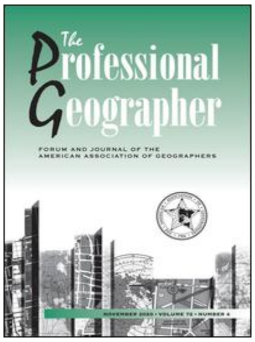

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Engaged Convergence Research: An Exploratory Approach to Heat Resilience in Mobile Homes

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Efforts to understand the complex, multidimensional nature of environmental vulnerability can generate new knowledge by deploying a convergence research framework within a community-engaged approach. We explore the benefits and shortcomings of what we call engaged convergence research (ECR) by narrating a case study that uncovered a pattern of indoor heat-related deaths that was previously unexplained: Although only 5 percent of Maricopa County, Arizona, residents live in mobile homes, residents of mobile homes account for 29 percent of indoor heat-related deaths. Exploring the multiplicative threats of economic precarity, population sensitivity to environmental exposure, site, and shelter type, we recharacterize the reality faced by mobile home dwellers to find them falling between the cracks of available heat resilience options. Beyond contributing to scholarship on indoor heat-related deaths, we demonstrate the potential for novel and actionable insights emerging from ECR. We also elucidate some of the challenges faced when enlisting community actors as coproducers of knowledge in geographic research. **Key Words: community geography, engaged convergence research, heat, mobile homes.**

The articulation of a national framework for convergence research (CR) affords geographers an opportunity to lead responses to emerging scientific priorities while addressing society's need for actionable knowledge. According to the National Science Foundation (NSF 2019), CR is characterized by identification of a specific and compelling problem and deep integration across disciplines—making it an ideal approach for studying complex phenomena. Although it might be premature to characterize the emergence of convergence discourse as a true paradigm shift (e.g., Kuhn 1962), CR offers the chance to creatively engage existing theoretical and methodological traditions to speak in new ways to impacts of local and global shocks and stressors.

We explore how integrating community geography (CG) with the CR framework yields novel and actionable findings. Although the NSF (2019) stopped short of stipulating community engagement, it noted that one route for defining problems is identifying "pressing societal needs," an area of strength among community geographers, who, together with stakeholders and actors with lived experience, identify and explore locally relevant and globally compelling challenges (Shannon et al. 2020). To support our call for integrating CG and CR, we narrate the unfolding of a case study focused on explaining the disproportionate number of indoor heat-related deaths in Maricopa County, Arizona, that occur in mobile homes. In doing so, we articulate what we term an *engaged convergence research* (ECR) approach, visualized in Figure 1.

Community Geography

CG gained prominence in the past decade due, in part, to critiques from critical geographers regarding the limitations of top-down scholarship (Roy 2009; Derickson and Routledge 2015), as well as shifting research valuations within universities (Sacha et al. 2013; Arizona State University 2020). Practitioners of CG study local problems defined alongside actively engaged community partners positioned as equal producers of insight and knowledge (Robinson 2010; Hawthorne et al. 2015; Pine et al. 2020; Shannon et al. 2020). Shared benefit is also explicitly emphasized, including benefit for local communities that are less privileged and, perhaps, have long gone

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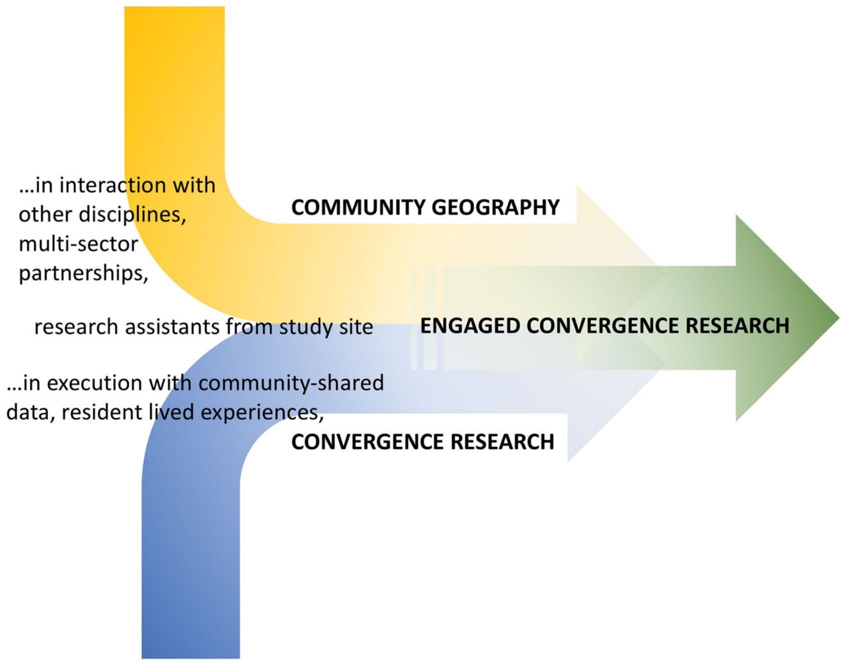

