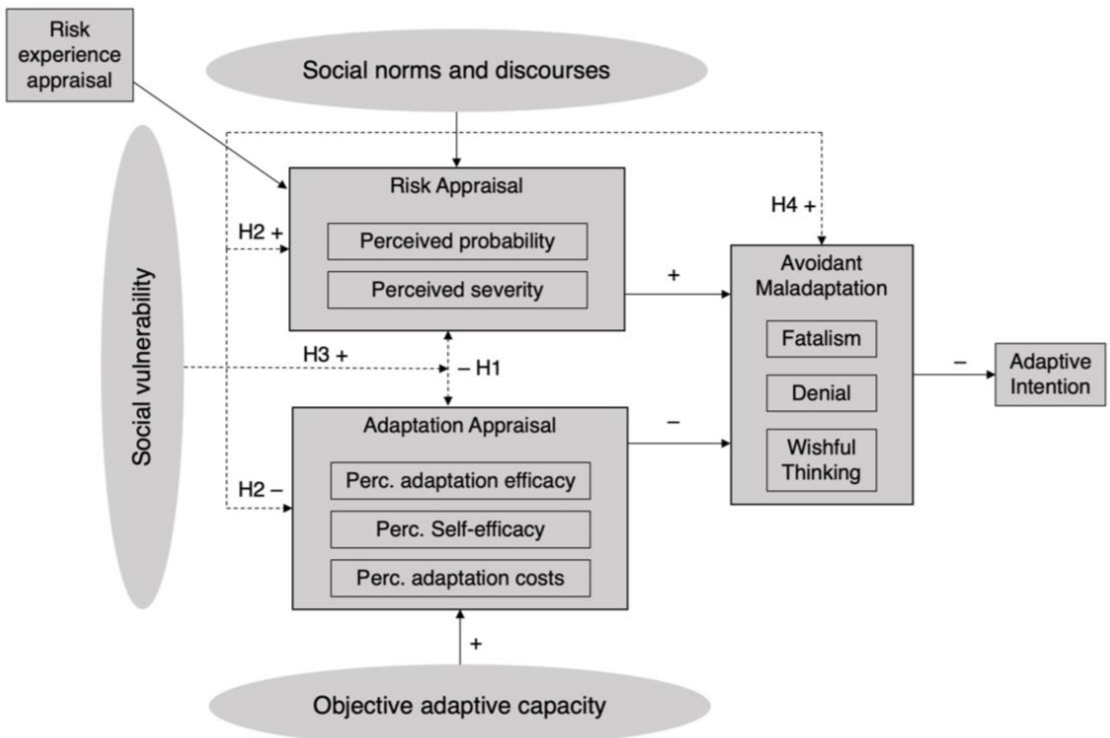

Figure 1. Solid lines hypothesized in original MPPACC framework, dashed lines are new hypotheses. Plus signs indicate positive relationships, minus signs indicate negative relationships. Adapted from (Grothmann & Patt, 2005).

METHODS

Data. Data for this study consisted of 40 semi-structured interviews collected in Phoenix, AZ between September and November 2016. Interviews were conducted by the first two authors. The interview protocol was designed to solicit information on what households would do in the event of a three-day power failure event and simultaneous heat wave (Appendix A). The interviews were vignette styled; respondents were walked through a hypothetical concurrent heat-wave power-failure scenario and provided with increasing constraints (limited communications, irregular water pressure, non-working gas pumps, etc.) at regular time intervals. Interviews averaged 50 minutes in length. Interview subjects were sub-sampled from, and largely representative of, a larger sample of survey respondents that were part of the NSF funded Hazards SEES 3-city Heat and Electrical failure AdapTation (3HEAT) project (NSF# 1520803). 3HEAT is a collaborative multi-university research project between Arizona State University, University of Michigan, and Georgia Tech designed to understand the impact of metro-wide power failure events and concurrent heatwaves in 3 different US cities (Phoenix, AZ; Detroit, MI; Atlanta, GA). This research involved the collection of surveys in each city designed to understand household adaptations to heat and power failure. Surveys in Phoenix were conducted door-to-door by graduate student surveyors during summer 2016. Sampling in Phoenix was designed to capture a diverse range of demographic profiles and household experiences with heat and power failure. The sample was geographically clustered at the census block group level and probability sampled at the neighborhood level to increase surveyor efficiency (by reducing logistical complexity) and control for selection bias (by randomizing target households). The final survey sample in Phoenix consisted of 163 subjects with a 30.4% minimum final response rate (RR1) (American Association for Public Opinion Research, 2016). Forty interview subjects were proportionally subsampled from this group. Interview respondents generally represented the City of Phoenix based on the 2016 American Community

Survey (ACS) from the US Census Bureau with some exceptions. The interview sample slightly underrepresented men, full-time workers, renters, and households with residents who were limited in their mobility (Appendix B).

Analysis. Survey and Interview data were analyzed using mixed methods. Interview transcripts were analyzed using content analysis in MAXQDA version 18.2 on Mac OSX version 10.14. Content analysis facilitates the quantitative analysis of qualitative data to test deductive hypotheses (Bernard, Wutich, & Ryan, 2016; Krippendorff, 2018). Coding was completed on line segments at the speaker turn level with multiple coding allowed (i.e. one line-segment could be marked with more than one code) using a structured codebook based on the MPPACC framework (MacQueen, McLellan, Kay, & Milstein, 1998) (Table 1. Appendix C). Codes representing risk appraisal and adaptation appraisal were coded independently for “high” or “low” sentiment (Table 2. Appendix C). Codes were tested for interrater reliability with a second coder (Kurtz) on a 10% sample of segments; all codes achieved a reliability coefficient of 0.8 or higher using Cohen’s Kappa (Cohen, 1960). Strong Kappa values, typically considered as 0.8 or greater, provide the conceptual validity needed to perform statistical analysis on qualitative codes (Roberts, 1997). After coding was completed, code frequencies were standardized by interview length as the percent of coded segments by total number of segments and exported into SPSS version 25 where they were joined with survey variables.

Social vulnerability was measured at the household scale using a vulnerability index following common methods in the literature (Cutter, Boruff, & Shirley, 2003; Bao, Li, & Yu, 2015). Though slight modifications were made from typical indexing procedures to account for the novel use of a vulnerability index with household data. Household survey variables that represented generally accepted vulnerability indicators (e.g. income, gender, children) were processed using exploratory factor analysis (EFA) in Mplus (Muthén & Muthén, 1998-2017) version 1.5 (Appendix D). EFA was conducted using a robust estimator (WLSMV), due to the non-normal mixed ordinal categorical nature of the survey data, and an orthogonal goemin rotation (Mplus provides both oblique and orthogonal goemin variants), which is consistent with typical vulnerability index methods by retaining the independence of each extracted factor (Cutter, et al., 2003; Brown, 2014). Survey variables were reverse-signed as needed to ensure consistent meaning. Five factors were extracted using the exploratory structural equation modeling (ESEM) function in Mplus. The number of factors to extract was determined based on factor interpretability, analysis of the scree plot, and chi-squared significance tests. Factors 1–5 reflected: dependents, mobility, status, resources, and social-isolation respectively (Table m1). Factor scores were summed using equal weighting to derive final vulnerability scores, which were imported with surveys variables in SPSS.

Table m1. Factor loadings for household social vulnerability index

Variable	Factor 1 (dependents)	Factor 2 (mobility)	Factor 3 (status)	Factor 4 (resources)	Factor 5 (social-isolation)
HH size (Q02)	**0.876***	-0.139	-0.054	0.113	-0.014
Heat risk (Q06)	0.22	**0.222***	0.168	**0.232***	0.029
Utility assistance (Q20)	0.265	-0.002	**0.398***	**0.360***	-0.053
Outdoor work (Q62)	-0.308	**-0.673***	0.164	-0.037	0.041
Over 64 (Q54)	-0.458	**0.910***	0.304	-0.022	0.001
Under 6 (Q55)	**0.589***	0.036	0.214	-0.034	-0.267
Age (Q57)	-0.06	**0.677***	0.037	0.194	0.013
No English (Q64)	**0.619***	0.018	**0.884***	0.037	0.224
Limited essentials (Q65)	0.163	-0.018	-0.012	**0.716***	0.009
Tenure (Q01)	0.313	**-0.408***	0.049	**0.416***	0.067
Car (Q30)	-0.032	**0.536***	0.458	**0.548***	-0.08
Gender (Q58)	**0.457***	0.344	0.042	-0.144	-0.13
Health (Q60)	0.145	**0.297***	0.179	**0.464***	0.141
Employment (Q61)	0.213	**0.799***	0.151	0.073	0.051
Non-white (Q63)	**0.418***	-0.094	**0.428***	-0.015	0.116

Food security (Q66)	0.189	0.141	-0.026	**0.591***	0.091
Income (Q67)	0.019	0.108	**0.871***	0.369*	0.011
Know neighbors (Q45)	0.133	-0.012	0.025	0.216	**0.551***
Talk to neighbors (Q46)	-0.15	-0.001	-0.033	-0.149	**0.628***
Ask help neighbor (Q47)	0.094	-0.231	0.052	0.115	**0.794***
Emerg. neighbor (Q48)	-0.055	**-0.363***	0.231	-0.043	**0.518***

Note: Produced using EFA with an orthogonal goemin rotation; Q30, Q60, Q66–67, and Q45–48 were reversed scored; * = $p < 0.05$

Initial tests were conducted for conceptual validity by checking for agreement between open-ended qualitative codes from the interviews and closed-ended survey responses from the 3HEAT survey. Qualitative code frequencies were regressed on a continuous risk perception measure derived from three closed-ended survey responses which measured the perceived risk of power failure during hot weather (Q05_pwrhot), heat waves (Q05_waves), and typical summer temperatures (Q05_typsumtemp) (Appendix D). Closed-ended risk perception responses were reduced using confirmatory factor analysis (CFA) in Mplus and showed very good model fit ($x^2 = 18.4$, p>.07; CFI = .98; TLI= .97; RMSEA= .06, 95% C.I.= 0-0.11). After validating the qualitative measures, tests for hypotheses 1–2 and 4 were conducted using a linear regression between code frequencies and subjects' social vulnerability scores derived from 3HEAT survey responses. Tests for hypothesis 3 were conducted using a generalized linear model (GLM) to assess independent and interaction effects. Individual interview high/low codes (see Appendix C) were subtracted to produce composite risk appraisal and adaptation appraisal measures consistent with the MPPACC framework (see Figure 1 main text), such that *x* high code count was subtracted from *y* low code count to produce a net sentiment measure (e.g. 50 high self-efficacy codes – 5 low self-efficacy codes = a net self-efficacy value of 45). These measures were summed in tests for hypothesis 3 and 4, in order to combine theoretically related concepts (e.g. risk probability + risk severity =

risk appraisal). Path analysis was used to detect indirect effects in tests for the fourth hypothesis and was completed in Mplus using a robust estimator designed for non-normal continuous data (WLSMV).

RESULTS

Data Validity. Qualitative codes were tested for reliability two ways. First, risk and adaptation appraisal codes were tested for internal reliability using Cohen's Kappa; all codes achieved high inter-rater agreement ($k > 0.8$) (Appendix C). Second, frequencies of open-ended qualitative codes for interview responses were regressed on closed-ended survey responses for the same individuals to test for conceptual validity (Appendix E). In a multiple regression model, risk appraisal and adaptation appraisal code frequencies explained over 50% of the variance in a closed-ended measure of the perceived risk of heat and power failure hazards ($R^2 = 0.58$, $p < 0.01$), indicating strong conceptual validity (Appendix E).

Motivating Adaptive Factors. I analyzed the relationship between risk and adaptation appraisal and the frequency of maladaptive codes in a single multiple regression model to control for confounding effects between motivating factors (Table 1).

Table 1. Maladaptive Intentions Regressed on Risk and Adaptation Appraisal *$R^2 = 0.50$*

Independent Variables	**B**	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
Risk Appraisal					
Probability	0.05	0.09	-0.09	0.19	0.48
Severity	0.04	0.13	0.05	0.12	0.37
Adaptation Appraisal					
Self-efficacy	-0.06	-0.23	-0.12	0.01	0.11

Adaptation efficacy	-0.22	-0.52	-0.35	-0.09	0.00**
Adaptation cost	0.17	0.10	-0.26	0.60	0.42

* p < 0.05; **p < 0.01 N = 40

After controlling for multiple motivational factors (risk and adaptation appraisal and their components), only perceived adaptation efficacy was significantly related to maladaptive intentions at p<.05 based on the sample (Table 1). Neither perceived risk severity nor perceived risk probability was significantly associated with maladaptive intentions (see Appendix C for examples). Overall, adaptation appraisal was negatively associated with risk appraisal (StdB = -0.33, p = 0.04), which is consistent with previous research and supports my first hypothesis (Milne, Sheeran, & Orbell, 2000).

The relationship between risk and adaptive appraisal and social vulnerability. Analyzing the impact of social vulnerability on risk and adaptation appraisal, independent sample linear regression models generally conformed to my expectations for hypothesis 2 (Table 2). Social vulnerability scores were moderately positively associated with subjects' perceived severity of risk, and moderately negatively associated with their perceived adaptation efficacy. That is, more vulnerable subjects viewed the risk of a heat-wave power failure event as more serious, and themselves as less able to address the risk. Vulnerability scores were negatively related to self-efficacy and positively related to adaptation cost, however these relationships were not significant at typical confidence levels.

Table 2. Risk and Adaptation Appraisal Regressed on Social Vulnerability

Dependent Variables	**B**	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**	**R^2**
Risk Appraisal						
Probability	0.001	-0.07	-0.001	0.00	0.65	0.00

Severity	0.004	0.44	0.001	0.007	0.00**	0.19
Adaptation Appraisal						
Self-efficacy	-0.002	-0.21	-0.006	0.001	0.19	0.05
Adaptation efficacy	-0.002	-0.38	-0.004	0.000	0.02*	0.14
Adaptation cost	0.00	0.15	0.000	0.001	0.35	0.02

Note: Increasing social vulnerability indicates less capacity N = 40

* $p < 0.05$; ** $p < 0.01$

Tests for interaction effects of risk appraisal and vulnerability on adaptation appraisal demonstrated significant negative effects, consistent with the third hypothesis. Vulnerability scores moderated the relationship between risk and adaptation appraisal, causing a stronger negative relationship. This finding supports the notion that risk perception may be determined by perceived adaptive capacity, which is in turn dependent on exogenous social vulnerability (Table 3).

Table 3. Adaptation Appraisal Regressed on the Interaction of Risk Appraisal and Social Vulnerability

Independent Variables	**B**	**Lower 95% CI**	**Upper 95% CI**	**P**
Vulnerability	0.00	-0.01	0.00	0.78
Risk Appraisal	-0.30	-0.74	0.15	0.16
Interaction	-0.40	-0.74	-0.06	0.00**

* $p < 0.05$; ** $p < 0.01$ N = 40

The impact of vulnerability on maladaptive intentions. While vulnerability scores were significantly related to maladaptive code frequencies in single regression models, these effects were not significant in multiple regression models that included risk appraisal. However, results from tests for hypotheses 2 and 3 demonstrated relationships between vulnerability and risk and adaptation appraisal in the sample, and test for my first hypothesis demonstrated a significant relationship between adaptation appraisal and maladaptive intentions. Based on this evidence, I tested a path analytical model to detect indirect effects from social vulnerability through adaptation appraisal on maladaptive intentions (Figure 2). Model results demonstrated significant indirect effects from social vulnerability scores on maladaptive intentions (StdB = 0.18, p = 0.01). The direct effect of social vulnerability with maladaptive intentions (StdB = 0.18, p = 0.13) was non-significant in the mediation model, suggesting that the relationship between maladaptive intentions and social vulnerability may be fully mediated by adaptation appraisal.

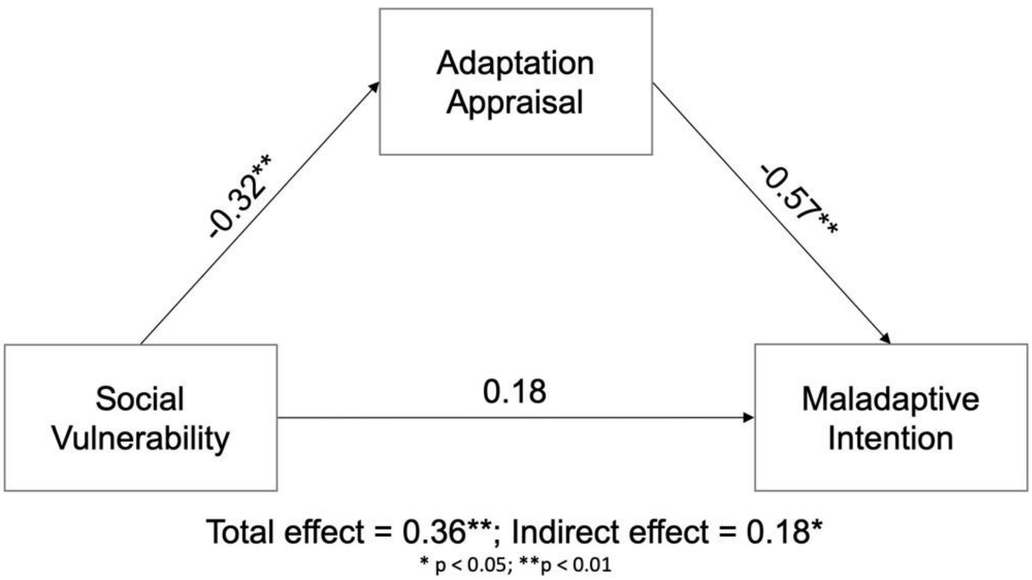

Figure 2. Mediation model of direct and indirect effects between social vulnerability, adaptation appraisal, and maladaptive intentions. Standardized estimates shown.

DISCUSSION

The results of this study demonstrate differences in risk attitudes between more and less vulnerable research subjects with important implications for risk communication strategy and climate change adaptation policy. More vulnerable subjects were more likely to view the risk of a concurrent heat wave power failure event as severe, and view themselves as less able to cope with the potential impacts. In addition, this research demonstrates an inverse relationship between risk appraisal and adaptation appraisal across all respondents, revealing an important insight about how individuals' assess risk. The inverse relationship between risk and adaptation appraisal suggests that respondents account for their own ability to adapt when assessing risk. Results from the interaction model support the hypothesis that more vulnerable residents account both for their increased vulnerability and their decreased capacity when assessing risk severity.

Understanding these constraints is important for effective risk communication; communication campaigns designed to amplify risk perception with the implicit goal of increasing protective behaviors can only work if targeted audiences have the capacity to undertake those behaviors. Overall, risk appraisal appears to have operated as an *effect* of perceived individual adaptive capacity and structural social vulnerability, rather than a *cause* of adaptive motivation in the sample. This finding challenges the common operationalization of risk perception as an antecedent factor to adaptive action.

The lack of relationship between risk appraisal and maladaptive intentions and the negative relationship between risk appraisal and adaptation appraisal found in the study suggests that individuals may asses risk severity based on their perceived or actual adaptive capacity. The lack of effect from perceived risk probability was likely due to the specific scenario presented to interview respondents, which was explicitly low-probability—resulting in little variation on that measure. Similarly, adaptation costs were infrequently discussed in the interviews, plausibly due to the hypothetical nature of the exercise. Based on the MPPACC model and previous research that shows a relationship between past hazard experience and risk perception, I tested the relationship between previous heat illness and power failure experience with risk appraisal (Weinstein, 1989). Results from the test between past experience and risk perception revealed no statistically significant relationships in the sample. This result suggests that subjects may have considered the multi-hazard cascade scenario presented to them as distinct from the independent risks of extreme heat or power failure that they may have previously experienced: suggesting that previous experience with independent hazards may not always translate to amplified risk perception of coupled events.

As far as I am aware, this is the first study to analyze the impact of self-efficacy or outcome efficacy on adaptive intentions to a multi-hazard risk, and one of very few to analyze multiple factors at once (Van Valkengoed et al., 2019). An important advantage to analyzing multiple motivational factors in one study is the ability to control for confounding effects as well as test for interactions. Syntheses of multiple independent case studies, including meta analyses, have not been able to control for the influence of multiple motivational factors on adaptive intentions (Van Valkengoed et al., 2019). Therefore, several factors identified as significant in previous reviews (e.g. risk perception, self-efficacy, or descriptive norms) may be predominantly operating through a single, or smaller set, of independent variables (e.g. outcome efficacy). Previous studies that identified relationships between risk perception and adaptive motivation that did not control for perceived adaptive efficacy may have misattributed subjects' motivation, which may more reliably be explained by a confounding adaptive efficacy variable.

The relationship between social vulnerability factors, psychological perspectives, and adaptive intentions may differ for different hazards and in different locations. Due to the case study nature of the analysis, results of these tests should be interpreted only within the context of these interviews and should not be assumed to represent all hazard scenarios. This case study looked at a specific low-likelihood high-impact combined power failure heat wave event in a hot urban climate. Future research should consider the role of structural vulnerability in influencing (or moderating the relationships between) perceived risk, perceived adaptive capacity, and adaptive intentions. This study supports the findings from recent meta-reviews, that adaptive efficacy is an important and understudied anteceded to adaptive motivation to climate change hazards (Van Valkengoed et al., 2019). More research is needed to understand potential confounding between multiple motivational factors that have been operationalized in the literature to date, including specifically between risk perception and adaptation efficacy. Together, these results have important implications for climate change and public health outreach, which challenge current norms.

CHAPTER 4

THE ROLE OF ADAPTIVE CAPACITY IN THE RELATIONSHIP BETWEEN HEAT ILLNESS EXPERIENCES, RISK PERCEPTIONS, AND ADAPTIVE BEHAVIORS

INTRODUCTION

The risks associated with heat exposure have established negative effects on human health, and these risks are growing (Ebi et al., 2018; Vose, Easterling, Kunkel, LeGrande, & Wehner, 2017; Jones et al., 2015). While temperatures are changing at different speeds all across the nation, decades of research demonstrate that heat-health outcomes are largely determined by social factors. (Harlan, Declet-Barreto, Stefanov, & Petitti, 2013; Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006). Furthermore, many studies demonstrate that behavioral factors may be better indicators of heat mortality and morbidity than exposure alone, both at present and in the future (Petitti et al. 2013, Reid et al., 2009; Stafoggia et al., 2006). These relationships are well explained in the existing research on social vulnerability to environmental hazards (Adger, 2006, Blaikie, Cannon, Davis, & Wisner, 2004; Adger & Kelly, 1999). Based on this work, we understand that some people, or groups of people, are more likely to suffer harm when exposed to a stress, like extreme heat, than others. Furthermore, these differences are not random, but are due to differences in material and non-material resources and adaptive capacities (Engle, 2011). While social structural explanations for social vulnerability to heat hazards are convincing, to date, structural solutions have been illusory. To address the challenges associated with increasing extreme heat risk, public health professionals and risk managers need to understand the circumstances that produce individual exposures and the specific adaptive behaviors that individuals have available to them. At present, we lack an understanding of the intervening circumstantial and behavioral mechanisms that bridge the theoretical gap between stratified resources and stratified outcomes. We can better isolate proximate causes of social vulnerability by increasing our understanding of how different individual heat adaptations relate to heat-health outcomes. At the same time, we may be able to produce more salient and more effective risk communication strategies by increasing our understanding of the relationship between individual risk perception and individual adaptation.

As a concept, risk perception has roots first in engineering (Starr, 1969), then in decision sciences as a tool for understanding human decision making under certainty (Johnson & Tversky, 1983; Slovic, Fischhoff & Lichtenstein, 1980). This research was purposed to, "aid risk analysis and societal decision making by, (i) improving methods for eliciting opinions about risk, (ii) providing a basis for understanding and anticipating public responses to hazards, and (iii) improving the communication of risk information among laypeople, technical experts, and policy makers." (Slovic, Fischhoff, & Lichtenstein, 1982). The early psychometric studies of perceived risk typically operationalized the concept using utility theory to understand how relatively risk seeking or risk averse individuals or populations were (Fischhoff, Slovic, Lichtenstein, Read, & Combs, 1978). There were soon parallel efforts by sociologists and anthropologists to explain risk perception and subsequent behavior using social structural variables, for example, Mary Douglas's grid-group typology (Rippl, 2002; Tansey & O'riordan, 1999; Dake, 1992; Wildavsky & Dake, 1990; Covello, 1983; Douglas & Wildavsky, 1982). While risk perception research of the decision sciences tradition is interested in understanding why individuals behave in certain ways when confronting a risk, it is rooted in a technocratic desire to prescribe right action, or perhaps more accurately, right *attitude*, in the face of an unreliable public who was prone to making heuristic shortcuts during their decision-making, or *attitude-forming*, processes. Unlike the risk perception literature then, theories of health-protective behaviors, which were developing during the same period, were fundamentally interested in understanding why and how individuals undertook behaviors to protect themselves from health risks (Rogers, 1983; Fishbein & Ajzen, 1975; Becker, 1974; Edwards, 1954).

Major theories of health-protective behaviors have considered individuals perception of the probability and severity of a negative outcomes (i.e. perceived risk). They also accounted either explicitly (Rogers, 1983; Becker, 1974) or implicitly (Fishbein & Ajzen, 1975; Edwards, 1954) for the perceived effectiveness of protective behaviors and barriers to undertaking those behaviors (Weinstein, 1993). As the separate conceptualizations of risk perception in the risk-management and public health literatures developed, scholars increasingly borrowed ideas from the other. Most commonly, this resulted in the managerial conceptualization of risk perception (i.e. as an a-temporal attitude), divorced from a larger behavioral framework, used to predict protective behaviors, and increasingly, to predict climate change adaptation (Van Valkengoed & Steg, 2019; Pidgeon, 2012; Renn, 2011; Weber, 2010; Leiserowitz, 2006, 2005; Lorenzoni, Pidgeon, & O'Connor, 2005; O'Connor, Bard, & Fisher, 1999).

Of studies that have found a relationship between risk perception and protective behavior, Rimal and Real, 2003, found that risk messaging salience could increase the relationship between perceived risk and protective or adaptive action (Rimal & Real, 2003). Generally, the risk communication literature suggests that communication campaigns based on an understanding of the target audience's risk perception can increase audience receptivity, and ultimately lead to increases in desired beliefs or behaviors. For example, it is believed that progress countering climate change denial has been the result, at least in part, of understating how uncertainty appeals by misinformation campaigns were generating doubt about the risk of climate change (McCright, Dunlap, & Chenyang, 2013). Similarly, plummeting rates of tobacco use in the United States have been linked to public health campaigns that were able to successfully raise the perceived risk of tobacco while reducing its perceived social and cultural benefits (Cummings, 2016). Across numerous studies, both direct and indirect previous experience was consistently shown to relate to perceived risk, while previous experience with non-voluntary risks had larger effects than voluntary risk (Wachinger, Renn, Begg, & Kuhlicke, 2013; Barnett & Breakwell, 2001).

For many individuals, extreme heat is an example of such a non-voluntary risk. Previous research on the perceived risk of extreme heat has focused either on specific sub-populations, like the elderly (Abrahamson et al., 2008), or the effectiveness of particular institutions, warnings, or communication strategies (Bruine de Bruin et al., 2016; Lane et al., 2014; Kalkstein & Sheridan, 2007; Sheridan, 2006), and have mostly consisted of single case-studies. Although there is evidence of an optimism bias for some vulnerable individuals (Sheridan, 2007; Weinstein, 1980), and especially for seniors (Lane et al., 2014; Sampson et al., 2013; Abrahamson et al., 2008), overall, the literature suggests that more vulnerable populations (excluding seniors) tend to have amplified risk perceptions (Ruddell, Harlan, Grossman-Clarke, & Buyantuyev, 2009; Semenza et al., 2008; Kalkstein & Sheridan, 2007). Risk theory and previous empirical studies suggest that individuals with increased risk perception may take greater protective action (Liu et al., 2013; Brewer et al., 2007; Kalkstein & Sheridan, 2007). However, other work has found a positive association between heat illness and risk perception. For example, individuals in the Guangdong province, China with the highest risk perception who employed the fewest adaptions were at greatest risk of heat illness (Liu et al., 2013). This finding supports the proposition made by Wachinger, Renn, Begg, & Kuhlicke, 2013, that more vulnerable individuals may have increased perceived risk, yet be unable to take the action necessary to protect themselves from health impacts due to decreased adaptive capacity (Wachinger, Renn, Begg, & Kuhlicke, 2013).

Overall, the risk perception and health behavior literature suggest that individuals with high perceived risk will be more likely to have experienced a hazard, will be more likely to act to adapt to a hazard, and may be more socially vulnerable. At the same time, the social vulnerability and hazards literature suggest that individuals who are socially vulnerable may be more likely to have experienced a hazard, but less likely to have the ability to adapt. The literature overall therefore suggests that the relationship between previous heat illness experiences and individual heat adaptations may be mediated by respondent risk perception. Mediation analysis is designed to understand the mechanism through which an independent variable affects an outcome variable and is tested by measuring the indirect effect of an independent variable on an outcome variable via a series of regressions, or partial correlations (Kenny, 2018; MacKinnon, Fairchild, & Fritz, 2007). In this study, I propose that respondent risk perception may help explain why some people who experience a hazard are more likely to act to adapt to that risk. At the same time, social vulnerability literature suggests that the relationship between previous heat illness experiences and respondent risk perception, and between respondent risk perception and heat adaptations, may be moderated by household adaptive capacity. Moderation refers to a change in slope between an independent variable and an outcome variable based on a third (moderating) variable and is often tested using an interaction term that is computed as the product of the independent variable and the moderating variable (MacKinnon, Fairchild, & Fritz, 2007; Muller, Judd, & Yzerbyt, 2005; Robins & Greenland, 1992).

Conceptually, moderation theorizes that the relationship between an independent variable and an outcome variable will differ for different cases or groups. In this study, I suggest that individuals with lower adaptive capacity will have stronger relationships between previous heat illness experience and risk perception compared to the population, and weaker relationships between risk perception and adaptive behavior compared to the population. I used data from household surveys in Phoenix, AZ and Detroit, MI, to test these theories in the form of the following five hypotheses (Figure 1):

Hypothesis 1. Respondents who reported previous direct (individual) or indirect (household) experience with heat illness (variable X) will report higher perceived risk of typical summer temperatures, heat waves, the urban heat island (UHI), and climate change (CC) (variables $M_{e1\text{–}4}$); there will be stronger relationships with individual compared to household heat illness experiences (paths $a_{1\text{–}4}$).

Hypothesis 2. Respondents who reported high risk perception will be more likely to report using a heat adaptation (variable Y) than respondents with low-heat risk perception; there will be stronger relationships on proximate risk perception (i.e. typical summer temperatures and heat waves) than distal (i.e. the UHI and CC) (paths $b_{1–4}$).

Hypothesis 3. Respondents who reported previous individual or household experiences with heat illness will be more likely to report using a heat adaptation than respondents who have not had previous heat illness experiences (path *c'*).

Hypothesis 4. Risk perception will partially or fully positively mediate the relationship between previous heat illness experiences (variable *X*) and adaptive behaviors (variable *Y*) such that heat illness will be positivity associated risk perception which will be positively associated with adaptive behaviors (paths $ab_{1–4}$).

Hypothesis 5. Adaptive capacity will moderate the path from previous heat illness to risk perception (path *a*) and the path from risk perception to adaptive behaviors (path *b*), such that increasing adaptive capacity will decrease the relationships between previous heat illness experiences (variable *X*) and risk perception (variable M_e) (paths $a_{1–4}$), and increase the relationship between risk perception (variable M_e) and adaptive behaviors (variable *Y*) (paths $b_{1–4}$). Thus, there will be inconsistent moderated-mediation between previous heat illness experiences (variable *X*) and adaptive behaviors (variable *Y*). I.e. while the direct (c') and the mediated (M_eX_1) effect between previous heat illness experiences (variable *X*) and adaptive behaviors (variable *Y*) will be positive (hypotheses 3 & 4), the moderated-mediated effect between previous heat illness experiences (variable *X*) and adaptive behaviors (variable *Y*) (paths $d_{1,1}d_{2,1}–d_{1,4}d_{2,4}$) will be oppositional, and therefore the total moderated-mediated effect from previous heat illness experiences (variable *X*) to adaptive behaviors (variable *Y*) (M_oM_e), and the total effect from previous heat illness experiences (variable X_1) and adaptive capacity (variable X_2) to adaptive behaviors (variable Y) (C_1+C_2), will be small.

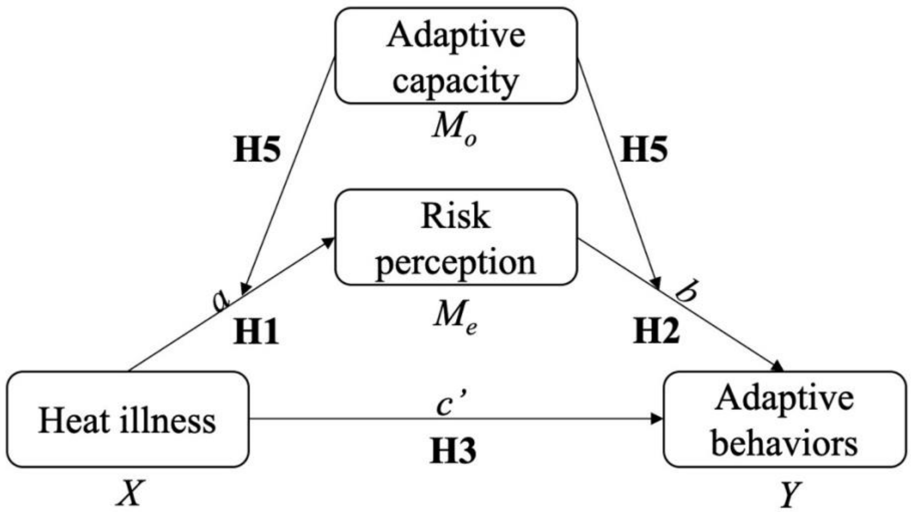

Figure 1. Conceptual diagram of the research hypotheses regarding associations between experienced heat illness, perception of heat risks, heat adaptations, and moderating effects by adaptive capacity.

METHODS

Using data from 266 household surveys collected over summer 2016 in Detroit, Michigan and Phoenix, Arizona, I used Structural Equation Modeling (SEM) to characterize (1) the association between heat-related illness and adaptive behaviors (2) the association between heat-related illness and heat risk perceptions, (3) associations between heat risk perception and adaptive behaviors (4) mediated relationships from heat related illness to adaptive behaviors through risk perception, and (5) moderated effects from adaptive capacity. Adaptive capacity, gender, and age were included as covariates in all models to control for possible confounding effects between adaptive capacity and other common social vulnerability indicators (Adger, 2006). Adaptive capacity was operationalized as a latent factor estimating measured variables pertaining to respondent household income (Q67), food security (Q66), and access to essentials (Q65) (see Appendix D).

Data. Survey data in Phoenix and Detroit come from a multi–university NSF Hazard SEES project titled 3HEAT, which is a collaboration between The Georgia Institute of Technology, University of Michigan, and Arizona State University (NSF# 1520803). The survey instrument consisted of 148 shared questions between the study cities that were designed to answer broad research questions on the target population's perception of, incidence of, and adaptions to, heat illness and thermal discomfort. In both cities, all risk perception questions were randomized to reduce ordering and anchoring biases. Surveys were administered using Kobo Toolbox open source survey software designed using the OpenDataKit (ODK) standard for mobile data collection. While both Detroit and Phoenix are large cities inside major American metropolitan areas, they exist in two substantially different climate zones and are the product of two different human histories. Detroit has a majority African American/Black population of approximately 680,000 residents spread over 143 square miles and exists in a humid continental climate (Dfa) with over 30" of precipitation per year on average. Average winter (DJF) lows in Detroit are between 18º–24ºF and average summer (JJA) highs are between 77º–82ºF (NOAA, 2019; U.S. Census Bureau, 2019). Phoenix, on the other hand, has a majority-White population of over 1.5 million residents sprawled over approximately 520 square miles in a hot desert climate (BWh) with less than 8.5" of precipitation per year on average (NOAA, 2019; U.S. Census Bureau, 2019). Phoenix experiences average summer (JJA) highs between 104º–106ºF and average winter (JJA) lows between 45º–49ºF (NOAA, 2019).

Phoenix Surveys. 163 surveys were administered between May 25 and December 15, 2016 in the City of Phoenix using a geographically clustered and socially stratified sampling protocol that was purposively sampled at the census-block group level and probability sampled at the household level. The protocol was designed to achieve a representative probability sample of 175 households across 25 Phoenix neighborhoods. All survey participants were offered an incentive of $5 cash. This sampling strategy achieved a final minimum response rate of 31% (RR1) (AAPOR, 2016). Phoenix survey respondents generally represented the city based on the 2016 American Community Survey (ACS) from the US Census Bureau (See Appendix B).

Detroit Surveys. In Detroit, 103 surveys were conducted from July–May 2017. Sampling was targeted at specific vulnerable populations that the researches had pre-established connections with using a community-based participatory research (CBPR) approach. Survey recruitment was conducted at a series of neighborhood workshops organized by local non-profits; respondents were volunteers. Surveys were completed both at events and in follow-up home visits. Due to the mixed recruitment approach total response rates could not be calculated, though participation in the study was generally good at workshops for which total attendance was known (55-60%). Surveys were conducted either by the project manager or an undergraduate student. Respondents in Detroit were offered $15 for completing the survey.

Variables. To mitigate the effects of measurement error, and reduce the complexity of the analysis and aid in interpretation of the results, several data reduction techniques were performed. Exploratory Factor Analyses (EFA's) were conducted independently with Detroit and Phoenix data to build independent adaptive capacity factors and reduce the original adaptive behavior measures. EFA's were ultimately interpreted based on the heat vulnerability literature to specify and test independent measurement models in each city using Confirmatory Factor Analysis (CFA) with a robust estimator (WLSMV) (Byrne, 2012). CFA models were evaluated in light of exact, absolute, and relative fit indices including the Chi Square test, RMSEA, and CFI (Jackson, Gillaspy, & Purc-Stephenson, 2009; Kenny, David, & McCoach, 2003; McDonald & Ho, 2002; Hu & Bentler, 1999). This method resulted in one latent adaptive capacity factor measured by an ordinal degree of the ease of affording essentials (Q65), an ordinal degree of food security (Q66), and continuously-modeled 10-point gross household income variable (Q67) (Appendix D). Because the adaptive capacity factors were just-identified (i.e. the number of free parameters equaled the number of known values), there were insufficient degrees of freedom to estimate global fit. Nonetheless, local fit for both the Phoenix and Detroit adaptive capacity models were strong with all indicator loadings estimated in the hypothesized directions at $p<0.01$.

The same methods were used to reduce the number of adaptive behaviors analyzed in this study. Twenty-one separate adaptive behavior questions were reduced into two composite variables in Phoenix (Q24–Q26). The first was represented by 11 binary passive cooling behavioral variables, e.g. wetting clothes or using a hand fan (see Appendix D). The second was represented by 6 binary active cooling behavioral variables, e.g. using window air conditioning, a fan, or swamp cooler (see Appendix D). Both factors showed strong conceptual validity in a 2 factor CFA ($x^2 = 129.02$, $p>.23$; CFI = .97; TLI= .96; RMSEA= .02, 95% C.I.= 0-0.05). EFA in Detroit suggested the same passive variable, conceptually validated in a 1-factor CFA ($x^2 = 48.32$, $p=0.30$; CFI

= .98; TLI= .97; RMSEA= .03, 95% C.I.= 0-0.08), however, responses to fan and window AC use substantially differed in that city (see table 1 of results). Subsequently, no active cooling variable was specified for Detroit. Instead, the active cooling variable was broken into two binary variables: the use of window AC or fans in windows respectively. This resulted in a total of 3 behavioral outcome variables for Phoenix: AC intensity, passive, and active cooling, and 4 in Detroit: AC intensity, passive cooling, window AC, or fan in window (blowing air into or out of the home) (Table 3). The AC intensity variable was constructed by subtracting respondent's preferred indoor summer temperature (Q22) from their average self-reported AC thermostat set temperature (Q12–Q13) (see Appendix D). AC intensity was used instead of a binary indicator of AC presence or absence because the later measure was unskilled at predicting heat-health outcomes in previous analyses (see chapter 2). All continuous variables were mean-standardized prior to final analyses in order to better facilitate comparison across cities.

Analysis. The analysis aimed to understand if and under what conditions previous heat illness experiences led to increased risk perception or adaptive behaviors for households in Detroit and Phoenix, and how those relationships were impacted by adaptive capacity as a social structural factor. To do this, I employed two-sample t-tests to understand differences in mean survey responses in each city and bivariate correlations to understand uncontrolled relationships between variables of interest. I then used Structural Equation Modeling (SEM) to test my research hypotheses and calculate direct, indirect (i.e. mediated), and moderated (i.e. interaction) effects between variables of interest. Generally, SEM is a family of analytical techniques used to test structural relationships by joining confirmatory factor analysis with multiple regression (Kline, 2015). Using SEM as a multivariate statistical tool allowed me to reduce measurement error, control for collinearity in the latent adaptive capacity measure, detect mediated, moderated, and moderated-mediated effects using non-normal non-continuous data, and control for all model variables simultaneously.

Testing for moderation using an interaction term involves operationalizing the product of an independent variable and a hypothesized moderating variable. Special techniques must be used to estimate the interaction variable when the hypothesized moderator is as a latent factor. Modeling latent factor interactions is a relatively new possibility; options to do so using the latent moderated structural equations (LMS) (Klein, Moosbrugger, 2000) method have only recently become available for desktop computing. Although Mplus software provides this feature, it is limited by the inability to report typical measures of global fit, standardized coefficients for categorical variables, or the variance explained by interaction terms (Muthén, Muthén, 2017; Maslowsky, Jager, Hemken, 2015). I have followed state-of-the-science techniques to address these limitations by running the analysis in multiple steps to estimate both moderated and un-moderated models (Maslowsky, Jager, Hemken, 2015). Moderated models were those for which adaptive capacity was specified as a moderator, un-moderated models were identical, but lacked a moderation hypothesis.

The analysis was conducted in the following six steps: First, for both cities, bivariate correlations were tested between the variables of interest to test (dis)agreement with theory (Tables 1a & 1b). Following recent guidance from the mediation methods literature, a lack of significant relationship between a primary independent variable and outcome variable would not preclude a test of mediation, as there are many circumstances under which mediation can be present despite null independent effects on distal outcomes (Fairchild & McDaniel, 2017; Shrout, Bolger, West, & Stephen, 2002). Second, Exploratory Factor Analyses (EFA) were run independently with Detroit and Phoenix data to third, specify latent adaptive capacity factors and perform data reduction on adaptive behavior variables in both cities. Fourth, measurement models were estimated using confirmatory factor analysis (CFA) to test the fit of specified factors. Fifth, based on the results of the EFA's and CFA models, 6 un-moderated structural mediation models were specified and tested in Phoenix, and 8 in Detroit (Table 2). Un-moderated structural mediation models provided estimates of global model fit. Finally, and sixth, 14 moderated-mediation models were estimated using Monte Carlo numerical integration and robust maximum likelihood (MLR) estimation in Mplus version 8 (Muthén & Muthén, 2017; Fairchild & McDaniel, 2017; Maslowsky, Jager, & Hemken, 2015; Muthén & Asparouhov, 2012; Klein & Moosbrugger, 2000) (Figures 2a & 2b) (Tables 3, 4a, and 4b).