Figure 1 *The engaged convergence research (ECR) approach.*

unnoticed (Robinson 2010; Robinson, Block, and Rees 2017; Shannon et al. 2020).

We applied a CG approach in our partnership with the Utility Assistance Network (UAN), a group of more than eighty nonprofit, municipal, and private organizations serving Maricopa County residents. (Partnerships are discussed in greater depth in the Data and Methods section.) The collaboratively defined goal was to better understand how utility assistance programming might reduce indoor heat-related deaths. After attending several months of meetings and activities convened by the UAN to gain a deep understanding of the actors and their knowledge, and after completing formal data-sharing agreements (including stringent confidentiality protocols), we gained access to ZIP code–level data that enabled us to collectively explore the relationship between utility assistance receipt and indoor heat-related deaths.

As shown in Figure 2, we used one tool in the CG toolkit by visualizing the data in an intuitive dot distribution pattern meant to elicit ideas from partners at a series of convenings.[1] This visualization, encompassing the most populous portion of Maricopa County, uncovered a striking and statistically significant pattern within the city of Mesa: a concentration of indoor heat-related deaths in an area where utility assistance receipt was minimal. Unable to explain this pattern, we used satellite imagery to gain contextual information about the site, revealing, as shown in Figure 3, that the hot spot is home to a densely packed array of mobile homes.

Our partnership with the Maricopa County Public Health Department (MCPHD) allowed for a more fine-grained review of the mortality data, disaggregated by tenure type (but aggregated at the county level to protect confidentiality). As shown in Table 1, though only 4.9 percent of Maricopa County residents live in mobile home parks, mobile home residents make up a disproportionate 27.5 percent of indoor heat-related deaths (American Community Survey [ACS] 2017; MCPHD 2006–2018).[2] Further, mobile home residents who perished from the heat were disproportionately likely to either not have had air conditioning (AC) present or, if present, to have their electricity turned off (MCPHD 2006–2018).

Given the dearth of research on the relationship between mobile home residence and heat vulnerability (but see Kovach, Konrad, and Fuhrmann 2015), our descriptive findings, and the enthusiasm of stakeholders, our shared goal coalesced into a research question: Why are mobile home residents disproportionately likely to perish from indoor heat?

Convergence Research

Among NSF's 10 Big Ideas for future investment (NSF 2017), CR inspires and challenges the U.S. academic community to develop "new frameworks, paradigms, or even disciplines" that "catalyze