Moderated-mediation models estimated all five research hypotheses simultaneously by testing 9 direct effects (between previous heat illness experiences, risk perceptions, and adaptive behaviors, paths a_1–a_4, b_1–b_4, and $c^{'}$), 4 mediated effects (between previous heat illness experiences and adaptive behaviors via risk perceptions, paths $ab_{1,1}$–$ab_{1,4}$), 8 moderated effects (between previous heat illness experiences and risk perceptions moderated by adaptive capacity, and between risk perceptions and adaptive behaviors moderated by adaptive capacity, paths $d_{1,1}$–$d_{1,4}$ and $d_{2,1}$–$d_{2,4}$), and 4 moderated-mediated effect (the mediated effect between previous heat illness experiences and adaptive behaviors via risk perceptions moderated by adaptive capacity, paths $d_{1,1}d_{2,1}$– $d_{1,4}d_{2,4}$) (Figures 2a/b).

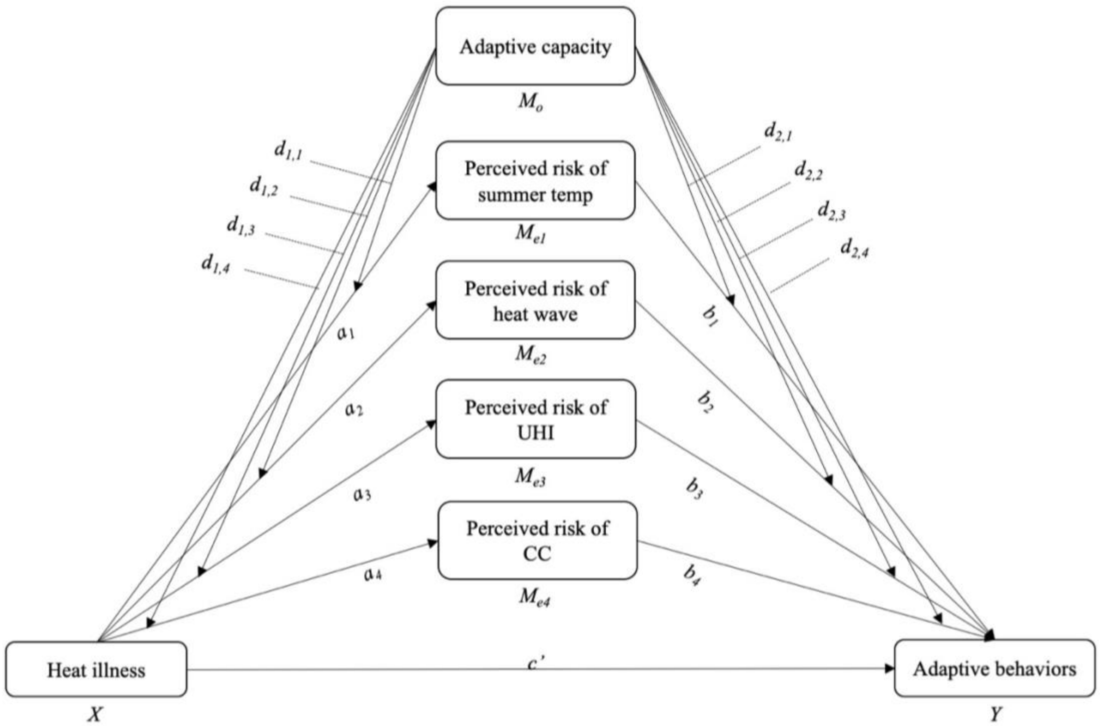

Figure 2a. Structural moderated-mediated model. UHI = Urban Heat Island, CC = Climate Change. Gender & Age control covariates hidden.

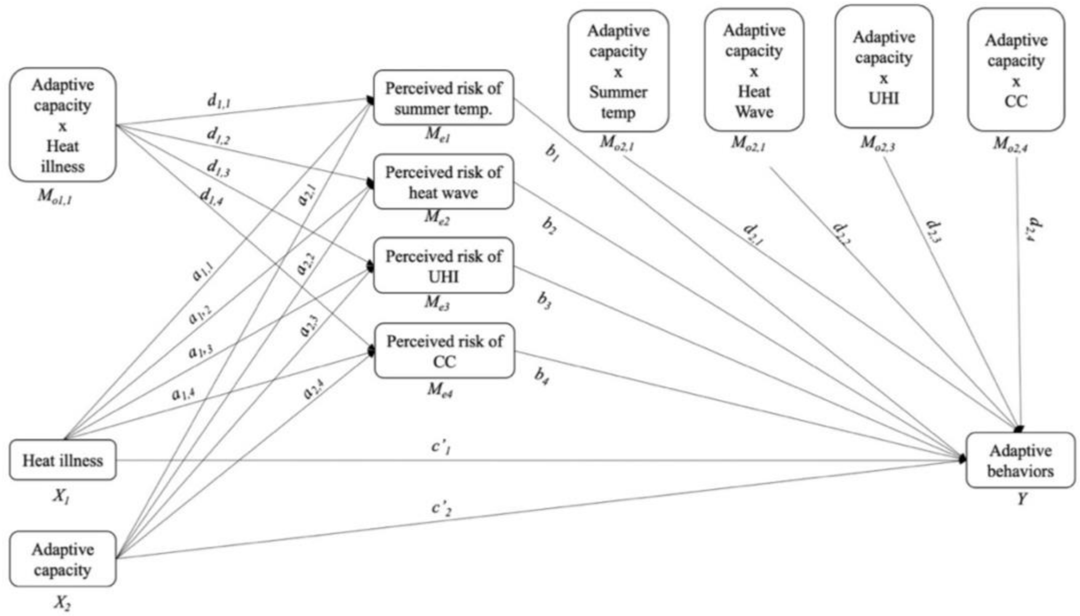

Figure 2b. Statistical moderated-mediated model. UHI = Urban Heat Island, CC = Climate Change. Gender & Age control covariates hidden.

RESULTS

Univariate Comparisons. Analysis of the survey results demonstrated that overall heat illness incidence in both samples was relatively similar (between 40-50%) (Table 1). Heat risk perceptions were also largely similar between the two cities except for the perceived risk of typical summer temperatures, which was rated as less-risky in Detroit than Phoenix (2.58 out of 4 vs. 2.85 out of 4), and is consistent with climatological conditions in those two cities. Adaptive behaviors that were relatively easy or low-cost to implement (e.g. wearing cooler clothes) were also similar across cities. Higher-cost behaviors significantly varied between the two cities, while respondents in Detroit were far less likely to report using central air-conditioning (32% vs. 96%), of those that did, they appear to have used them much more liberally, setting their thermostats much cooler in relation to their preferred temperatures compared to respondents in Phoenix (on average 1.19ºF cooler than preferred in Detroit vs. 1.78ºF warmer than preferred in Phoenix). At the same time, adaptive strategies that rely on favorable diurnal shifts in weather, for example opening or placing fans in windows, were much more common in Detroit than Phoenix (70% open windows in Detroit vs. 20% in Phoenix), which is also consistent with climatological differences between the two cities.

Table 1. Descriptive Statistics for Survey Variables in Phoenix and Detroit

Variable	**Phoenix**			**Detroit**		
	Mean	**SD**	**N**	**Mean**	**SD**	**N**
Individual illness	42%	--	163	47%	--	103
Household illness	47%	--	163	55%	--	103
Risk Summer Temperatures	**2.85**	**0.93**	**163**	**2.58**	**0.90**	**103**
Risk Heat Waves	2.98	0.97	163	3.19	0.94	103
Risk Urban Heat Island	2.92	0.81	163	2.85	0.92	103
Risk Climate Change	**3.01**	**0.96**	**163**	**3.32**	**0.76**	**103**
Use Central Air	**96%**	**–**	**163**	**32%**	**–**	**103**
Use Window Air	**10%**	**–**	**163**	**48%**	**–**	**103**
Use Swamp Cooler	8%	–	163	--	--	0
Use Indoor Fan	**93%**	**–**	**163**	**76%**	**–**	**103**
Use Open Windows	**20%**	**–**	**163**	**70%**	**–**	**103**
Use Fan in Window	**9%**	**–**	**163**	**49%**	**–**	**103**
Use Hand Fan	**15%**	**–**	**163**	**29%**	**–**	**103**
Wear Cooler Clothes	80%	--	163	70%	--	103
Close Window Shades	82%	--	163	74%	--	103
Eat Lighter Meals	66%	--	163	69%	--	103
Eat Cold or Frozen Foods	70%	--	163	58%	--	103
Use Fewer Appliances	56%	--	163	52%	--	103
Take Cold Showers	62%	--	163	64%	--	103
Put a Wet Cloth on Skin	30%	--	163	38%	--	103
Reduce Physical Activity	54%	--	163	59%	--	103
Change Schedule	77%	--	163	70%	--	102
Left Home	37%	--	163	36%	--	103
AC Intensity	**-1.78°F**	**3.23°F**	**151**	**1.19°F**	**7.19°F**	**52**

Note: Independent sample t tests were used to determine statistically different means between Phoenix and Detroit samples, bolded rows are different at 95% or better confidence levels.

Initial exploration of the data showed general agreement with the conceptual model (Figure 1): In both cities, previous heat illness experiences were associated with at least one cooling behavior, and with the perceived risk of heat; in Phoenix, associations were stronger for individual heat illness experiences than household, and for proximal heat risks compared to distal. Risk perceptions were associated with some cooling behaviors in Phoenix, but not in Detroit (Tables 2a & 2b).

Table 2a. Correlations between previous heat illness experiences, risk perceptions, and adaptive behaviors in Phoenix, AZ

	Perceived risk of summer temp.	Perceived risk of heat wave	Perceived risk of UHI	Perceived risk of CC	AC intensity	Active	Passive
Adaptive Capacity	**-.184***	**-.161***	-.099	-.020	**.151****	**-.019***	**-.063***
Individual heat illness	**.334****	**.236****	.065	.098	**-.170***	**.274****	**.277****
Household heat illness	**.275****	**.224****	.064	.127	**-.140**†	**.213****	**.227****
Perceived risk of summer temp.	--	--	--	--	**-.188***	.080	.338
Perceived risk of heat wave	--	--	--	--	**-.148**†	.025	**.270****
Perceived risk of UHI	--	--	--	--	-.091	.135	**.167***
Perceived risk of CC	--	--	--	--	**-.211****	.098	**.191***

Note: Correlations between nominal and continuous variables are reported as point-biserial correlation coefficients (r_{pb}), correlations between ordinal and continuous variables are reported as Spearman's Rho (ρ), correlations between latent and measured variables were derived using a weighted least square mean and variance adjusted estimator (WLSMV) in Mplus. UHI = Urban Heat Island, CC = Climate Change. **p<0.01, *p < 0.05, †p < 0.10

Table 2b. Correlations between previous heat illness experiences, risk perceptions, and adaptive behaviors in Detroit, MI

	Perceived risk of summer temp.	Perceived risk of heat wave	Perceived risk of UHI	Perceived risk of CC	AC intensity	Window AC	Passive	Window fan
Adaptive Capacity	**-.152***	.053	-.008	**.126**†	-.065	.013	.033	.006
Individual heat illness	**.456****	.127	.186†	**.189**†	**-.311***	.006	.124	**.183**†
Household heat illness	**.526****	**.183**†	**.301****	**.186**†	**-.249**†	.113	.059	.130

Perceived risk of summer temp.	--	--	--	--	-.201	.100	-.031	.053
Perceived risk of heat wave	--	--	--	--	-.074	-.008	.024	.071
Perceived risk of UHI	--	--	--	--	-.140	-.001	.038	-.055
Perceived risk of CC	--	--	--	--	-.101	.008	-.015	.040

Note: Correlations between nominal and continuous variables are reported as point-biserial correlation coefficients (r_{pb}), correlations between ordinal and continuous variables are reported as Spearman's Rho (ρ), correlations between latent and measured variables were derived using a weighted least square mean and variance adjusted estimator (WLSMV) in Mplus. UHI = Urban Heat Island, CC = Climate Change. **p<0.01, *p < 0.05, $^{\dagger}p < 0.10$

Moderated-Mediation Models. Results from the final models of previous heat illness experience, risk perception, and adaptive behaviors were mixed; overall, global fit from mediation-only models was poor (tables 4a & 4b). In general, for both cities, results were stronger and more significant for effects that involved adaptive capacity, and for the left side of the causal model (the relationship between previous illness and risk perception) as opposed to the right side (the relationship between risk perception and adaptive behaviors).

H1. The relationship between individual and household previous heat illness experiences and individual risk perceptions were positive, significant, and strong in both cities ($a_{1–4}$). In Phoenix, relationships were significant for the perceived risk of summer temperatures across all models, and for heat waves only when the outcome variable was AC intensity. Overall, effects sizes were larger for Detroit, and more risk perception measures were significant in Detroit compared to Phoenix. Relationships were stronger and more reliable for proximate heat risk perceptions than distal, and for individual compared to household heat illness experiences in both cities.

H2. Estimates for the second hypothesis were mixed ($b_{1–4}$). There was opposing mediation between multiple independent risk perception variables and the AC intensity outcome variable in Phoenix. Opposing mediation, also called inconsistent mediation, describes a situation in which multiple mediated effects have opposing signs (Kenny, 2018; MacKinnon, Fairchild, Fritz, 2007). In this case, risk perception of typical summer temperatures, heat waves, and the urban heat island were positively associated with AC intensity, while risk perception of climate change was negatively associated with AC intensity. Thus, the negative effect from climate change risk perception attenuated the total indirect effect from heat illness experiences to AC intensity (M_eX_1). In Detroit, risk perception was generally negatively associated with adaptive behaviors, though no relationships were significant at conventional confidence levels.

H3. In Phoenix, previous heat illness experiences were negatively associated with AC intensity, but unassociated with non-central-AC active or passive cooling when controlling for age, gender, risk perception, and adaptive capacity. In Detroit, there were no significant relationships between previous heat illness experiences and adaptive behaviors when controlling for the same variables. These results were contrary to the correlational analysis, indicating possible confounding by other model variables.

H4. The fourth hypothesis suggested that risk perception of heat hazards would mediate the relationship between previous heat illness experiences and adaptive cooling behaviors. Consistent with this hypothesis, in Phoenix, the relationship between both individual and household previous heat illness experiences and passive cooling behaviors may have been fully mediated by the perceived risk of typical summer temperatures ($ab_{1,1}$). However, full models in Phoenix demonstrated inconsistent mediation for AC intensity models (Model 1 & 6): Opposite the correlational results, heat illness was indirectly positively associated with AC intensity via the perceived risk of summer temperatures and heat waves ($ab_{1,1}$–$ab_{1,2}$); overall indirect effects were also positive (M_eX_1). However, heat illness experiences were directly negatively associated with AC intensity (c'_1); because the direct relationship was smaller than the indirect relationship, the total effect was negative (c_1). There were no significant indirect effects in Detroit based on the joint test of significance. The joint test of significance tests the null hypothesis that the mediated effect equals zero by determining if the direct effects of the mediator on the independent variable and of the outcome variable on the mediator equals zero. The mediated effect is considered significant if both the direct effects are also significant (Kenny, 2018; Hayes & Scharkow, 2013; Fritz & MacKinnon, 2007).

H5. Based on the fifth hypothesis, I expected to see negative moderated relationships between previous heat illness experiences and risk perception ($d_{1,1}$–$d_{1,4}$) and positive moderated relationships between risk perception and adaptive behaviors ($d_{2,1}$–$d_{2,4}$) (Figure 4b). In-line with the hypotheses, there was significant negative moderation between both individual and household heat illness and risk perception of typical summer temperatures in Phoenix, but only for models with AC intensity as the outcome variable ($d_{1,1}$). In Phoenix, there was significant positive moderation between the perceived risk of climate change and AC intensity ($d_{2,4}$), but this moderated relationship was negative for the perceived risk of the urban heat island ($d_{2,3}$), which indicates that adaptive capacity decreased the otherwise positive relationship between the perceived risk of the urban heat island and AC intensity, and increased the otherwise negative relationship between the perceived risk of climate change and the AC intensity. Log likelihood difference tests between the un-moderated and moderated models in Phoenix suggest that moderated models between both individual and household heat illness experiences and AC intensity did not represent a significant loss of fit compared to un-moderated models, supporting a moderation hypothesis—this was not the case for the relationship between heat illness experiences and active or passive cooling behaviors, suggesting that adaptive capacity may not moderate mediated paths in these models.

In Detroit, as opposed to Phoenix, the relationship between previous heat illness experiences and risk perceptions were strongly positively moderated by adaptive capacity, such that previous individual or household heat illness experiences were associated with a greater increase in risk perception for high adaptive capacity cases compared to low adaptive capacity cases across all models ($d_{1,1}$–$d_{1,4}$). While there were no direct effects from risk perception on adaptive cooling behaviors, the relationship between the perceived risk of typical summer temperatures and AC intensity as moderated by adaptive capacity was strong, positive, and significant ($d_{2,1}$). Based on the joint test of significance, there may be significant moderated-mediation in Detroit between both individual and households heat illness experiences and AC intensity mediated by the perceived risk of summer temperatures and moderated by adaptive capacity ($d_{1,1}d_{2,1}$). However, contrary to the hypothesis, this moderated-mediation was not inconsistent: heat illness experiences were positivity indirectly related to AC intensity in Detroit when moderated by adaptive capacity. Nonetheless, while non-significant, the total indirect (M_eX_1), direct (c'_1), and total (c_1) effects between previous heat illness and AC intensity were negative. Log likelihood difference tests between the un-moderated and moderated models in Detroit, with the exception of the relationship between individual heat illness experiences and passive cooling behaviors (model 3), suggest that the moderated models do not represent a significant loss of fit compare to the un-moderated models. This result also supports a moderation hypothesis, suggesting that in Detroit, adaptive capacity significantly changes the slope of the relationships between previous heat illness experience, risk perception, and adaptive behaviors.

Adaptive Capacity. Although adaptive capacity was hypothesized to act only as a moderator of the relationship between previous heat illness experience and risk perception and of risk perception and adaptive behaviors, the analysis revealed additional interesting and unexpected direct effects from adaptive capacity. In both Phoenix and Detroit, adaptive capacity was uniformly negatively associated with risk perception ($a_{2,1}$–$a_{2,4}$). In Phoenix, there was inconsistent mediation between adaptive capacity and AC intensity; adaptive capacity was indirectly negatively associated with AC intensity ($ab_{2,1}$–$ab_{2,4}$), due to the negative relationship with risk perception, but was positively directly related to AC intensity. Total effects between adaptive capacity and AC intensity in Phoenix were likewise small, and because the indirect effect was larger than the direct effect, negative (c_2). Finally, and consistent with the fifth hypotheses, although specific moderated-mediated effects from heat illness to AC intensity were not inconsistent, total effects from *both* independent variables (c_1+c_2) (heat illness experiences and adaptive capacity) with AC intensity were inconsistent in both cities, and thus approached zero in both case

Table 3. Model legend

	Phoenix		Detroit	
	X_1	Y	X_1	Y
Model 1	Individual heat illness	AC intensity	Individual heat illness	AC intensity

Model 2	Individual heat illness	Active cooling	Individual heat illness	Window AC
Model 3	Individual heat illness	Passive cooling	Individual heat illness	Passive cooling
Model 4	Household heat illness	AC intensity	Individual heat illness	Window fan
Model 5	Household heat illness	Active cooling	Household heat illness	AC intensity
Model 6	Household heat illness	Passive cooling	Household heat illness	Window AC
Model 7	--	--	Household heat illness	Passive cooling
Model 8	--	--	Household heat illness	Window fan

Table 4a. Path coefficients for Phoenix models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
$a_{1,1}$	**1.000**	**1.077**	**1.052**	**0.772**	**0.809**	**0.783**
$a_{1,2}$	**0.725**†	2.119	1.978	**0.702**†	1.424	1.737
$a_{1,3}$	0.032	0.111	0.106	0.038	0.072	0.069
$a_{1,4}$	0.111	0.140	0.135	0.160	0.170	0.165
$a_{2,1}$	**-0.922**	**-0.848**	**-0.852**	**-0.894**	**-0.880**	**-0.868**
$a_{2,2}$	**-1.639**	-4.610	-4.372	**-2.038**	-4.191	-5.589
$a_{2,3}$	**-0.613**	**-0.529**	**-0.553**	**-0.548**	**-0.551**	**-0.570**
$a_{2,4}$	**-0.416***	**-0.516**	**-0.532**	**-0.460***	**-0.547**	**0.556**
b_1	**0.509***	0.001	**0.120**	**0.448***	0.003	**0.135**
b_2	**0.843**	-0.006	0.154	**0.950**	-0.014	0.153
b_3	**0.514**	0.011	0.035	**0.487**	0.008	0.027
b_4	**-0.197***	0.009	**0.083***	-0.170	0.009	**0.087***
$ab_{1,1}$	**0.509**	0.001	**0.126**	**0.346**	0.002	**0.106**
$ab_{1,2}$	**0.611**	-0.013	0.305	**0.667**	-0.020	0.266
$ab_{1,3}$	0.016	0.001	0.004	0.019	0.001	0.002
$ab_{1,4}$	-0.022	0.001	0.011	-0.027	0.002	0.014
$ab_{2,1}$	**-0.469**	-0.001	**-0.102**	**-0.401**	-0.003	**-0.117**
$ab_{2,2}$	**-1.382**	0.028	-0.673	**-1.936**	0.059	-0.855
$ab_{2,3}$	**-0.315**	-0.006	-0.019	**-0.267**	-0.004	-0.015
$ab_{2,4}$	**0.082**	-0.005	**-0.044**	0.078	-0.005	**0.048**
$d_{1,1}$	**-0.665***	-0.582	-0.540	**-0.580**	-0.534	-0.487
$d_{1,2}$	-0.219	-0.393	-0.419	0.185	0.319	0.533
$d_{1,3}$	-0.082	-0.292	-0.292	-0.185	-0.245	-0.242
$d_{1,4}$	0.070	0.154	0.184	0.125	0.205	0.227
$d_{2,1}$	-0.109	-0.011	-0.016	-0.127	-0.008	-0.022
$d_{2,2}$	0.057	0.002	0.014	0.059	-0.003	0.006
$d_{2,3}$	**-0.466**	0.013	-0.012	**-0.474**	0.019	0.011
$d_{2,4}$	**0.356**	-0.014	-0.035	**0.329**	-0.019	-0.050
$d_{1,1}d_{2,1}$	0.072	0.006	0.009	0.074	0.004	0.011
$d_{1,2}d_{2,2}$	-0.012	-0.001	-0.006	0.011	-0.001	0.003
$d_{1,3}d_{2,3}$	0.038	-0.004	0.004	0.088	-0.005	-0.003
$d_{1,4}d_{2,4}$	0.025	-0.002	-0.006	0.041	-0.004	-0.011
c'_1	**-0.668**	0.067	0.105	**-0.659***	0.062	0.061
c'_2	**1.985**	0.038	**0.262**†	**2.112**	0.028	**0.268**†
c_1	0.447	0.058	0.551	0.345	0.047	0.449
c_2	-0.099	0.054	-0.577	-0.413	0.075	-0.671

M_oM_e	0.123	0.000	0.000	0.213	-0.005	0.000
M_eX_1	**1.115**	-0.009	0.446	**1.004**	-0.015	0.388
M_eX_2	**-2.084**	0.016	-0.839	**-2.525**	0.047	-0.939
Log p	**<0.001**	0.288	0.341	**<0.001**	0.187	0.783
X^2 p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
RMSEA	0.153	0.156	0.151	0.155	0.156	0.152
CFI	0.769	0.748	0.777	0.761	0.742	0.769

Note: Relationships involving categorical or ordinal outcomes are reported as raw scores; relationships with latent or continuous outcomes are reported as fractional standard deviations from the mean. Indirect effects were calculated by multiplying direct effects estimates, significance (bolded) was determined using the joint test of significance, which precludes exact confidence estimates (Kenny, 2018; Hayes, Scharkow, 2013; Fritz, MacKinnon, 2007). M_oM_e reports the total moderated-mediated effect of X on Y; M_eX_1 reports the total mediated effect of X_1 on Y; M_eX_2 reports the total mediated effect of X_2 on Y. Log p reports the significance level from the log-likelihood difference test between the moderated and un-moderated model (see Maslowsky, Jager, Hemken, 2015). Measures of global fit pertain to the un-moderated model (M0). **p<0.01, *p < 0.05, †p < 0.10

Table 4b. Path coefficients for Detroit models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
$a_{1,1}$	**1.255****	**1.240****	**1.249****	**1.269****	**1.344****	**1.517****	**1.499****	**1.537****
$a_{1,2}$	**0.608**	0.435	**0.407****	0.422	0.745	0.606†	**0.601**†	**0.604**†
$a_{1,3}$	0.472	**0.481**†	0.493	**0.463**†	**0.760****	**0.773****	**0.769****	**0.751****
$a_{1,4}$	**1.130***	**1.054***	**1.015**†	**1.021***	**0.830***	**0.780***	**0.717***	**0.742***
$a_{2,1}$	**-0.593***	**-1.008****	**-1.047****	**-1.045****	-0.591	**-1.241****	**-1.327****	**-1.309****
$a_{2,2}$	-0.620	**-1.136***	**-1.071****	**-1.025**†	-0.448	**-1.056**†	-0.939	-0.925
$a_{2,3}$	**-0.602**†	**-0.579***	**-0.566***	**-0.575***	-0.426	**-0.430**†	-0.426	**-0.441**†
$a_{2,4}$	-0.474	**-0.702***	**-0.649**†	**-0.669**†	-0.367	-0.576	-0.464	-0.500
b_1	0.177	0.072	-0.072	-0.032	0.130	0.024	-0.068	-0.024
b_2	-0.161	-0.060	0.038	0.037	-0.099	-0.046	0.029	0.034
b_3	**-0.433**†	-0.014	-0.011	-0.067	-0.257	-0.016	-0.007	-0.075
b_4	-0.350	0.046	-0.035	0.011	-0.313	0.050	-0.017	0.026
$ab_{1,1}$	0.222	0.089	-0.090	-0.041	0.175	0.036	-0.102	-0.037
$ab_{1,2}$	-0.098	-0.026	0.015	0.016	-0.074	-0.028	0.017	0.021
$ab_{1,3}$	-0.204	-0.007	-0.005	-0.031	-0.195	-0.012	-0.005	-0.056
$ab_{1,4}$	-0.396	0.048	-0.036	0.011	-0.260	0.039	-0.012	0.019
$ab_{2,1}$	-0.105	-0.073	0.075	0.033	-0.077	-0.030	0.090	0.031
$ab_{2,2}$	0.100	0.068	-0.041	-0.038	0.044	0.049	-0.027	-0.031
$ab_{2,3}$	0.261	0.008	0.006	0.039	0.109	0.007	0.003	0.033
$ab_{2,4}$	0.166	-0.032	0.023	-0.007	0.115	-0.029	0.008	-0.013
$d_{1,1}$	**1.244***	**1.473****	**1.483****	**1.521****	**1.045***	**1.619****	**1.630****	**1.672****
$d_{1,2}$	**1.794****	**2.208****	**2.051****	**2.031****	**1.555****	**2.150****	**1.907***	**1.929***
$d_{1,3}$	**1.281***	**1.185****	**1.192****	**1.136****	**1.088***	**1.076****	**1.031***	**1.013****
$d_{1,4}$	**1.952***	**2.020****	**1.915****	**1.961****	**1.480***	**1.619***	**0.340***	**1.442***
$d_{2,1}$	**1.241***	0.007	0.091	0.074	**0.997****	0.038	0.133	0.095
$d_{2,2}$	-0.436	0.041	-0.056	0.024	-0.314	0.003	-0.073	0.015
$d_{2,3}$	-0.416	0.052	0.008	-0.082	-0.358	0.028	-0.015	-0.076
$d_{2,4}$	-0.428	-0.024	0.006	0.104	-0.366	-0.052	-0.026	0.093
$d_{1,1}d_{2,1}$	**1.544**	0.010	0.135	0.113	**1.042**	0.062	0.217	0.159
$d_{1,2}d_{2,2}$	-0.782	0.091	-0.115	0.049	-0.488	0.006	-0.139	0.029
$d_{1,3}d_{2,3}$	-0.533	0.062	0.010	-0.093	-0.390	0.030	-0.015	-0.077
$d_{1,4}d_{2,4}$	-0.835	-0.048	0.011	0.204	-0.542	-0.084	-0.009	0.134
c'_1	-0.425	-0.154	0.146	0.117	-0.462	0.053	0.100	0.068
c'_2	0.595	-0.221	-0.084	-0.252	0.420	-0.111	-0.044	-0.263
c_1	-0.901	-0.049	0.031	0.072	-0.816	0.088	-0.002	0.015
c_2	1.016	-0.250	-0.020	-0.225	0.612	-0.114	0.030	-0.243
M_oM_e	-0.607	0.114	0.041	0.272	-0.378	0.014	0.053	0.245

M_eX_1	-0.476	0.105	-0.115	-0.045	-0.354	0.035	-0.102	-0.053
M_eX_2	0.421	-0.029	0.064	0.027	0.192	-0.003	0.074	0.020
Log p	**<0.001**	**<0.001**	0.116	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
X^2 p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
RMSEA	0.151	0.138	0.153	0.141	0.150	0.135	0.150	0.137
CFI	0.600	0.606	0.575	0.593	0.615	0.622	0.588	0.615

Note: Relationships involving categorical or ordinal outcomes are reported as raw scores; relationships with latent or continuous outcomes are reported as fractional standard deviations from the mean. Indirect effects were calculated by multiplying direct effects estimates, significance (bolded) was determined using the joint test of significance (Kenny, 2018; Hayes, Scharkow, 2013; Fritz, MacKinnon, 2007). M_oM_e reports the total moderated-mediated effect of X on Y; M_eX_1 reports the total mediated effect of X_1 on Y; M_eX_2 reports the total mediated effect of X_2 on Y. Log p reports the significance level from the log-likelihood difference test between the moderated and un-moderated model (see Maslowsky, Jager, Hemken, 2015). Measures of global fit pertain to the un-moderated model (M0). **p<0.01, *p < 0.05, †p < 0.10

DISCUSSION

H1. For both cities, both in bivariate correlations and when controlling for other model variables, previous individual and household experiences with heat illness were positively associated with the perceived risk of summer temperatures. Effects between previous heat illness and other risk perceptions variables were less consistent. This finding has important implications for both risk theory as well as risk communication practice: previous hazard impacts may have greater effects on the perceived risk of chronic or latent hazard risks compared to acute or manifest hazard risks. This may be due to psychological thresholds toward perceived risk, which have been documented in prior studies (Maddux, Rogers, 1983). That is, the perceived risk of a situation previously considered safe (e.g. typical summer temperatures) may be more effected by a violation of that perception (experiencing heat illness), than the perception of circumstances already perceived to be risky (a heat wave). This may also help explain why effects between previous heat illness experiences and risk perception were larger in Detroit, a typically temperate or cool climate, than Phoenix, a typically warm or hot climate. To the extent that risk perception may influence self-protective action, messaging focused on the possible health impacts of latently risky circumstances may be more salient than those focused on situations already perceived to be manifestly risky. For example, public health messaging in the summer that focuses on health impacts during typical weather as opposed to only extreme weather. In addition, weaker and fewer significant relationships between previous heat illness experiences and the perception of casually-distal risks—like climate change or the urban heat island—suggest that individuals may not strongly associate negative health impacts with distal causes. Therefore, risk messaging may also want to rely on examples of impacts that are conceptually or casually proximate to the target risk, something that may be hard to do for complex and abstract risks, like climate change.

H2. The effects between risk perceptions and adaptive cooling behaviors were variable across cities and models, which is consistent with decades of inconsistent findings regarding the relationship between risk perception and behavior (Van Valkengoed & Steg, 2019; Wachinger, Renn, Begg, & Kuhlicke, 2013; Bubeck, Botzen, & Aerts, 2012; Weinstein,1989). In particular, in Phoenix, risk perception was more often related to AC intensity than other cooling behaviors, and not all risk perception variables were related to AC intensity in the same direction. While in most models, risk perception variables were positively related to adaptive cooling behaviors, the perceived risk of climate change was negatively related to AC intensity, and positively related to non-AC passive cooling behaviors. This finding likely reflects the multidimensional aspect of perceived risk, and the relative coarseness of the survey instrument (Weinstein, 1993). From the perspective of Cultural Theory, it seems quite plausible that the climate change risk perception variable captured respondents' cosmological attitudes: respondents who were more concerned about climate change were less likely to choose adaptive strategies with high perceived costs to society (for example, air conditioning), consistent with a high “group” type worldview (Douglas & Wildavsky, 1982) (table 4a, models 1 & 4). The negative relationship between the perceived risk of the Urban Heat Island and AC intensity in Detroit may have been caused by the same effect (table 4b, model 1).

In general, there were few significant relationships between risk perception and adaptive behaviors in Detroit. This could have been due to multiple factors, including the difference in climate, fewer occasions to engage in adaptive behaviors in Detroit than Phoenix, and differences in sampling methodology and sample sizes (significance was more easily reached in Phoenix tests). However, an alternate explanation for the different result is suggested by the strong effects from adaptive capacity in all Detroit models. The only significant effects from previous heat illness to adaptive cooling in Detroit were from the interaction of previous individual or household heat illness with adaptive capacity through the interaction of the perceived risk of summer temperatures and adaptive capacity with AC intensity (models 1 & 5). In all Detroit cases, adaptive capacity had strong positive associations with adaptive cooling behaviors, suggesting that adaptive capacity was a superior predictor of adaptive behaviors than perceived risk, and may confound the relationship between perceived risk and adaptive behaviors when such a relationship exists.

H3. While I have operationalized heat illness experiences as past events, and adaptive behaviors as indicative of future intentions, the negative bivariate correlations and direct relationships between heat illness experiences and AC intensity in both cities suggest that AC use prevents heat illness, which is consistent with previous heat morbidity and mortality research (Semenza et al., 1996; Basu, Rupa, & Samet, 2002;

Naughton et al., 2002; Kamp, Evans, & Campo-Flores, 2017; Altavena, 2017). Theory suggests that heat illness experiences should lead to increased heat risk perception, and that increased heat risk perception should lead to increased cooling behavior, logically implying that heat illness experience is positively related to cooling behaviors, despite the fact that cooling behaviors should mitigate the risk of heat illness (figure 5, below). Without the ability to model time as a variable I was unable to definitively determine the causal order of events in this study (Weinstein, 1989). There may therefore be reverse causal effects in this and many previous studies between adaptive behavior and risk perception, such that adaptive behaviors in the past, as constrained by adaptive capacity, influences the perceived risk of future hazards, rather than the perceived risk of future hazards influencing adaptive behaviors (Lemmer & Gollwitzer, 2017). There may also be reverse or bi-directional causal effects between adaptive behaviors and hazard experience, such that adaptive behaviors reduce hazard experiences, and hazard experiences motivate adaptive behaviors.

H4. However, in Phoenix models, the indirect relationship between heat illness experiences and AC intensity was positive. The positive indirect relationship between heat illness and AC intensity in Phoenix supports a standard model of self-protective behavior, which typically operationalizes past experience as a motivating antecedent to protective action (Esplin, Marlon, Leiserowitz, & Howe, 2019; Weinstein, 1989). This effect was not seen in Detroit, where there were no direct or indirect relationships between previous heat illness and adaptive cooling behaviors. While this study is not able to determine why this difference exited in Detroit, it may be due to the different relationship that Detroit residents have with heat. In particular, Detroit residents were less concerned with typical summer temperatures than residents in Phoenix, and on average set their AC thermostats closer to their preferred temperatures (Table 1).

H5. Consistent with direct effects, moderated relationships between previous heat illness experiences, perceived risk of heat hazards, and adaptive cooling behaviors were significantly positively impacted by adaptive capacity in both cities. This finding reaffirms the need to consider adaptive capacity when attempting to predict, or influence, individual or household behaviors via risk perception. In general, high adaptive capacity households may be more likely to undertake adaptive behaviors, and those decisions may be more heavily influenced by their risk perceptions and previous experiences (tables 4a & 4b). However, they are also likely to have lower baseline risk perception and fewer previous experiences of heat illness than low adaptive capacity households (table 2a & 2b).

Together, the impacts of adaptive capacity in the models highlight three logical inconsistency in contemporary risk theory. The first two were recognized in the risk literature over 20 years ago, yet continue to create serious quandaries in the scholarship (Weinstein, Rothman & Nicolich, 1998; Van der Pligt, 1996; Weinstein, 1989). First, as was briefly noted above, the a-temporal relationship between previous hazard experiences, risk perception, and adaptive behavior is internally contradictory (figure 5, below) (Weinstein, 1989). Second, when considering the relationship between risk perception and adaptive behaviors scholars also have the option of measuring subject's conditional perception of risk, which would constrain their assessment to particular conditions, for example, perceptions of a risk in the absence of any adaptive behaviors, or under specific adaptive circumstances. However, conditional risk perception is rarely measured (Van Valkengoed, Steg, 2019; Van der Pligt, 1996). Unconditional assessments of risk are problematic when attempting to predict any adaptive actions that not only reduce the severity of a risk impact, but that directly reduce the probability of, or exposure to, a risk. For example, in the context of heat, having sufficient air conditioning reduces the probability of personally experiencing the high temperatures of a heat wave to near-zero, thus significantly impacting one's perception of the unconditional risk of heat waves. Only for adaptive actions that solely moderate the severity of being exposed—but not the likelihood of exposure—like using passive cooling adaptations during a heat wave (or wearing a seatbelt while driving) would one expect the relationship between perceived risk and adaptive action to be remain relatively constant over time (Weinstein, Rothman, & Nicolich, 1998).

In addition, this study suggests a third contradiction: if adaptive capacity decreases risk perception broadly, as the literature and this research suggest, and adaptive capacity also increases adaptive behaviors, as social vulnerability theory and empirical research strongly suggest, then risk perception cannot positively relate to adaptive behaviors. That is, except in cases where adaptive behaviors require little capacity (e.g. passive cooling), when an individual has high risk perception, they will be more likely to have low-adaptive capacity, which would limit their ability to undertake adaptive behaviors, and when an individual has high adaptive capacity (and thus the ability to act) they will be less likely to have high risk perception (Figure 4, below). The same problem occurs when you consider the effect of adaptive capacity with previous hazard experience: individuals' who are more likely to have experienced a hazard, are less likely to have the means to act to lower their risk, and therefore the effect of previous experience on their risk perception, or adaptive action, will likely be minimal (Figure 5, below).

Because adaptive capacity is a latent feature of the social structure, it is unlikely to change dramatically over time. Thus, adaptive capacity likely confounds the relationship between risk perception and adaptive behavior in both temporal and a-temporal analyses. Therefore, any measure of risk perception will only provide useful information about the likelihood that someone will or will not undertake adaptive action if controlling for adaptive capacity. This could be done, for example, by comparing an individual's perceived risk from a hazard against their own baseline adaptive capacity-dependent assessment of risk. Based on this finding, it seems quite likely that in cases where risk perception has been operationalized independently from adaptive capacity—as is common practice—risk perception was likely operating as a redundant measure of adaptive capacity, i.e. an independent variable providing information about a respondent's structural capacity, and *not* an independent predictor of adaptive behavior (Feingold, MacKinnon, & Capaldi, 2018; Valente et al., 2017; MacKinnon, 2012). This is supported by previous research which found that social vulnerability (a larger concept which includes adaptive capacity) negatively moderates the relationship between risk perception and adaptive intentions, and that, perceived adaptive outcome efficacy, which is largely dependent on adaptive capacity, may confound the relationship between risk perception and adaptive action ("chapter 2"; Van Valkengoed & Steg, 2019).

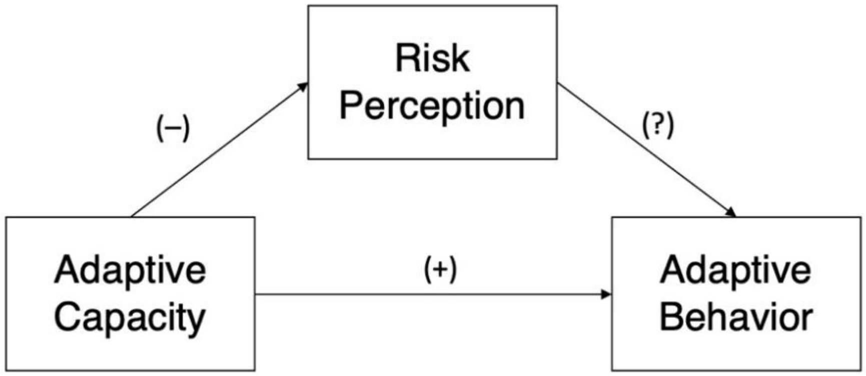

Figure 4. The theoretical relationship between risk perception and adaptive behavior confounded by adaptive capacity. Risk perception and adaptive capacity cannot have the same effect on adaptive behavior if they are inversely related.

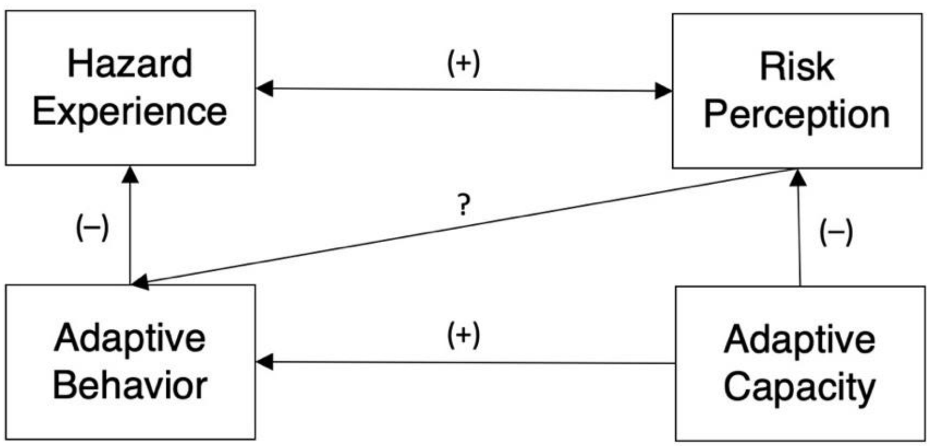

Figure 5. The theoretical relationship between previous heat hazard experience, risk perception, and adaptive behavior confounded by adaptive capacity. Risk perception and adaptive capacity cannot have the same effect on adaptive behavior if they are inversely related. Risk perception cannot have a positive effect on adaptive behavior if it is positively related to hazard experience, which is negatively related to adaptive behavior.

Together, these results may help explain why, despite the substantial intellectual investment made in the risk perception concept over the last 60 years, empirical results of its skill as a predictor for behavior have been mixed. Differences in risk perception traditions and conceptualizations (i.e. as a tool for understanding political attitudes toward risk vs. understanding public health behaviors) may help explain part of this discrepancy. In general, studies which adopted a holistic public health approach to predicting self-protective behaviors demonstrated greater skill in estimating behavioral outcomes, which is consistent with the important role of adaptive capacity found in this study (Van Valkengoed & Steg, 2019; Ferrer & Klein, 2015; Wachinger, Renn, Begg, & Kuhlicke, 2013; Bubeck, Botzen, & Aerts, 2012; Brewer et al., 2007; Vaughan, Matthews, & Karen, 1993). However, while theories of health-protective behaviors tend to operationalize adaptive capacity as an individual attribute (e.g. via "adaptation appraisal), this study suggests that adaptive capacity as a latent, structural social feature may largely capture those same effects. This provides the potential opportunity to use more easily collected sociodemographic data, instead of in-depth psychological questionnaires, to more fully understand adaptive intentions toward hazard risks.

CONCLUSION

This study attempted to analyze the relationship between previous heat illness experiences, the perceived risk of heat related hazards, and heat adaptive behaviors, as influenced by latent structural adaptive capacity in two cities. I found that previous heat illness experiences were positively associated with the perceived risk of summer temperatures in both cities, but effects between previous heat illness experience and the perceived risk of heat waves was less clear. There were larger effects between previous heat illness experiences and the perceived risk of summer temperatures in Detroit than in Phoenix. In both cities, effects were weaker and less significant between previous heat illness experiences and the perception of casually distal risks, including the risk of climate change and of the urban heat island. In Phoenix, the relationship between risk perception and adaptive behaviors was mixed, though effects were strongest with air conditioning use. There were no significant effects between risk perception and adaptive behaviors in Detroit. Consistent with previous finings, there were significant negative direct effects between heat illness experiences and AC intensity in both cities. Consistent with a standard model of self-protective behavior, there were positive indirect relationships between heat illness experiences and AC intensity in Phoenix mediated by the perceived risk of typical summer temperatures, heat waves, and climate change. However, there were no significant direct or indirect effects between previous heat illness and AC intensity in Detroit. There was significant moderation of the relationships between previous heat illness experiences, perceived risk of heat hazards, and adaptive cooling behaviors by adaptive capacity in both cities. Households with high adaptive capacity were more likely to report engaging in adaptive behaviors, and those responses were more influenced by their risk perceptions and previous experiences than households with low adaptive capacity. In general, high adaptive capacity households, reported lower baseline perceptions of risk and fewer previous experiences of heat illness than low adaptive capacity households.

Despite compelling results, on whole, this study highlights serious dilemmas in the contemporary application of the risk perception concept and inescapable contradictions in the theory upon which it is based. Confusion when investigating the relationship between risk perception and behavior occurring from the disregard for the temporal order of events, or from measuring unconditional versus conditional risk perception, has been documented previously, yet persists. In addition to these known limitations, the present study also reveals that when operationalized as an independent variable, risk perception may be additionally confounded by adaptive capacity, or more generally by social vulnerability, and when operationalized as an outcome variable, may be a redundant measure of adaptive capacity or social vulnerability. Therefore, even when conducting longitudinal analyses, it is likely inappropriate to operationalize risk perception as an independent predictor of behaviors without considering subjects' adaptive capacity dependent baseline perception of risk. Moving forward, researchers should design studies of risk perception and adaptive behavior to (1) differentiate between adaptive behaviors that do or do not lower a subject's likelihood of exposure to a risk (Weinstein, Rothman, & Nicolich, 1998), (2) decide carefully whether to measure subjects' conditional or unconditional perception of risk (Van der Pligt, 1996), and (3) in either case, control for subjects' structural adaptive capacity when assessing the influence of risk perception on behaviors.

CHAPTER 5

CONCLUSION

This dissertation has used a mechanisms-oriented epistemology based in analytical sociology to explain relationships between sociodemographic indicators of vulnerability, adaptive intentions, and health outcomes in the context of a concurrent extreme heat and electrical power failure event in Phoenix, AZ, and extreme heat alone in Detroit, MI. The purpose of this dissertation has been to argue the need for an improved understanding of the causal pathways and generative mechanism that create differential, and often inequitable, outcomes for different individuals and communities exposed to hazard risks. In addition, I have attempted to demonstrate novel methods that can be used to conduct mechanisms-oriented environmental social science research. This dissertation has focused on two important, growing, and interdependent risks: extreme heat and power failure.

STUDY CONTEXT

Extreme Heat. Rising global greenhouse gas emissions continue to contribute to atmospheric warming, while conventional urban land-use decisions continue to generate additional near surface warming in many cities around the world (Cao, Yu, Georgescu, Wu, & Wang, 2018; Jackson, 2018; Kaplan, Georgescu, Alfasi, & Kloog, 2017; Myint, Wentz, Brazel, & Quattrochi, 2013). The combined effects of global and urban warming are of particular concern for extreme heat events, which are projected to become more severe and pose significant challenges for human health (Krayenhoff, Moustaoui, Broadbent, Gupta, & Georgescu, 2018; Ebi et al., 2018; Vose, Easterling, Kunkel, LeGrande, & Wehner, 2017; Jones et al., 2015). The Fourth National Climate Assessment determined that across the United States minimum, maximum, and average temperatures have increased over the last fifty years (Vose, Easterling, Kunkel, LeGrande, & Wehner, 2017). The same report shows that average temperatures across the US are projected to rise another 1.4-1.6ºC by 2050 over a 1976-2005 baseline dependent on human-induced radiative forcing. Both coldest and warmest extremes are projected to increase by at least 2.8ºC by 2065 under a high forcing scenario (RCP 8.5). Meanwhile, heat waves defined as five-day long 90th percentile events could be up to 6ºC hotter nationwide by mid-century (Vose, Easterling, Kunkel, LeGrande, & Wehner, 2017). Based on relatively coarse estimates, 3,332 individuals died from heat related causes in the US between 2006–2010 (Berko, Ingram, Saha, & Parker, 2014). While in Maricopa County, Arizona alone, there were nearly 2000 hospital visits due to high temperatures across the 2008–2010 warm season (Petitti, Hondula, Yang, Harlan, & Chowell, 2015). The risks of heat related morbidity and mortality will increase with more warming (Ebi et al., 2018).

Power Failure. At the same time, the risks of large-scale electrical power failure have been growing due to: ageing infrastructure, increasing grid regulatory and market complexity, increasing security threats, and climate change (Sullivan & Kamensky, 2017; Greenberg, 2017; Koch, Reiter, & Bach, 2016; Burillo, Chester, & Ruddell, 2016; Bartos & Chester, 2015; Koeppel, 2015; Byrd & Matthewman, 2014; Hines, Apt, & Talukadar, 2008; Helbing, Ammoser, & Kuhnert, 2006). These circumstances also present significant risks to human health and wellbeing, especially for vulnerable populations who may be reliant on electrical powered medical devices like dialysis, continuous positive airway pressure devices (CPAP), or refrigerated medications (Chakalian, Kurtz, & Hondula, 2019; Molinari et al., 2017; Klinger, Vandeg, & Murray, 2014; Abir et al., 2013). Wide-spread outages decrease emergency management capacity (Beatty, Phelps, & Rohner, 2006) and increase mortality from foodborne illness, diarrheal diseases, carbon monoxide poisoning, and decreased access to healthcare (Kishore et al., 2018; Yates, 2013; Anderson & Bell, 2012; Beatty, Phelps, & Rohner, 2006; Marx, Rodriguez, & Greenko, 2006). Previous studies have shown that wide-spread electrical outages can cause mortality rates to increase as much as 25–122% (Kishore et al., 2018; Anderson & Bell, 2012).

Coupled Heat and Power Failure. Thus, changes in the physical, social, and built environments are increasing the independent risks of extreme heat or power failure, as well as the concurrent risk of extreme heat and wide-spread power failure (Chakalian, Kurtz, & Hondula, 2019; Broadbent, Gupta, & Georgescu, 2018; Ebi et al., 2018; Vose, Easterling, Kunkel, LeGrande, & Wehner, 2017; Myint, Wentz, Brazel, & Quattrochi, 2013; Byrd & Matthewman, 2014). Coupled physical and social processes affecting anthropogenic warming, electrical engineering, and household behaviors create the potential for heat and power failure hazard cascades (Clark, Chester, Seager, & Eisenberg, 2019; EPA, 2019; Pescaroli & Alexander, 2018; Klinger, Vandeg, & Murray, 2014; Abi-Samra, Forsten, & Entriken, 2010; Miller, Hayhoe, Jin, & Auffhammer, 2008). Extreme heat in power-out conditions is extremely dangerous, especially since air conditioning has been repeatedly established as one of the most protective factors against heat-related mortality and morbidity (Kamp, Evans, & Campo-Flores, 2017; Altavena, 2017; Basu, Rupa, & Samet, 2002; Naughton et al., 2002; Semenza et al., 1996).

CHAPTER SUMMARIES

Introduction. The introduction to this dissertation began with a typology of research traditions that have considered social vulnerability to environmental hazards, and this dissertation's closest intellectual neighbors. The concept of entitlements has been used in the political economic tradition of social vulnerability research, and the entitlements research orientation has been a major influence on this dissertation (Adger, 1999). The introduction provided a brief account of the particular epistemic approach of analytical sociology, in the sense defined by scholars such as Peter Hedstrom, Jon Elster, and Peter Bearman. Analytical sociology uses a positivist epistemology that is founded on four fundamental ideas (Hedström, Bearman, & Bearman, 2009). First, analytical sociology is based in *structural individualism*, which assumes that a whole is always explainable by the sum of its parts, and focuses on the importance of relations between wholes as well as relations from wholes-to-parts and parts-to-wholes. Second, methods based in analytical sociology assume that the parts which explain wholes operate mechanistically, i.e. phenomena are understandable from their constituent parts, and those parts are understandable as unique identifiable and measurable entities in relation to other parts. Third, analytical sociology seeks to achieve causal depth. A deep inquiry demonstrates relationships across epistemic scales by explaining the mechanisms that connect large social structures to individual behaviors and individual behaviors to large social structures. Similarly, and fourth, analytical sociology attempts to bridge the macro and the micro by measuring and operationalizing both macro and micro social features in their analyses. This dissertation has used these ideas to investigate the relationship between social vulnerability as a social structural feature, and psychological characteristics and behavioral intentions as causal mechanisms that may explain heat-health outcomes for socially vulnerable individuals.

Chapter Two. In the second chapter, I used structural equation modeling (SEM) to conducted an exploratory analysis of 163 surveys in Phoenix, AZ. The analysis tested variables that may mediate, or explain, relationships between typical social vulnerability indicators (i.e. socioeconomic status, age, gender, and racialized group) and heat-health outcomes. This chapter demonstrated a first-of-its-kind approach to measure and test psychological and behavioral variables as mediators between social vulnerability indicators and health outcomes. The second chapter thus provided an increased understanding of how social vulnerability manifests, and also made a significant methodological contribution to the field of social vulnerability and environmental hazards research. Results from the second chapter showed that thermal discomfort and self-reported heat illness were only predicted by SES (StdB = -0.52, $p < 0.01$); Age, gender, and racialized group did not relate to heat illness or thermal comfort based on the sample. Specified explanatory mechanisms did not fully explain the relationship between SES and thermal comfort or heat illness. Suggesting that common assumptions about how and why socially vulnerable individuals experience heat illness in greater numbers are incomplete. Self-reported indoor thermal comfort was a strong and significant predictor of indoor heat illness outcomes (StdB = 0.59, $p < 0.01$). This result suggests that heat risk messaging could encourage individuals to trust their feelings: if someone feels too warm they are at increased risk for heat illness. The second chapter concludes with 14 evidence-based hypotheses about the mechanistic relationships between social vulnerability and heat health outcomes. SEM methods are a promising tool for testing these hypotheses in the future.

Chapter Three. The third chapter explored 40 semi-structured interviews from summer 2016. Interviews were vignette styled and asked respondents to imagine their experience of a concurrent metro-wide heat wave and power failure event in Phoenix, AZ. This chapter combined a novel household-level social vulnerability index with code frequency counts from a content analysis to use inferential statistics to test a revised version of the Model of Private Proactive Adaptation to Climate Change (MPPACC) (Grothmann, Patt, 2005). This chapter tested four specific hypotheses: (1) that risk appraisal and adaption appraisal would be inversely related; (2) that more socially vulnerable subjects would have increased risk appraisal and decreased adaptation appraisal; (3) that social vulnerability would moderate the relationship between risk and adaptation appraisal, decreasing adaptation appraisal when controlling for risk appraisal; and (4) that more socially vulnerable subjects would be more likely to report a maladaptive adaptation intention. Results from the third chapter showed that adaptation appraisal was negatively associated with risk appraisal (StdB = -0.33, $p = 0.04$), and that social vulnerability was associated with an increase in perceived hazard severity (StdB = 0.44, $p < 0.01$), a decrease in perceived adaptation efficacy (StdB = -0.38, $p = 0.02$), and an indirect increase in maladaptive intentions (StdB = 0.18, $p = 0.01$). This chapter helped advance both social vulnerability theory as well as health behavior theory by showing a relationship between the two. Based on these results, heat-health risk messaging may benefit from targeting socially vulnerable populations and focusing on increasing perceived adaptive efficacy.

Chapter Four. The fourth chapter of the dissertation built on results from the third chapter by investigating the role of adaptive capacity, as a component of social vulnerability, in moderating relationships between previous heat illness experiences, risk perceptions, and adaptive intentions. 244 survey responses from Phoenix, AZ and Detroit, MI were modeled using SEM to test for positive relationships between previous heat illness experience, risk perceptions, and adaptive behaviors, negative moderation between previous heat illness and risk perception from adaptive capacity, and positive moderation between risk perception and adaptive behaviors from adaptive capacity. Results from the fourth chapter showed significant positive effects between both individual and household previous heat illness experiences and the perceived risk of heat in both Phoenix and Detroit. There were positive effects between the perceived risk of heat and adaptive behaviors in Phoenix, but not in Detroit. Moderated effects between previous heat illness experiences and risk perceptions were positive in both cities, i.e. increasing adaptive capacity was associated with an increased positive effect between previous heat illness experiences and the perceived risk of heat hazards. Moderated effects between risk perceptions and adaptive behaviors were also positive; increasing adaptive capacity was associated with an increased positive effect between previous heat illness experiences and the perceived risk of heat hazards. Overall, high adaptive capacity households were more likely to indicate using heat adaptive behaviors in the summer, and those decisions appeared to be more heavily influenced by their perceptions of heat risks and previous heat illness experiences. At the same time, high adaptive capacity households had overall lower perceptions of heat risk and fewer experiences with heat illness than low adaptive capacity households. To date, risk perception theories in the hazards and health protective behaviors literatures have assumed that increased risk perception leads to increased adaptive behaviors, and simultaneously that increased adaptive capacity leads to increased adaptive behaviors. However, there is growing evidence showing increasing adaptive capacity associated with a reduction in risk perception, confounding the relationship between risk perception and adaptive behaviors. This conflict is shown clearly in the fourth chapter of this dissertation: high adaptive capacity households were both more likely to undertake adaptive behaviors, and less likely to have a high perception of heat risks compared to the population.

SYNTHESIS

Together, results from this dissertation highlight the importance of understanding causal mechanisms across the environmental social sciences. Understanding causal pathways that lead to negative and often inequitable environmental health outcomes will enhance the ability to mitigate health risks and build happy, healthy, and resilient communities. However, at the moment, we know very little about the social and behavioral mechanisms that lead to differential negative health and wellbeing outcomes for individuals and groups. There are many well-developed theories that explain social phenomena at social structural scales (e.g. social vulnerability theory or social determinates of health theory), and equally well-developed theories that explain individual behaviors across the social sciences broadly (e.g. protection motivation theory or theories of decision making under uncertainty), and especially in the environmental health and hazards fields. However, we have very little empirical evidence about the mechanistic connections between social structural forces (e.g. particular political economies, schemes of social stratification, or institutionalized prejudices) and individual psychologies and behaviors that generate health and wellbeing outcomes.

It is unlikely that any one study or dissertation could reveal the universe of causal mechanisms that explain a social phenomenon. This dissertation identified two specific mechanisms that help explain observed social vulnerability to heat: air conditioning use, and risk appraisal. While I have not provided a long list of discovered causal mechanisms, this dissertation has provided three examples of mechanisms-oriented environmental health research using both quantitative and qualitative data and mixed analytical methods. By making the argument for this type of analysis, and providing examples of how it can be done, this dissertation serves as a first step and guide for building a body of mechanisms-oriented environmental social science research.

Chapter two made a compelling case that common assumptions about how or why social phenomena manifest may be misguided, and it seems plausible that this is true for hazards beyond heat and in places beyond Phoenix, AZ. The second chapter also demonstrated the suitability of structural equation modeling (SEM) for testing causal pathways in the environmental social sciences. Using SEM, I was able to test if and how socio-demographic variables like age, racialized group, gender, and socioeconomic status—as proxies for social structural forces (e.g. stratification and discrimination)—operated through particular psychological or behavioral mediators to produce negative heat-health outcomes. These methods could be replicated with samples from other cities, to test for different mediators, and in relation to hazard risks and impacts beyond heat. SEM is particularly well-suited to environmental social science research because it can accommodate small non-normal samples that are common in social science studies, as well as common survey variable types including ordinal and nominal scales (Muthén & Muthén, 2017; MacKinnon, Fairchild, & Fritz, 2007). In addition to significance testing to determine the likelihood that a specified mediator explained the relationships between an independent and outcome variable, SEM can also provide estimates of the size of an effect, and in some cases, the amount of variance explained by independent and mediating variables (Muthén & Muthén, 2017; MacKinnon, Fairchild, & Fritz, 2007). Environmental social scientists can enhance the use-value of their work by approaching their research with a structural individualist epistemology and adopting mechanisms-oriented analytical methods, including SEM.

The third chapter of this dissertation demonstrated the value in operationalizing both social structural and individual behavioral variables in environmental health research. By including social vulnerability in the analysis of adaptive motivations to a heat and power failure hazard cascade in Phoenix, AZ, I not only gained a better understanding of who was more likely than others to have healthy adaptive intentions, but how and why some people were more likely than others to have healthy adaptive intentions. Had I adopted a more traditional approach to this study, which had not considered both social structural and individual variables in concert, I would not have known that perceived adaptive efficacy was mechanistically responsible for the discovered increase in maladaptive intentions among socially vulnerable households. Thus, I would not have discovered that the consequences of social vulnerability could be reduced by increasing perceived adaptive efficacy. This discovery allows me to make concrete recommendations for practitioners who conduct risk communication: risk messaging that increases perceived adaptive efficacy may be more likely to succeed in motivating adaptive behaviors than risk messaging that only increases the perceived probability of a hazard's occurrence, or the severity of a hazard's impacts, and this appears to be especially true for socially vulnerable populations who are most at-risk and most likely to report maladaptive intentions.

Results from the third chapter of this dissertation aligned well with results from the fourth, which explored additional mechanisms that may explain relationships between risk perceptions and adaptive intentions. As in the third chapter, the fourth chapter operationalized both social structural and individual variables. As in the second chapter, the fourth chapter tested specific mediators as possible explanatory variables for hypothesized relationships between independent and outcome variables. The fourth chapter expanded methodologically on the second chapter, by testing not only for mediation but also for moderated difference in effects sizes. The fourth chapter expanded conceptually on the third chapter, by testing if and how previous hazard experiences impacted perceived risk, in addition to how perceived risk impacted adaptive behaviors. The fourth chapter also highlighted the analytical versatility of SEM, which was able to test for mediation and moderation simultaneously.

While questions of mediation attempt to understand *how* relationships between two variables are produced, questions of moderation seek to understand under what conditions, or for *whom* those relationships exist, and whether a third moderating variable may change their direction or intensity (MacKinnon & Luecken, 2008). Questions of moderation are at the very core of social science. For whom does increasing education lead to increasing pay, and is this relationship stronger for some groups than others? What explains whether children of alcoholics develop an aversion or affinity toward alcohol in adulthood? Each of these questions are examples of moderation. Yet, despite social science's clear interest in questions of moderation, they have rarely been tested in the environmental social sciences, and especially outside of psychology.

The fourth chapter of this dissertation demonstrated the value in considering the ways that social structure may moderate relationships at the individual or household level. By investigating the role of adaptive capacity as moderator of the relationships between previous heat illness experience and heat risk perceptions, and between heat risk perceptions and adaptive behaviors, I discovered that adaptive capacity acted as a confounder of these relationships. Previous studies have found inconsistent results when testing risk perception as an antecedent to adaptive behavior, and confounding by unmeasured adaptive capacity may explain why. I discovered this because I combined robust mixed-methods with a novel mix of social structural and behavioral variables to conduct mechanisms-oriented research.

It should be noted that adaptive capacity in the fourth chapter was measured in a very similar way as SES in the second chapter. While this does not undermine adaptive capacity's role as an important moderator, it does suggest that social vulnerability theory may need to develop to distinguish adaptive capacity from existing social science concepts. Previous scholars have suggested that researchers use "the existing terminology of the social sciences" to describe problems when possible; this may be an example where social vulnerability theory has more work to do to define and defend adaptive capacity's unique attributes (Hinkel, 2011. pg. 206).

IMPLICATIONS FOR PRACTICE

Findings from the three main chapters of this dissertation have significant implications for hazards mitigation practice. While historically the hazards and social vulnerability communities have been somewhat separated from the disaster and emergency management communities, there have been pushes to better integrate schools of thought and practice (National Research Council 2006). To that end, environmental hazards research conducted from an analytical perspective could be highly valuable to emergency management (EM) practice. This is especially the case as current EM practice tends run counter to the ideas of analytical inquiry as outlined previously. This can be seen most clearly in the propagation of an all-hazards model of emergency planning.

While the idea behind all-hazards planning can be nebulous, and the guidance provided by the US Federal Government has evolved with time, the basic premise is in the name: EM departments should plan for all hazards. The Federal Emergency Management Agency (FEMA) suggests, in their standing guidance on the matter, titled *Guide for All-Hazard Emergency Operations Planning* (1996), that state and local governments should take a "functional approach to the structure of emergency operations plans (EOP's)" (pg. 3-1). EOP's "describe who will do what, as well as when, with what resources, and by what authority—before, during, and immediately after an emergency" (FEMA, 1996. pg. i). FEMA suggests that an all-hazards approach makes sense because,

"While the causes of emergencies vary greatly, the potential effects of emergencies do not, [which] means that jurisdictions can plan to deal with effects common to several hazards, rather than develop separate plans for each hazard" (FEMA, 1996. pg. 3-1).

However, this simple assumption fails to address the causes of those effects, which are likely to differ between different hazards in the same place and among single-hazards in different places (Cutter, 1996). The planning document goes on to advise:

“Creating a different plan for each hazard is an option, but not one that FEMA recommends. The functional approach: Avoids duplication of the planning effort for every hazard and for every task, by dividing the EOP into four levels of specificity (Basic Plan, functional annexes, hazard-specific appendices, and SOPs). Serves in all hazard situations, even unanticipated ones, by organizing the EOP around performance of "generic" functions. Permits *emphasis* on hazards that pose the greatest risk to a jurisdiction, through the use of hazard-specific appendices.” (Pg. 3-3)

Though “hazard-specific appendices” do leave room for capacity-building around different causal pathways, there is a strong inclination in the planning guidance toward generic functions and high-level all-hazard planning. This focus on “generic” capacity building has been even more apparent in on-the-ground EM practice (Office of Public Health Preparedness and Response, 2013). Though some academic and practitioner stakeholders have at least implicitly challenged the appropriateness of all-hazards planning (National Research Council 2006; Hinkel, 2011), few have focused on the importance of understanding the specific causal mechanisms which underlie unique societal vulnerabilities. As opposed to FEMA’s consequentialist approach (focusing on *effects* and how to mitigate them), a mechanistic approach has the ability to provide insights into the *causes* of negative outcomes—giving practitioners the ability to not only mitigate outcomes when trigger events occur, but potentially mitigate the trigger events altogether (and therefore the outcomes as well).

Although no approach to emergency planning will allow us to stop many unavoidable hazards, like a heat wave, some approaches will be more likely than others to stop human-caused hazards, such as terrorist attacks or industrial accidents. Furthermore, even in the case of an unavoidable hazard, such as extreme heat, a mechanistic approach to emergency management may allow for the prevention of negative outcomes earlier in the "causal chain" (Elster, 1989). For example, while traditional "generic" capacity building may advise public health department to be ready to deploy additional resources in "vulnerable" neighborhoods during heat waves, it is often unclear what these resources should be, and in practice usually arrive to treat symptoms that are already occurring: such as heat exhaustion or death. More targeted capacity-building based on a mechanistic understanding of heat risk may allow public health practitioners to deploy specific resources to specific neighborhoods before illnesses occur. Resources could take the form of portable air conditioning units, or utility vouchers. Research into the fundamental mechanisms that drive negative hazard outcomes is essential for effective emergency planning. Results from the second chapter of this dissertation demonstrated that self-reported thermal comfort, and relative AC thermostat set temperature, are both better predictors of heat-illness outcomes than total AC use or socioeconomic status alone, suggesting an important mechanism driving negative health outcomes (relative thermal discomfort). Without a robust understanding of the specific causal mechanisms that lead to negative health outcomes for different households exposed to different hazards in different places, public health officials and emergency planners are less able to prevent negative outcomes before they occur. The ability to prevent these events is likely to not only protect lives, but also increase long-run programmatic efficiency by reducing the overall scale of risk.

Beyond emergency management, this dissertation has implications for individuals and organizations tasked with managing and mitigating extreme heat risks broadly. Results from this dissertation point to clear suggestions for risk messaging: heat risk communication will benefit from catering messaging to more or less socially vulnerable groups, encouraging individuals to trust their sense of thermal comfort, priming previous heat illness experiences, and increasing perceived adaptive efficacy. Messaging designed for broad audiences should focus on priming both direct and indirect previous heat illness experiences and may want to focus on relative thermal comfort. For example,

"*Have you or someone you know ever felt dizzy, nauseous, or extremely tired from the heat? these are all symptoms of heat illness. Avoid outdoor activities during the hottest times of the day and move to an air-conditioned space if you or someone you know is feeling too warm*."

"*If you are feeling too warm, you are at risk for potentially life-threatening heat illness, move to an air-conditioned space and avoid strenuous activity."*

While messaging designed to target socially vulnerable groups should focus on increasing perceived self and adaptive efficacy, for example,

"*You are able to stay safe in the heat. Staying in air conditioning during the hottest times of day will effectively reduce your risk of potentially life-threatening heat illness."*

Results from this dissertation suggest that the above messages will be more likely to motivate self-protective adaptive behaviors for socially vulnerable groups, compared to traditional messaging that is focused on hazard probability or severity, for example,

"Afternoon heat is extremely dangerous, avoid outdoor activities in the afternoon".

Specifically, heat risk messaging focused on increasing the perception of heat hazard severity or probability of occurrence are likely to only be effective for audiences that have high adaptive capacity, and low social vulnerability—who are the least likely to experience heat illness, and the least in need of intervention.

FINAL THOUGHTS

As a whole, results from this dissertation point to the importance of individual socioeconomic resources in mitigating heat risks. Individuals without sufficient resources are less likely to use effective adaptive measures and more likely to be too warm and experience heat illness in the summer. Effects from socioeconomic status on self-reported heat illness were stronger than for any other sociodemographic indicator including age, gender, and racialized group. These results point to an important role for policymakers in mitigating heat risks. Political economic levers that affect relative income inequality or redistribution, and the general economic health of society, are important loci for public health intervention. Increasing relative income is directly related to a reduction in heat illness risk even when controlling for other sociodemographic, psychological, and behavioral variables. Typical models of health protective behaviors that fail to account for social structural adaptive capacity did not accurately predict self-protective behaviors or health outcomes. Therefore, public health interventions that do not address underlying social vulnerabilities are unlikely to produce consistent outcomes.

Over the course of the four previous chapters, I first outlined the broad field of environmental hazards and social vulnerability research. I then provided a thorough discussion of analytical sociology as a sociological research orientation focused on mechanistic explanations. I also argued for structural individualism as a useful epistemology for conducting environmental social science research. In the second chapter, I presented the first of three studies included in this dissertation. The second chapter demonstrated the use of structural equation modeling (SEM) for both exploring and testing social and behavioral mechanisms that may explain environmental health outcomes and showed the importance influence of thermal comfort on heat illness risk. In the third chapter, I conducted a mechanisms-oriented study using qualitative data and mixed analytical methods. The third chapter demonstrated the value in operationalizing both social structural variables and individual psychological and behavioral variables in a single analysis. In so doing, the third chapter discovered a possible mechanism that generated differential hazard outcomes for socially vulnerable groups: perceived adaptive efficacy. The last of three studies included in this dissertation was presented in the fourth chapter. The fourth chapter built on the previous two by testing both questions of how, i.e. by what mechanisms did outcomes occur? and questions of who, i.e. what influences for whom outcomes occur? The fourth chapter discovered an important contradiction in existing risk perception, social vulnerability, and health protective behaviors theory: adaptive capacity has been theorized to simultaneously decrease perceived risk and increase adaptive behaviors, which contradicts the theorized positive relationship between risk perception and adaptive behaviors. Finally, this dissertation has finished with a concluding chapter that has summarized and synthesized the findings from the previous four chapters and highlighted practical implications for future academic research programs as well as for public health and emergency management practice and policy. Taken as a whole, this dissertation makes a strong argument for mechanisms-oriented environmental social science research. Results from the studies included in this dissertation make a compelling case for the inclusion of both social structural and individual level variables when conducting environmental social science research and point to the important role of socioeconomic status and relative adaptive capacity in influencing adaptive choices and heat-health outcomes.

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APPPENDIX A

RISK/EMOTIONAL PERCEPTION Q'S

APPENDIX A

Appendix A

Part I. Risk/Emotional Perceptions Q's:
To get us started, I am going to begin by asking you to tell me a little about your household.

1. Who lives here?
   Sub-Questions:
      a. How many people?
      b. What is their relationship to you/each other?
      c. Who makes important household decisions?

Thanks, next I am going to ask you some open-ended questions about how you perceive different risks in your life. Please take as much time as you need when answering. There are no right/wrong answers.

1. What types of emergencies are you worried about here in the Phoenix metro area?

2. Are you worried about a power outage or blackout that lasts more than two days and affects the whole Phoenix metro area?
   a. If you are, can you tell me why? If not, why not?
   b. How likely do you think this is to occur?
   c. Can you tell me briefly how you feel about that?
   d. Do you think this poses a serious risk to your health or not? Why or why not?

3. Are you worried about a heat wave that lasts more than two days?
   a. If you are, can you tell a little bit about why? If not, why not?
   b. How likely do you think this is to occur?
   c. Can you tell me briefly how you feel about that?
   d. Do you think this poses a serious risk to your health or not? Why or why not?

4. Are you worried about a heat wave that lasts more than two days during a concurrent power outage or blackout in the whole metro area?
   a. If you are, why? If not, why not?
   b. How likely do you think this is to occur?
   c. Can you tell me briefly how you feel about that?
   d. Do you think this poses a serious risk to your health or not?

Part II. Household Vignette:

Please imagine – using real memories or your imagination – that it is 7:00 in the morning on a weekday in the summer, it has been much hotter than normal this week – it is 100ºF outside in Phoenix right now. You are at home when your electrical power goes out.

##Note: Add realistic structural constraints (e.g., gas pumps don't work, slow or no emergency response or bus service, no water pressure) in the vignette **on day 2**. If the respondent wants to evacuate the metro area, allow them to describe their process attempting to do so, then bring them back to the city. E.g., *I understand that you would try to leave the city. Since we cannot know for sure if you would be successful or not, and to help us better understand what residents would do in the urban area during this type of event, let's pretend that for whatever reason you were unsuccessful in your attempt to leave and that you remained in the metro area.*

1. What do you do after the power goes out?
   Probes:
   a. What are your first priorities?
   b. What responsibilities do you have?
   c. Who do you tell? / Whom do you call?
   Sub-questions:
   a. What are you concerned about?
   b. Are you worried about anyone? If you are, what do you do?
   c. Is there anything you do in your home?
   d. Do you change any of your plans?
   e. Do you look for more information? If so, Where from? And about what?
   f. How long do you think this power outage will last?
      i. (If more than a few hours) Do you prepare and if so how?

Now, please imagine that several hours have passed, it's now mid-day or noon, and you've discovered that no one in the metro area has power, except for some essential services that are running on backup generators. It is 123ºF outside now.

2. What are you doing now? Please tell me what you're doing and why.
   Probes:
   a. Just as a reminder, this is during a heat wave. How does that affect what you are doing?
   b. Just as a reminder, there is no power anywhere in the city. How does that affect what you're doing?
   Sub-questions:
   a. Where are you? Follow-up: where are the other members of your household?
   b. Have you been in contact with anyone? Is there anyone else you're worried about now? If yes, how will you help?
   c. Are you trying to get more information? Where do you look? Do you trust that information?
   d. Are you making a plan?
   e. What do you and other people in your house need?

f. Whom are you helping? Who is helping you?

Reminders for interviewers:
a.) How much did [X resource] cost?
b.) How many of [X resource] do you have?
c.) How do you know [X person who will help?]
d.) How did you get [X resource]?
e.) Where did you learn that [X adaptation] would help?
f.) How did you know of [X resource]?

3. What is your biggest worry?

Now it is late afternoon, dinnertime, you are hungry, and perhaps others you are with are hungry as well.

4. What do you do?

Probes:
a. What will you do for food?
b. How do you cook your food?
c. Are you worried about running out of food? If so, what are you doing to avoid running out of food?

Reminders for interviewers:
a.) How much did [X resource] cost?
b.) How many of [X resource] do you have?
c.) How do you know [X person who will help?]
d.) How did you get [X resource]?
e.) Where did you learn that [X adaptation] would help?
f.) How did you know of [X resource]?

Now it's nighttime, around the time you usually head to bed, you are tired and hot, it is now 116ºF outside. It is completely dark inside and outside.

5. Now that it's dark, what are you doing?

Sub-questions:
a. Are you still at home? If not, where are you?
b. Where are you sleeping?
c. How are you keeping cool?
d. Do you have light? If so, what are you using for light?
e. How are you feeling? Are you afraid or worried?
f. Are you worried about keeping yourself, others, and your property safe?
   i. If yes, why? and what would you do about it?

Reminders for interviewers:
a.) How much did [X resource] cost?
b.) How many of [X resource] do you have?
c.) How do you know [X person who will help?]

d.) How did you get [X resource]?
e.) Where did you learn that [X adaptation] would help?
f.) How did you know of [X resource]?

The next morning you realize the power is still out. You find out the power may be out for several more days. It is still >100ºF outside. With the power out in the whole region many utilities are no longer working or are unreliable. This includes: cell service, Internet, water pressure, gas pumps, and telephone landlines. Many other basic services may be unreliable as well including: public transit, the airport, sewage treatment, hospitals, and police and fire services.

6. Do you do anything differently from yesterday?

Sub-questions:

a. Do you have the same plan, or make a new one?
a. Do you have the same concerns, or are you worried about anything new?
b. How is your house affected by the power being out for 24 hours?
c. How do you feel physically with regards to the heat?

Now imagine the power has been out for another 48 hours, so the blackout has lasted three full days and there is still no official word about when service will be restored.

7. Please tell me how your situation is changing or what you might do differently now that the power has been out for a long period of time.

Sub-questions:

a. Do you have any new concerns?
b. Are there any new problems?
c. Are you worried about anyone else that you haven't been worried about previously?
d. If yes to any of the above, how/why?

Reminders for interviewers:
a.) How much did [X resource] cost?
b.) How many of [X resource] do you have?
c.) How do you know [X person who will help?]
d.) How did you get [X resource]?
e.) Where did you learn that [X adaptation] would help?
f.) How did you know of [X resource]?

Wrapping up Questions for Individual Vignette:

Thank you, that was the end of the scenario. Coming back to the present, I would like to ask you some questions about the exercise you just participated in and the scenario you described.

1. What helped you most during this scenario?
2. What do you wish you had, that you didn't, that would have helped you during this time?

3. How would your responsibilities change before, during, and after an event like this?
4. What are you worried about having to deal with once the power comes back on?
    a. Of these, which are most concerning? How would you tackle them?
5. How prepared do you feel for a scenario like this?
6. What do you think you would need to be more prepared for a scenario like this?

##Note: Now is the time to ask about anything that the respondent did not mention that you found interesting (e.g., they never mentioned trying to leave the valley even though they had a car, they never mentioned their kids even though they said they had them, etc.)

Thank you! That is the end of the interview. I just want to make sure you feel comfortable with the questions. Imagining this scenario can be stressful for some people, and I'm happy to discuss it further if you have questions or concerns. Do you have any questions for me?

We know the scenario we presented to you is extreme and it is not very likely to happen in the near future. But being prepared for emergencies, such as blackouts, is always a good idea. Here are some resources to help you be better prepared if any emergencies should arrive.

APPENDIX B

3HEAT PHOENIX SURVEY & INTERVIEW RESPONDENTS-DEMOGRAPHICS

APPENDIX B

Table 1. 3Heat Survey & Interview respondents – demographics

Respondent Demographics	**Survey**		**Interview**		
Gender	#	%	#	%	ACS %
Female	84	51.5	23	57.5	50.2
Male	78	47.9	17	42.5	49.8
Other	0	0	0	0	NA
Prefer not to answer	1	0.6	0	0	NA
Race/Ethnicity*					
Native American or American Indian	14	8.6	5	12.5	2.9
Asian or Asian American	6	3.7	1	2.5	4.5[1]
Black or African-American	15	9.2	3	7.5	8.1
Hispanic, Latino, Mexican, Mexican-American or Spanish	39	23.9	8	20.0	41.8[2]
Middle Eastern	2	1.2	0	0	N/A
Native Hawaiian or other Pacific Islander	5	3.1	1	2.2	0.4
White	102	62.6	28	70	75.3
Other	5	3.1	0	0	12.5
Don't know	1	0.6	0	0	
Prefer not to answer	3	1.8	0	0	
*Non-exclusive category, Σ > 100%					
Preferred language for survey					
English	159	97.5			
Spanish	4	2.5			
Age					
18 – 24	14	8.6	1	2.5	7.5[3]
25 – 35	35	21.5	7	17	15.7[4]
36 – 45	23	14.1	7	17	14.0[5]
46 – 55	29	17.8	8	20	13.1[6]
56 – 65	23	14.1	5	12.5	10.4[7]
65 +	29	17.8	8	20	9.8[8]
Don't know	1	0.6			
Prefer not to answer	3	1.8			
Missing	8	4.9	4	10	
Employment status					
Work full-time	82	50.3	18	45	
Work part-time	16	9.8	2	5	

Unemployed (out of work but looking for work)	6	3.7	0	0	
Unemployed (out of work and not looking for work)	2	1.2	1	2.5	
Full-time student	5	3.1	1	2.5	
Homemaker	10	6.1	4	10	
Disabled	5	3.1	2	5	
Retired	35	21.5	12	30	
Other	1	0.6	0	0	
Don't know	0	0.0	0	0	
Prefer not to answer	1	0.6	0	0	
"How often do you struggle to afford essentials?"					
Never	92	56.4	20	50	
Rarely	41	25.2	14	35	
Sometimes	21	12.9	5	12.5	
Often	8	4.9	1	2.5	
Don't know	0	0	0	0	
Prefer not to answer	1	0.6	0	0	
Residence – Own/rent					
Own	111	68.1	31	77.5	57.5[9]
Rent	49	30.1	8	20	42.4[10]
Other	1	0.6	1	2.5	
Don't know	0	0	0	0	
Prefer not to answer	0	0	0	0	
Residence – Years lived in home					
Less than one	1	0.6	1	2.5	
One – three	46	28.2	11	27.5	
Four – 10	50	30.7	11	27.5	
11 – 20	38	23.3	11	27.5	
20 +	25	15.3	6	15	
Don't know	1	0.6	0	0	
Prefer not to answer	1	0.6	0	0	
"Compared to other people your age, would you say your health is…"					
Excellent	54	33.1	15	37.5	
Good	75	46.0	15	37.5	
Fair	30	18.4	10	25	
Poor	4	2.5	0	0	
Don't know	0	0	0	0	
Prefer not to answer	0	0	0	0	

Incidence of heat-related illness (respondent, last 5 years)					
Never	95	58.3	25	62.5	
Once	24	14.7	6	15	
More than once	44	27.0	9	22.5	
Don't know	0	0	0	0	
Prefer not to answer	0	0	0	0	
Household Demographics					
Household size					
One	38	23.3	12	30	27.1
Two	49	30.1	13	32.5	28.8
Three – five	62	38.0	15	47.5	36.2
Six or more	13	8.0	0	0	7.7
Don't know	0	0	0	0	
Prefer not to answer	1	0.6	0	0	
Head of household*					
Respondent	41	32.8	8	20	
Respondents' spouse/partner	26	20.8	9	22.5	
Respondent and spouse/partner	31	24.8	9	22.5	
Shared between 1+ resident, not relatives	4	3.2	1	2.5	
Shared between 1+ resident, some or all relatives	1	0.8	0	0	
Respondents' parent or grandparent	15	12.0	1	2.35	
Someone else related to respondent	6	4.8	0	0	
Someone else not related to respondent	1	0.8	0	0	
Don't know	0	0	0	0	
Prefer not to answer	0	0	0	0	
** If household size >1*					
Income (household)					
$20,000 and under	16	9.8	4	10	
$20,001 – 40,000	24	14.7	5	12.5	
$40,001 – 60,000	25	15.3	5	12.5	
$60,001 – 80,000	19	11.7	8	20	
$80,001 – 100,000	13	8.0	3	7.5	
$100,001 – 120,000	9	5.5	2	5	
$120,001 – 140,000	9	5.5	4	10	
$140,001 – 160,000	6	3.7	2	5	
$160,001 – 180,000	4	2.5	1	2.5	

$180,001 – 200,000	1	0.6	0	0	
More than 200,000	6	3.7	1	2.5	
Don't know	10	6.1	1	2.5	
Prefer not to answer	21	12.9	4	10	
"Which of these statements best describes your household in the last five months?"			34	85	
"We always have enough to eat and the kinds of food we want."	121	74.2	6	15	
"We have enough to eat but not always the kinds of food we want."	36	22.1	0	0	
"Sometimes we don't have enough to eat."	3	1.8	0	0	
"Often we don't have enough to eat."	1	0.6	0	0	
Don't know	1	0.6	0	0	
Prefer not to answer	1	0.6	34	85	
Study site					
Camelback	32	19.6	9	19.6	
Downtown	46	32.5	14	30.4	
Cave Creek	53	28.2	14	30.4	
South Mountain	32	19.6	9	19.6	
Incidence of heat-related illness (respondent, last 5 years)*					
Never	88	54.0			
Once	28	17.2			
More than once	7	4.3			
Don't know	2	1.6			
Prefer not to answer	0	0			
** If household size >1*					
# of households with members…					
Age > 64 (not including respondent)	28	17.2	10	25	17.9
Age < 6	26	16.0	5	12.5	12.0
Limited in mobility	10	6.1	1	2.5	10.2[11]
Who do not speak English	11	6.7	0	0	13.9[12]
With pets	117	71.8	30	75	

[1] ACS = Asian only
[2] ACS = Hispanic of any race
[3] ACS = (20 – 24)
[4] ACS = (25 – 34)
[5] ACS = (35 – 44)

[6]ACS = (45 – 54)
[7]ACS = (54 – 59), (60 – 64)
[8]ACS = (65 – 74), (75 – 84), (85 +)
[9] ACS = Owner-occupied housing units
[10] ACS = Renter-occupied housing units
[11] ACS = Any disability
[12] ACS = English less than "very well"

APPENDIX C

STRUCTURED CODEBOOK

APPENDIX C

Table 1. Structured Codebook

Domain	Code Name	Description	Inclusion Criteria
Risk Appraisal	Low probability	Conveying a skeptical opinion or low expectation of the likelihood of the event or any part of the event	Includes assessments of institutional mitigation / risk management
	High probability	Conveying a high expectation of the likelihood or plausibility of the event or any part of the event	Includes assessments of institutional mitigation / risk management
	Low severity	Conveying a low opinion or relatively benign expectation of the impact of the event or any part of the event	Includes assessments of institutional support / EM capacity
	High severity	Conveying a high or relatively severe expectation of the impact of the event or any part of the event	Includes assessments of institutional support / EM capacity
Adaptation Appraisal	Low self-efficacy	Conveying a low opinion or expectation of the ability to adapt to or respond to the event or any part of the event	
	High self-efficacy	Conveying a high or ambitious opinion or expectation of the ability to adapt to or respond to the event or any part of the event	
	Low adaptation efficacy	Conveying a low opinion or expectation of the usefulness or efficaciousness of a given adaptation	
	High adaptation efficacy	Conveying a high opinion or expectation of the usefulness or efficaciousness of a given adaptation	
Adaptation Intention	Maladaptive	Conveying a positive intention to do nothing in response to the event as a whole or a specific aspect of the event due to fatalism or wishful thinking	

Table 2. Code Exemplars

Low Probability: "*Why I am not worried about? Mostly, because I think I have faith in technology and the power structure so I don't think it is likely that that is ever going to happen so I wouldn't worry about it."* (subject AS406)

High Probability: ***"****Probably higher than what I think it is to occur, just because of the strains that are put on the electrical during the summer months. I don't know how ya know, 70% likely I dunno."* (subject AS416)

Low Severity: ***"****Well most stores run on generators...have generators so I don't find that I would be worried. I'd just go to the store and pick up non-perishable food."* (subject AS417)

Low Severity: ***"****Um, if I didn't do those things to try to stay cool as best I could, certainly. You could very easily run into risk but I think we would survive it pretty well. I wouldn't be too concerned about myself."* (subject AS419)

High Severity: ***"****Definitely, well again especially it is happens at this time of year at my age if I didn't have air conditioning or couldn't go some place where it is air conditioned, except my car I'd get in my car and just keep driving, but yeah I think it would be a serious, have a serious effect on my health."* (subject AS406)

High Severity: *"Yes, yeah I think that would be a big problem, I think that, like I said just the fact that it would be hard to cool down if you don't have fans. You still have access to water but with the food, with the restaurants and the stores and everything, it would be, I think it would be hard. And I think it would pose, I mean I don't see myself passing away from it but I would think that it would, I do think it would create problems like for my kids and you know just being able to deal with the heat for a lot of adults too."* (subject AS406)

High Severity & Maladaptive Intention *"I definitely wouldn't be here. Either I would be dead or would be gone*". (subject AS420).

Maladaptive Intention: *"Participant: Miserable. You're miserable because it's, there's nothing you can do."* (subject AS420).

Low Self-Efficacy & Maladaptive Intention *"If you could get to it, yeah. No, I'd probably start writing out my will. It's time to go"* (subject AS412)

Low Self-Efficacy: "I don't know where else I could look. No TV and no radio." (AS413)

Low Self-Efficacy: *"Oh, like anxious. Like what would I do? Where would I go? Drive around with my air conditioning on, I don't know what I would do. I don't even, wouldn't know what to do. I would probably feel anxious about it like 'What are we gonna do?'"* (AS404)

High Self-Efficacy & High Adaptation Efficacy: *"And we've got a/c. We got our a/c, I'm taking a nice ice-cold shower. And I'm sleeping like a log."* (subject AS416).

Low Adaptation Efficacy: *"Yeah I might not open, like I usually open up the blinds in the morning, I might try to keep it as cool, you know cooler by keeping the blinds shut. Opening windows is not really gonna help."* (subject AS407)

Low Adaptation Efficacy: *"I know there'd be air conditioning in vehicles, but you can't really sit in a vehicle all day."* (subject AS409)

High Cost: *"A generator would be nice, but I'm too cheap probably to go out and buy one."* (subject AS418)

Low Cost: *"It depends on the length of time. But one night away—one or two nights away isn't going to break the bank."* (subject AS411)

APPENDIX D

3HEAT SURVEY VARIABLE CODEBOOK

APPENDIX D

Note: Some survey items were asked conditionally dependent upon responses to prior questions; conditions are indicated in **boldface** prior to relevant questions. If no condition is listed, survey items were asked to all participants.

(Master_ID) [administrator-generated master ID]

[open-ended alphanumeric – ID is composed of two letters identifying the university that collected the data and the following number is unique to that case.]

AS = Arizona State University
UM = University of Michigan
GT = Georgia Tech

201-401 = University of Michigan
000-200 = Georgia Tech
402-603 = Arizona State University

(Consent) "Do you give your informed consent to be asked questions and have your answers recorded?"

[1] yes
[0] no

(Residence) "Did you live in this home last summer, that is in summer 2015? For the purpose of this survey, we define summer as the months June, July, and August. It is ok if you were away from your home for part of this time." [Residence]

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q01) "Do you own or rent your current home?"

[1] own

[2] rent
[97] other
[98] don’t know
[99] prefer not to answer

Ask if Q01 = [97] other
(Q01oa) “If you do not own or rent, please explain... (audio)”

[audio file]

Ask if Q01 = [97] other
(Q01ot) “If you do not own or rent, please explain... (text)”

[open-ended text]

(Q02) “How many people currently live in your household, including yourself? Living in your household means people who slept and ate meals for at least the previous two weeks.”

[open-ended numeric]
[98] Don’t know
[99] Prefer not to answer

(Q03) “Who pays the electrical bill for your household?”

[1] People who live in this home pay the bill
[2] The landlord pays the bill
[97] Other
[98] Don’t know
[99] Prefer not to answer

Ask if Q03 = [97] other
(Q03oa) “If electrical bill other, please explain... (audio)”

[audio file]

Ask if Q03 = [97] other
(Q03ot) “If electrical bill other, please explain... (text)”

[open-ended text]

(Q04cd_all) “Does your home have the following, please select all that apply. [ADMINISTRATOR, If the respondent is unsure of the working order of any of their belongings please still record that they have the item.] [ADMINISTRATOR, please provide respondent with answer card.]”

[list of selected string variables]

(Q04cd_cntrl) “Central air conditioner”

[1] yes
[0] no

(Q04cd_win) “Window air conditioner”

[1] yes
[0] no

(Q04cd_swmp) “Swamp or evaporative cooler”

[1] yes
[0] no

(Q04cd_mist) “Misters”

[1] yes
[0] no

(Q04cd_flrceilfan) “Floor or ceiling fans”

[1] yes
[0] no

(Q04cd_winfan) “Window fans”

[1] yes
[0] no

(Q04cd_shades) “Awning, shades and/or shutters”

[1] yes
[0] no

(Q04cd_trees) “Yard with trees”

[1] yes
[0] no

(Q04cd_grass) “Yard with grass”

[1] yes
[0] no

(Q04cd_pool) “Yard with swimming pool"

[1] yes
[0] no

(Q04cd_base) "Basement "

[1] yes
[0] no

(Q04cd_gen) "Back-up power or generator"

[1] yes
[0] no

(Q04cd_othr) "Other home cooling device"

[1] yes
[0] no

(Q04cd_none) "None of these"

[1] yes
[0] no

(Q04cd_noans) "Prefer not to answer"

[1] yes
[0] no

Ask if Q04cd_win = [1] yes
(Q04cd_winnum) "If you have window a/c, how many rooms have units?"

[open-ended numeric]

Ask if Q04cd_othr = [1] yes
(Q04cd_oa) “If other home cooling device, please explain... (audio)"

[audio file]

Ask if Q04cd_othr = [1] yes
(Q04cd_ot) “If other home cooling device, please explain... (text)”

[open-ended text]

“We are interested in your thoughts about some health risks to you and the people who live in your household. Please indicate if you think the risks posed by each of the following conditions are: Very serious; Somewhat serious; Not too serious; Not at all serious; No opinion; Don’t know; or Prefer not to answer. [ADMINISTRATOR, please provide respondent with answer card.]”

[Notes: The order of risk measures differs amongst four different survey form versions, data organized in Form A ordering in processing. “No opinion” is coded as the intermediate option in a 5-point scale but was provided as an answer option after the four choices very/somewhat/not too/not at all serious.]

(Q05_typsumtemp) “The health risks of TYPICAL SUMMER TEMPERATURES to you and the people who live in your household”

[5] Very serious
[4] Somewhat serious
[3] No opinion
[2] Not too serious
[1] Not at all serious
[98] Don’t know
[99] Prefer not to answer

(Q05_waves) “The health risks of HEAT WAVES to you and the people who live in your household”

[5] Very serious
[4] Somewhat serious
[3] No opinion

[2] Not too serious
[1] Not at all serious
[98] Don't know
[99] Prefer not to answer

(Q05_pwrhot) "The health risks of ELECTRICAL POWER OUTAGE OR BLACKOUT DURING HOT WEATHER to you and the people who live in your household."

[5] Very serious
[4] Somewhat serious
[3] No opinion
[2] Not too serious
[1] Not at all serious
[98] Don't know
[99] Prefer not to answer

(Q05_cold) "The health risks of EXTREMELY COLD WEATHER to you and the people who live in your household"

[5] Very serious
[4] Somewhat serious
[3] No opinion
[2] Not too serious
[1] Not at all serious
[98] Don't know
[99] Prefer not to answer

(Q05_pwrco) "The health risks of ELECTRICAL POWER OUTAGE OR BLACKOUT DURING EXTREMELY COLD WEATHER to you and the people who live in your household"

[5] Very serious
[4] Somewhat serious
[3] No opinion
[2] Not too serious
[1] Not at all serious
[98] Don't know
[99] Prefer not to answer

(Q05_uhi) “The health risks of the URBAN HEAT ISLAND (the urban heat island is a term for hot temperatures in cities due to more buildings, pavement, and cars, and less greenery than the countryside) to you and the people who live in your household”

[5] Very serious
[4] Somewhat serious
[3] No opinion
[2] Not too serious
[1] Not at all serious
[98] Don’t know
[99] Prefer not to answer

(Q05_cc) “The health risks of GLOBAL WARMING AND CLIMATE CHANGE to you and the people who live in your household”

[5] Very serious
[4] Somewhat serious
[3] No opinion
[2] Not too serious
[1] Not at all serious
[98] Don’t know
[99] Prefer not to answer

(Q05_air) “The health risks of AIR POLLUTION to you and the people who live in your household”

[5] Very serious
[4] Somewhat serious
[3] No opinion
[2] Not too serious
[1] Not at all serious
[98] Don’t know
[99] Prefer not to answer

(Q06) "Is the health of some member of your household more at risk than others during extremely hot weather?"

[0] No
[1] Yes, only one person
[2] Yes, more than one person
[98] Don't know
[99] Prefer not to answer

Ask if Q06 = [1] yes, only one person
(Q06oa_sing) "Please explain why that person is more at risk... (audio)"

[audio file]

Ask if Q06 = [1] yes, only one person
(Q06ot_sing) "Please explain why that person is more at risk... (text)"

[open-ended text]

Ask if Q06 = [2] yes, more than one person
(Q06oa_multi) "Please explain why each of those people are more at risk... (audio)"

[audio file]

Ask if Q06 = [2] yes, more than one person
(Q06ot_multi) "Please explain why each of those people are more at risk... (text)"

[open-ended text]

Ask if Q04cd_cntrl = [1] yes AND/OR Q04cd_win = [1] yes
(Q07) "Do you use the air conditioner to cool your home during the summer?"

[1] yes
[0] no
[97] other
[98] don't know
[99] prefer not to answer

Ask if Q07 = [97] other
(Q07_oa) "If summer a/c cooling other, please explain... (audio)"

[audio file]

Ask if Q07 = [97] other
(Q07_ot) "If summer a/c cooling other, please explain... (text)"

[open-ended text]

Ask if Q07 = [1] yes OR [97] other
(Q08) "Do you (or someone else in your own household) control the temperature of the air conditioner during the summer?"

[1] yes
[0] no
[97] other
[98] don't know
[99] prefer not to answer

Ask if Q08 = [97] other
(Q08oa) "If summer a/c control other, please explain... (audio)"

[audio file]

Ask if Q08 = [97] other
(Q08ot) "If summer a/c control other, please explain... (text)"

[open-ended text]

Ask if Q07 = [1] yes OR [97] other
(Q09) "Do you have a programmable thermostat for your air conditioner or do you adjust the temperature manually? A programmable thermostat means a thermostat you can set to adjust automatically at different times of day or on different days of the week"

[1] Programmable thermostat
[2] Set temperature manually
[98] don't know
[99] prefer not to answer

Ask if Q09 = [1] programmable thermostat
(Q10) "Do you program the thermostat during the summer?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

Ask if Q07 = [1] yes OR [97] other
(Q11_all) "During the summer, what times of day do you use your air conditioner to cool your home? [SELECT ALL THAT APPLY]"

[list of selected string variables]

(Q11_6_9) "6:00 am-09:00 am"

[1] yes
[0] no

(Q11_9_12) "9:00 am-noon "

[1] yes
[0] no

(Q11_12_15) "noon-3:00 pm"

[1] yes
[0] no

(Q11_15_18) "3:00 pm-6:00 pm"

[1] yes
[0] no

(Q11_18_21) "6:00 pm-9:00 pm"

[1] yes
[0] no

(Q11_21_24) "9:00 pm-midnight "

[1] yes
[0] no

(Q11_24_3) "midnight-3:00 am"

[1] yes
[0] no

(Q11_3_6) “3:00 am-6:00 am”

[1] yes
[0] no

(Q11_noknow) “Don’t know"

[1] yes
[0] no

(Q11_noans) “Prefer not to answer”

[1] yes
[0] no

Ask if Q07 = [1] yes OR [97] other
(Q12) “During the summer, when you are awake at home, what temperature is your thermostat usually set?” (ADMINISTRATOR, please put 98 for "I don't know" and 99 for "Prefer Not To Answer").

[open-ended numeric, degrees Fahrenheit]
[98] don’t know
[99] prefer not to answer

Ask if Q07 = [1] yes OR [97] other
(Q13) “During the summer, when you are sleeping at home, what temperature is your thermostat usually set? (ADMINISTRATOR, please put 98 for "I don't know" and 99 for "Prefer Not To Answer").

[open-ended numeric, degrees Fahrenheit]
[98] don’t know
[99] prefer not to answer

Ask if Q07 = [1] yes OR [97] other
"We are interested in whether anything limits your use of air conditioning in your home during the summer. Please tell us whether each of the following items influences your use of air conditioning. The choices are very limiting, somewhat limiting, not too limiting, or not at all limiting."

(Q14l_costelec) "When it comes to air conditioning, the COST OF ELECTRICITY is…"
[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting
[98] Don't know
[99] Prefer not to answer

(Q14l_broke) "When it comes to air conditioning, it BEING BROKEN OR NOT WORKING is…"

[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting
[98] Don't know
[99] Prefer not to answer

(Q14l_costrep) "When it comes to air conditioning, the COST OF REPAIRS is…"

[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting
[98] Don't know
[99] Prefer not to answer

(Q14l_noise) "When it comes to air conditioning, NOISE is..."

[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting

[98] Don’t know
[99] Prefer not to answer

(Q14l_blkout) “When it comes to air conditioning, CONCERNS ABOUT CAUSING BLACKOUTS are...”

[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting
[98] Don’t know
[99] Prefer not to answer

(Q14l_enviro) “When it comes to air conditioning, CONCERNS ABOUT ENVIRONMENTAL IMPACTS are...”

[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting
[98] Don’t know
[99] Prefer not to answer

(Q14l_med) “When it comes to air conditioning, MEDICAL CONCERNS OR RESTRICTIONS are...”

[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting
[98] Don’t know
[99] Prefer not to answer

Ask only if Q04cd_swmp = [1] yes
(Q14l_swmp) “When it comes to air conditioning, HAVING A SWAMP COOLER is…”

[4] Very limiting
[3] Somewhat limiting
[2] Not too limiting
[1] Not at all limiting
[98] Don’t know
[99] Prefer not to answer

(Q14l_other) “Does anything else limit your use of air conditioning in your home during the summer?”

[1] yes
[0] no
[98] Don’t know
[99] Prefer not to answer

Ask only if Q14l_other = [1] yes
(Q14loa) “Other A/C limitation, please explain... (audio)”

[audio file]

Ask only if Q14l_other = [1] yes
(Q14lot) “Other A/C limitation, please explain... (text)”

[open-ended text]

(Q15) “Does your electrical utility charge you different rates for electricity per hour based on HOW MUCH electricity you use?”

[1] Yes they do
[0] No they do not
[98] Don’t know
[99] Prefer not to answer

(Q16) “Does your electrical utility offer a program that charges you different rates for electricity per hour based on the TIME OF DAY you use electricity?”

[1] Yes they do
[0] No they do not
[98] Don’t know
[99] Prefer not to answer

Ask only if Q16 = [1] yes they do
(Q17) “You said that your electrical utility offers a program that charges you different rates for electricity per hour based on the time of day you use electricity. Does your household participate in this program?”

[1] Yes
[0] No
[98] Don’t know
[99] Prefer not to answer

Ask only if Q17 = [1] yes
(Q18_all) “Do you change your use of air conditioning during the times of day when electricity is more expensive? Please select all options that apply. [ADMINISTRATOR, please provide respondent with answer card.]”

[list of selected string variables]

(Q18_alloff) “Yes, I always turn the air conditioner off."

[1] yes
[0] no

(Q18_someoff) “Yes, I sometimes turn the air conditioner off.”

[1] yes
[0] no

(Q18_alladjust) “Yes, I always adjust the thermostat to a higher temperature.”

[1] yes
[0] no

(Q18_someadjust) “Yes, I sometimes adjust the thermostat to a higher temperature.”

[1] yes
[0] no

(Q18_nochange) “No, changes in the price of electricity throughout the day does not change my AC use.”

[1] yes
[0] no

(Q18_noknow) “Don’t know”

[1] yes
[0] no

(Q18_noans) “Prefer not to answer”

[1] yes
[0] no

(Q19) “Are you aware of any programs that help some people pay their energy bills?”

[1] yes
[0] no
[98] don’t know
[99] prefer not to answer

Ask only if Q19 = [1] yes
(Q20) “Have you participated in a program to help pay your home energy bills this summer or last summer?”

[1] yes
[0] no
[98] don’t know
[99] prefer not to answer

(Q21) “Are you ever too hot inside your home during the summer? The options are: Very Often; Often; Sometimes; Rarely; Never; Don't Know; or Prefer Not To Answer.”

[4] Very Often
[3] Often
[2] Sometimes
[1] Rarely
[0] Never
[98] Don’t know
[99] Prefer not to answer

(Q22) “What temperature inside your current home is most comfortable for you in the summer? That is, ignoring any limitations on how much you can cool your home, what is your ideal comfortable temperature? (ADMINISTRATOR, please put 98 for "I don't know" and 99 for "Prefer Not To Answer")”

[open-ended numeric]
[98] Don’t know
[99] Prefer not to answer

(Q23) “At what temperature inside your home in the summer do you start to feel too hot for your comfort? (ADMINISTRATOR, please put 98 for "I don't know" and 99 for "Prefer Not To Answer").”

[open-ended numeric, degrees Fahrenheit]

[98] Don’t know
[99] Prefer not to answer

(Q24_all) “We know we asked you what cooling devices you have in your home, but now we want to know how you use these devices. When the temperature inside your home is too hot during the summer, what do you do to cool off or try to stay cool? [ADMINISTRATOR, please provide respondent with answer card.”

[list of selected string variables]

(Q24_csnctrl) “Use central air conditioner ”

[1] yes
[0] no

(Q24_cswin) “Use window air conditioner"

[1] yes
[0] no

(Q24_csswmp) “Use Swamp or evaporative cooler"

[1] yes
[0] no

(Q24_csflrclfn) “Use Floor or ceiling fans"

[1] yes
[0] no

(Q24_csopwin) “Open windows"

[1] yes
[0] no

(Q24_csfanin) “Use window fan blowing air into the home"

[1] yes
[0] no

(Q24_csfanout) “Use window fan blowing air out of the home"

[1] yes
[0] no

(Q24_cshdfn) “Fan self with a hand fan"

[1] yes
[0] no

(Q24_csshades) “Close blinds, drapes or shades"

[1] yes
[0] no

(Q24_csclcloth) “Dress in cooler or lighter clothing or wear less clothing"

[1] yes
[0] no

(Q24_csnonalc) “Drink cold non-alcoholic beverages"

[1] yes
[0] no

(Q24_csalch) “Drink alcoholic beverages"

[1] yes
[0] no

(Q24_cslghtml) “Eat light meals that don’t require cooking”

[1] yes
[0] no

(Q24_cscldfd) “Eat cold or frozen foods”

[1] yes
[0] no

(Q24_csapp) “Don’t use appliances as much”

[1] yes
[0] no

(Q24_cscldshw) “Take cold shower or bath"

[1] yes
[0] no

(Q24_cswtclth) “Use a wet cloth or ice pack on skin (including wet sheets or blankets in bed)”

[1] yes

[0] no

(Q24_cslsphys) “Engage in less physical activity”

[1] yes
[0] no

(Q24_csbase) “Go to the basement or lower floor in the building”

[1] yes
[0] no

(Q24_csyard) “Go outdoors in the yard (including pool)”

[1] yes
[0] no

(Q24_csoth) “Other”

[1] yes
[0] no

(Q24_csnothing) “Do nothing”

[1] yes
[0] no

(Q24_noknow) “Don’t know”

[1] yes

[0] no

(Q24_noans) “Prefer not to answer”

[1] yes
[0] no

Ask only if Q24_csoth = [1] yes
(Q24_csoa) “If you do something other to stay cool inside during the summer, please explain... (audio)”

[audio file]

Ask only if Q24_csoth = [1] yes
(Q24_csot) “If you do something other to stay cool inside during the summer, please explain... (text)”

[open-ended text]

(Q25) “During the summer, do you alter your daily schedule to avoid the heat?”

[1] yes
[0] no
[98] don’t know
[99] prefer not to answer

(Q26) “Have you ever left your current home because the temperature inside was too hot?”

[1] yes
[0] no
[98] don’t know
[99] prefer not to answer

Ask only if answer to Q26 = [1] yes
(Q27_all) "If you ever left your current home because the temperature inside was too hot, where did you go?"

[list of selected string variables]

(Q27_leftcity) "Left the city"

[1] yes
[0] no

(Q27_friend) "Friends', relatives', or neighbors' homes nearby"

[1] yes
[0] no

(Q27_indrcom) "Indoor commercial establishments, including movie theaters, stores, malls, restaurants, museums, casinos, concert halls or recital halls"

[1] yes
[0] no

(Q27_indrpub) "Indoor public places, including libraries, schools, senior or recreation centers"

[1] yes
[0] no

(Q27_indroth) "Any other type of indoor place that serves as a public Heat Refuge Station or Cooling Center during the summer"

[1] yes
[0] no

(Q27_outcom) "Outdoor commercial recreational area, including paying parks, swimming and water recreation areas, or other paying outdoor recreation"

[1] yes
[0] no

(Q27_outpub) "Outdoor public places, including free parks, swimming and water recreation areas, or other free outdoor recreation"

[1] yes
[0] no

(Q27_other) "Other "

[1] yes
[0] no

(Q27_noknow) "Don't know "

[1] yes
[0] no

(Q27_noans) "Prefer not to answer "

[1] yes
[0] no

(Q27oa) "If you ever left your current home because the temperature inside was too hot, and went somewhere other, where did you go? (audio)"

[audio file]

(Q27ot) “If you ever left your current home because the temperature inside was too hot, and went somewhere other, where did you go? (text)”

[open-ended text]

Ask only if answer to Q26 = [1] yes
(Q28_all) “How did you get to the places you went to cool off?”

[list of selected string variables]

(Q28_car) “Drive personal car ”

[1] yes
[0] no

(Q28_friend) “Get a ride from a friend/family”

[1] yes
[0] no

(Q28_taxi) “Take a taxi, jitney, Uber, or Lyft”

[1] yes
[0] no

(Q28_public) “Take a public transportation or van service”

[1] yes
[0] no

(Q28_walk) “walk or bicycle”

[1] yes
[0] no

(Q28_other) “other”

[1] yes
[0] no

(Q28_noknow) “Don’t know”

[1] yes
[0] no

(Q28_noans) “Prefer not to answer”

[1] yes
[0] no

(Q28oa) “If you got to the places you went to cool off in another way, please explain... (audio)”

[audio file]

(Q28ot) “If you got to the places you went to cool off in another way, please explain... (text)”

[open-ended text]

Ask only if answer to Q26 = [1] yes
(Q29_all) "Does anything limit you from leaving your home to go to places to cool off?

[list of selected string variables]

(Q29_toofar) "Places are too far away "

[1] yes
[0] no

(Q29_notrans) "Lack of transportation "

[1] yes
[0] no

(Q29_dis) "Disability of someone in my household"

[1] yes
[0] no

(Q29_pets) "Pets not allowed "

[1] yes
[0] no

(Q29_nosafe) "Personal safety "

[1] yes
[0] no

(Q29_vacant) "Don’t want to leave my home vacant"

[1] yes
[0] no

(Q29_unwel) "Would feel unwelcome somewhere else"

[1] yes
[0] no

(Q29_bored) "Would feel bored somewhere else"

[1] yes
[0] no

(Q29_privacy) "Lack of privacy"

[1] yes
[0] no

(Q29_nowhere) "Don't know where to go"

[1] yes
[0] no

(Q29_expens) "Too Expensive"

[1] yes
[0] no

(Q29_other) "Other"

[1] yes
[0] no

(Q29_nothing) "Nothing limits me"

[1] yes
[0] no

(Q29_noknow) "Don’t know"

[1] yes
[0] no

(Q29_noans) "Prefer not to answer"

[1] yes
[0] no

Ask only if answer to Q29_other = [1] yes
(Q29oa)"If something other limits you from leaving your home to go to places to cool off, please explain... (audio)"

[audio file]

Ask only if answer to Q29_other = [1] yes
(Q29ot)"If something other limits you from leaving your home to go to places to cool off, please explain... (text)"

[open-ended text]

(Q30) "Do you own a working car that you use for transportation?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

Questions 31-32 (inclusive) were only asked of renters
Ask only if answer to Q01 = [2] rent

(Q31_all) "In the last five years, have you made the following changes to this home you live in now? Please select all that apply [ADMINISTRATOR, if they lived in their current home for less than 5 years, then please tell them to answer since they lived in their current home] "

[list of selected string variables]

(Q31ltcr_shades) "Added or replaced awnings or window shades"

[1] yes
[0] no

(Q31ltcr_winac) "Added or upgraded window or wall air conditioning units"

[1] yes
[0] no

(Q31ltcr_none) "none of these"

[1] yes
[0] no

(Q31ltcr_noknow) "don't know"

[1] yes
[0] no

(Q31ltcr_noans) "prefer not to answer"

[1] yes
[0] no

Ask only if answer to Q31ltcr_shades = [1] yes
(Q32ltcr_shdimp) "When you added or replaced awnings or window shades, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important
[98] Don't know
[99] Prefer not to answer

Ask only if answer to Q31ltcr_winac = [1] yes
(Q32ltcr_winimp) "When you added or upgraded window/wall air conditioning units, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important
[98] Don't know
[99] Prefer not to answer

Questions 33-34 (inclusive) were only asked of homeowners
Ask only if answer to Q01 = [1] own

(Q33ltco_all) "In the last five years, have you made the following changes to this home you live in now? Please select all that apply [ADMINISTRATOR, if they lived in their current home for less than 5 years, then please tell them to answer since they lived in their current home] [ADMINISTRATOR, please provide respondent with answer card.]"

[list of selected string variables]

(Q33ltco_shades) "Added or replaced awnings or window shades"

[1] yes
[0] no

(Q33ltco_winac) "Added or upgraded window/wall air conditioning units"

[1] yes
[0] no

(Q33ltco_grass) "Landscaped the yard by adding grass or trees"

[1] yes
[0] no

(Q33ltco_roof) "Installed building materials that reflect more sunlight or shade your roof, such as a light-colored roof or solar panels"

[1] yes
[0] no

(Q33ltco_wthr) "Added or upgraded weather-proofing, such as weather stripping, insulation, sealing ducts, or upgrading doors or windows"

[1] yes
[0] no

(Q33ltco_cntrl) "Added or upgraded the central air conditioning system, such as installing a new system or performing maintenance "

[1] yes
[0] no

(Q33ltco_ceilfans) "Added or upgraded ceiling fans, such as installing new fan(s) or performing maintenance"

[1] yes
[0] no

(Q33ltco_swmp) "Add or upgrade swamp or evaporative cooling"

[1] yes
[0] no

(Q33ltco_none) "none of these"

[1] yes
[0] no

(Q33ltco_noknow) "don't know"

[1] yes
[0] no

(Q33ltco_noans) "prefer not to answer"

[1] yes
[0] no

Ask only if answer to Q33ltco_shades = [1] yes
(Q34ltco_shdimp) "When you added or replaced awnings or window shades, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it? "

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important

[98] Don’t know
[99] Prefer not to answer

Ask only if answer to Q33ltco_winac = [1] yes
(Q34ltco_winimp) "When you added or upgraded window/wall air conditioning units, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important
[98] Don’t know
[99] Prefer not to answer

Ask only if answer to Q33ltco_grass = [1] yes
(Q34ltco_grimp) "When you landscaped the yard by adding grass or trees, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important
[98] Don’t know
[99] Prefer not to answer

Ask only if answer to Q33ltco_roof = [1] yes
(Q34ltco_rfimp) "When you installed building materials that reflect more sunlight or shade your roof, such as a light-colored roof or solar panels, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important

[98] Don’t know
[99] Prefer not to answer

Ask only if answer to Q33ltco_wthr = [1] yes
(Q34ltco_wthimp) "When you added or upgraded weather-proofing, such as weather stripping, insulation, sealing ducts, or upgrading doors or windows, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important
[98] Don’t know
[99] Prefer not to answer

Ask only if answer to Q33ltco_cntrl = [1] yes
(Q34ltco_cntimp)"When you added or upgraded the central air conditioning system, such as installing a new system or performing maintenance, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important
[98] Don’t know
[99] Prefer not to answer

Ask only if answer to Q33ltco_ceilfans = [1] yes
(Q34ltco_fanimp) "When you added or upgraded the ceiling fans, such as installing new fan(s) or performing maintenance, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important

[98] Don’t know
[99] Prefer not to answer

Ask only if answer to Q33ltco_swmp = [1] yes
(Q34ltco_swpimp) "When you added or upgraded swamp or evaporative cooling, was making your home cooler during hot weather a very important, somewhat important, not too important, or not at all important reason you did it?"

[4] Very important
[3] Somewhat important
[2] Not too important
[1] Not at all important
[98] Don’t know
[99] Prefer not to answer

(Q35) "In your current home, how often have you experienced a power blackout or electricity failure in the summer?"

[0] Never
[1] Once
[2] Twice
[3] More than two times
[98] Don’t know
[99] Prefer not to answer

Ask only if Q35 = [1] Once, [2] Twice, OR [3] More than two times
(Q36_all) "What was the most recent year in which you experienced a black out or electricity failure in your current home?"

[list of selected string variables]

(Q36_year) "Specific Year (enter number on next screen)"

[1] yes
[0] no

(Q36_lessfive) "Don't remember exactly, but less than 5 years"

[1] yes
[0] no

(Q36_morefive) "Don't remember exactly, but 5 years or more"

[1] yes
[0] no

(Q36_noknow) "don't know"

[1] yes
[0] no

(Q36_noans) "prefer not to answer"

[1] yes
[0] no

Ask only if answer to Q36_year = [1] yes
(Q36_yearnum) "Which year was the most recent year in which you experienced a black out or electricity failure in your current home?"

[open-ended numeric]

Ask only if Q35 = [1] Once, [2] Twice, OR [3] More than two times
(Q37) "How long were you without power in that most recent event? [ADMINISTRATOR, please provide respondent with answer card.]"

[1] Less than one hour
[2] One to six hours
[3] Six to twelve hours

[4] Twelve to 24 hours
[5] One to three days
[6] More than three days
[7] Don’t remember exactly, but less than 24 hours
[8] Don’t remember exactly, but 24 hours or more
[98] Don’t know
[99] Prefer not to answer

Ask only if Q35 = [1] Once, [2] Twice, OR [3] More than two times
(Q38) "What is the longest time you have been without power in your current home during a summer black out or electricity failure? [ADMINISTRATOR, please provide respondent with answer card.]

[1] Less than one hour
[2] One to six hours
[3] Six to twelve hours
[4] Twelve to 24 hours
[5] One to three days
[6] More than three days
[7] Don’t remember exactly, but less than 24 hours
[8] Don’t remember exactly, but 24 hours or more
[98] Don’t know
[99] Prefer not to answer

(Q39) "During the past 5 years or so, have you had medical symptoms related to heat exhaustion from high temperatures such as muscle cramps, dizziness, tiredness, weakness, throbbing headache, nausea or vomiting, fainting, or paleness?"

[1] yes, once
[2] yes, more than once
[0] no
[98] Don’t know
[99] Prefer not to answer

Ask only if Q39 = [1] yes, once OR [2] yes, more than once
(Q40_all) "Where were you when the heat-related symptoms occurred?"

[list of selected string variables]

(Q40_inhome) "Inside your home"

[1] yes
[0] no

(Q40_inelse) "Inside somewhere else"

[1] yes
[0] no

(Q40_out) "Outdoors"

[1] yes
[0] no

(Q40_other) "Other "

[1] yes
[0] no

(Q40_noknow) "don't know"

[1] yes
[0] no

(Q40_noans) "prefer not to answer"

[1] yes
[0] no

(Q40oa) "If you were somewhere other when the heat-related symptoms occurred, please explain... (audio)"

[audio file]

(Q40ot) "If you were somewhere other when the heat-related symptoms occurred, please explain... (text)"

[open ended text]

Ask only if Q39 = [1] yes, once OR [2] yes, more than once
(Q41) "When the heat symptoms occurred, did you seek medical treatment for heat-related illness?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

Ask only if Q02 ≥ 1
(Q42) "During the past 5 years or so, has anyone else in your household had medical symptoms related to heat exhaustion from high temperatures?"

[1] yes, one person
[2] yes, more than one person
[0] no
[98] Don’t know
[99] Prefer not to answer

Ask only if Q42 = [1] yes, one person OR [2] yes, more than one person
(Q43) "When that person or those persons experienced heat symptoms, did any of them seek medical treatment?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q44) "How safe or unsafe do you feel in your neighborhood?"

[4] Very safe
[3] Somewhat safe
[2] Somewhat unsafe
[1] Very unsafe
[98] No opinion/ don’t know
[99] Prefer not to answer

(Q45) "How many of your neighbors do you know? The options are: All; Most; Some; Few; None; Don't Know; or Prefer Not to Answer."

[4] All
[3] Most
[2] Some
[1] Few
[0] None
[98] Don't Know
[99] Prefer Not to Answer

Ask only if Q45 = [1] few, [2] some, [3] most, OR [4] all
(Q46) "How often do you talk to them?"

[5] Every day
[4] Talk often
[3] Talk occasionally
[2] Talk seldom
[1] Talk Never
[98] Don’t know
[99] Prefer not to answer

(Q47) "Is there a neighbor you would feel comfortable asking for assistance if you were too hot at home?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q48) "In this home you live in now, have you ever called a neighbor in an emergency?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q49) "Is there anyone else nearby (for example, a relative, friend, or co-worker) you would feel comfortable asking for assistance if you were too hot at home?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q50) "Would you feel comfortable asking for assistance from a religious organization or community group if you were too hot in your home?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q51) "Have you ever asked for assistance from a religious organization or community group in an emergency?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q52) "How many years have you lived in this home? (ADMINISTRATOR: If they do not remember exactly, an estimate is acceptable)"

[open-ended numeric]

Ask only if Q02 > 1
(Q53) "What is your relationship to the head of this household? The head of household is defined as whomever in the household is considered the head by the residents of the home. The head of the household is typically chiefly responsible for the monetary and material maintenance and upkeep of the home. This responsibility can be shared between more than one person."

[1] Me
[2] My spouse or partner
[3] My spouse or partner and I
[4] Shared between more than one person in the home, none of whom are related
[5] Shared between more than one person in the home, some or all of whom are related
[6] My parent or grandparent
[7] Someone else related to me
[8] Someone else not related to me [98] Don't know
[99] Prefer not to answer

Ask only if Q02 > 1
(Q54) "Is anyone who lives here, including yourself, over age 64?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

Ask only if Q02 > 1
(Q55) "Is anyone who lives here under age 6?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q56_badage) "In what year were you born? (ADMINISTRATOR, please put 98 for "I don't know" and 99 for "Prefer Not To Answer")."

NOTE: This column is marked "Q56_badage" because it is the raw data from participants, some of whom may have misinterpreted the question and put their current age rather than the year they were born (i.e., "57" could mean 1957 or 57 years of age.)

[open-ended numeric, years]
[98] don't know
[99] prefer not to answer

(Q56_updated) "In what year were you born? (ADMINISTRATOR, please put 98 for "I don't know" and 99 for "Prefer Not To Answer")."

NOTE: This column has been screened and cleaned by survey administrators/survey code designers to resolve the problem detailed above, by cross referencing with other survey questions on a case-by-case basis:

-if respondents indicated they were retired and had entered a value that would not make sense as the year they were born, it was assumed to be their age, not the year they were born (i.e. if the respondent wrote 73 and said they were retired, it was assumed that 73 is their age, not the year they were born).

-if respondents indicated that no one over the age of 64 lived in the household, it was assumed that 2 digit responses over 64 were the year they were born

-respondents that answered '98' or '99' were considered to be "I don't know" and "Prefer Not To Answer" respectively, as some people born in 1998 and all people born in 1999 would have been ineligible for the survey when it was administered in summer 2016

[open-ended numeric, years]
[98] don't know
[99] prefer not to answer

(Q57) "Are any of the people who live here limited in their ability to move about freely without assistance? (examples: wheelchair, bedridden, on oxygen, confused)"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q58) "We are required to ask, what do you consider your gender? [Respondent Self Selection]"

[1] male
[2] female
[97] other
[98] don't know
[99] prefer not to answer

(Q59) "Does your household have any pets?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q60) "In general, compared to other people your age, would you say your health is . . . [Respondent Self Selection]"

[4] Excellent
[3] Good
[2] Fair
[1] Poor
[98] Don’t know
[99] Prefer not to answer

(Q61) "Which of the following best describes your current employment or labor force status? Please select the single most appropriate option. [Respondent Self Selection]"

[1] Work full-time
[2] Work part-time
[3] Unemployed (out of work but looking for work)
[4] Not employed and not looking for work
[5] Full-time student
[6] Homemaker
[7] Disabled
[8] Retired
[97] Other

[98] Don’t know
[99] Prefer not to answer

Ask only if Q61 = [97] other
(Q61ot) "You said that your current employment or labor force status is "other", please explain... [Respondent Self Selection]

[open ended text]

Ask only if Q61 = [1] work full-time or [2] work part-time
(Q62) "How often does your job require you to work outdoors in the summer?"

[0] Never
[2] Sometimes
[3] Most of the time
[4] Always
[98] Don’t know
[99] Prefer not to answer

(Q63_all) "With which group or groups do you identify yourself? [Respondent Self Selection]"

[list of string variables]

(Q63_native) "Native American or American Indian"

[1] yes
[0] no

(Q63_asian) "Asian or Asian American"

[1] yes
[0] no

(Q63_black) "Black or African American"

[1] yes
[0] no

(Q63_hisplati) "Hispanic, Latino, Mexican, Mexican-American or Spanish"

[1] yes
[0] no

(Q63_mideast) "Middle Eastern"

[1] yes
[0] no

(Q63_pacific) "Native Hawaiian or Other Pacific Islander"

[1] yes
[0] no

(Q63_white) "White"

[1] yes
[0] no

(Q63_other) "Other"

[1] yes
[0] no

(Q63_noknow) "Don't know"

[1] yes
[0] no

(Q63_noans) "Prefer not to answer"

[1] yes
[0] no

(Q63_ot) "You said that you identify yourself with other group(s), please explain... [Respondent Self Selection]"

[open-ended text]

(Q64) "Is there any adult in your household who does not speak English?"

[1] yes
[0] no
[98] don't know
[99] prefer not to answer

(Q65) "How often do you struggle to afford essentials such as food, housing, utilities and medicine? [Respondent Self Selection]"

[0] Never
[1] Rarely
[2] Sometimes
[3] Often
[98] Don’t know
[99] Prefer not to answer

(Q66) "Which of these statements best describes your household in the last 12 months? [Respondent Self Selection]"

[4] We always have enough to eat and the kinds of food we want
[3] We have enough to eat but not always the kinds of food we want
[2] Sometimes we don’t have enough to eat
[1] Often we don’t have enough to eat
[98] Don’t know
[99] Prefer not to answer

(Q67) "Please, as best as you can, choose a category that represents the total combined income before taxes for all the people in your household last year. [Respondent Self Selection]"

[1] $20,000 and under
[2] $20,001-40,000
[3] $40,001-60,000
[4] $60,001-80,000
[5] $80,001-100,000
[6] $100,001-120,000
[7] $120,001-140,000
[8] $140,001-160,000
[9] $160,001-180,000
[10] $180,001-200,000
[11] More than 200,000
[98] Don’t know
[99] Prefer not to answer

(FollowUp) "We will be contacting some people who answered this survey to participate in some follow-up research activities related to heat and health.[ADMINISTRATOR, Hand respondent a one-page illustrated flyer about the HOBO/GIS study]. Would you consider participating if your household is selected?"

[1] yes
[0] no
[2] maybe
[98] don't know
[99] prefer not to answer

(Q68a) "Is there anything else you would like to tell us that is related to heat or hot weather? (audio)"

[audio file]

(Q68t) "Is there anything else you would like to tell us that is related to heat or hot weather? (text)"

[open-ended text]

(Q69a) "What can we do, as researchers at ASU, to help you and your household on matters related to extreme heat and power failures? (audio)"

[audio file]

(Q69t) "What can we do, as researchers at ASU, to help you and your household on matters related to extreme heat and power failures? (text)"

[text file]

APPENDIX E

TABLE 1. PERCEIVED RISK OF SUMMER TEMPERATURES AND SUMMER POWER FAILURE REGRESSED ON RISK AND ADAPTATION APPRAISAL CODE FREQUENCIES

APPENDIX E

Table 1. Perceived Risk of Summer Temperatures and Summer Power Failure Regressed on Risk and Adaptation Appraisal Code Frequencies *$R^2 = 0.580$* *$P = 0.002$*

Dependent Variables	**B**	**Std B**	**Lower 95% CI**	**Upper 95% CI**	**p**
High probability	137.53	0.44	54.10	220.95	0.00
Low probability	10.82	0.15	-10.89	32.52	0.32
High severity	5.61	0.10	-12.07	23.30	0.52
Low severity	-27.63	-0.45	-46.72	-8.54	0.00
High self-efficacy	-7.40	-0.21	-17.52	2.74	0.15
Low self-efficacy	-7.30	-0.08	-37.14	22.56	0.62
High adaptation efficacy	-0.58	-0.01	-23.78	22.63	0.96
Low adaptation efficacy	30.73	0.34	3.80	57.65	0.27
High cost	-31.76	-0.11	-108.36	44.85	0.40
Low cost	51.59	0.20	-13.86	117.02	0.12

* $p < 0.05$; **$p < 0.01$ N = 40