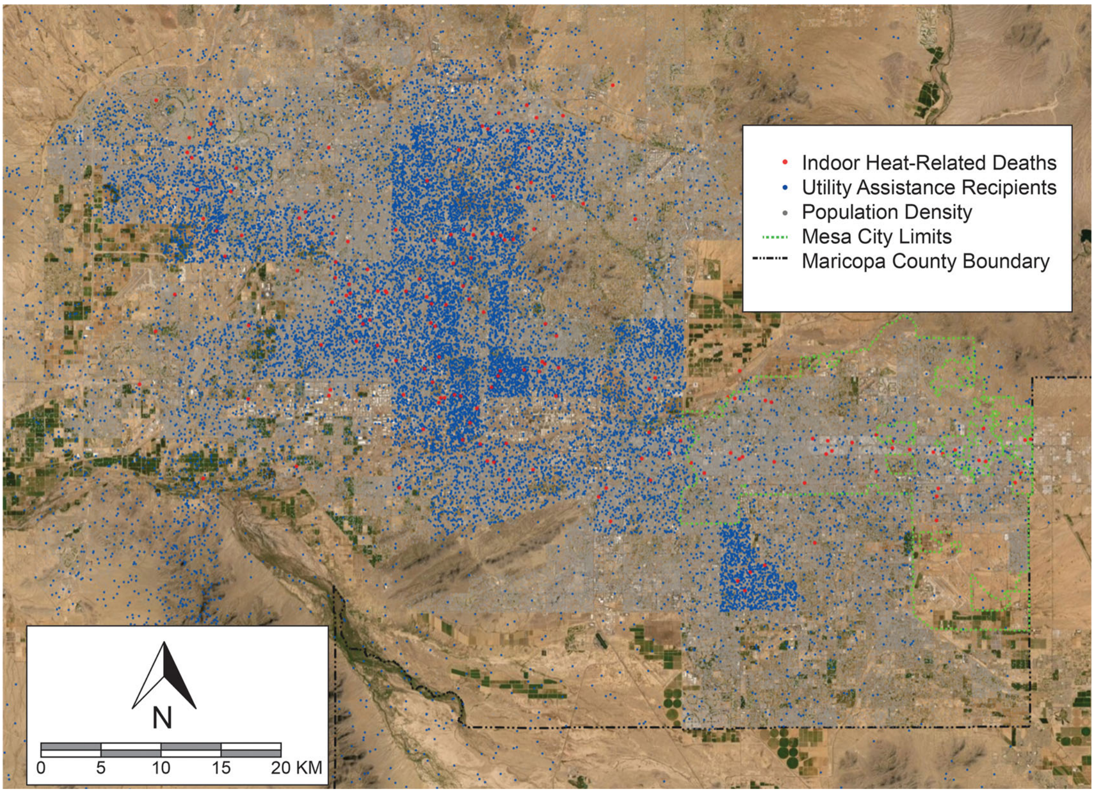

Figure 2 *Distribution of indoor heat-related deaths and utility assistance beneficiaries in Maricopa County, 2012–2018. Source: Wildfire, American Community Survey (ACS 2012-2018), Maricopa County Public Health Department.*

scientific discovery and innovation." This NSF investment, which coalesced from a series of compilations between 2002 and 2014 (Roco 2002; Roco and Bainbridge 2002, 2013; Roco and Montemagno 2004; National Research Council 2014; Bainbridge and Roco 2016), encourages intellectually diverse communities, historically siloed, to reach beyond typical boundaries and form "sustained interactions," devising "a new scientific language" that could ultimately "afford solving the problem that engendered the collaboration, developing novel ways of framing research questions, and opening new research vistas" (NSF 2020).

Although not yet touted as a premier example of CR, the heat and health literature lives up to this vision through its span across diverse disciplines, design of new techniques, production of new measuring equipment, and solutions-oriented knowledge innovations in the face of global environmental change (Harlan et al. 2006; Yip et al. 2008; Uejio et al. 2011; Harlan et al. 2013; Bao, Li, and Yu 2015). Indeed, scholars have identified numerous factors associated with heat vulnerability, including sociodemographic characteristics, preexisting health concerns, social isolation, indoor environment, outdoor environment, neighborhood effects, and political capacity and responsiveness (Klinenberg 2002; Naughton et al. 2002; Browning et al. 2006; Smargiassi et al. 2009; Chow, Chuang, and Gober 2012; Harlan et al. 2013; Hondula et al. 2015; Putnam et al. 2018). Despite the breadth and depth of the existing literature, mobile home residents remain greatly understudied relative to those living in single-family homes and apartments; only one known study includes explicit mention of mobile home residence as a heat vulnerability factor (Kovach, Konrad, and Fuhrmann 2015).

On the other hand, scholars studying mobile homes find that residents exhibit distinct vulnerabilities to acute environmental crises, owing to their generally less advantaged sociodemographic background (Manufactured Housing Institute [MHI] 2020) and the unique nature of their tenure (State of Arizona 2014; interview, S. Morgan, Arizona LIHEAP coordinator, Phoenix, AZ, 2019; Rumbach, Sullivan, and Makarewicz 2020). Thus far, however, mobile home scholarship has neglected heat as an acute environmental crisis of import.

The Case in Context

Extreme heat is deadlier than any other weather-related hazard (Center for Climate and Energy

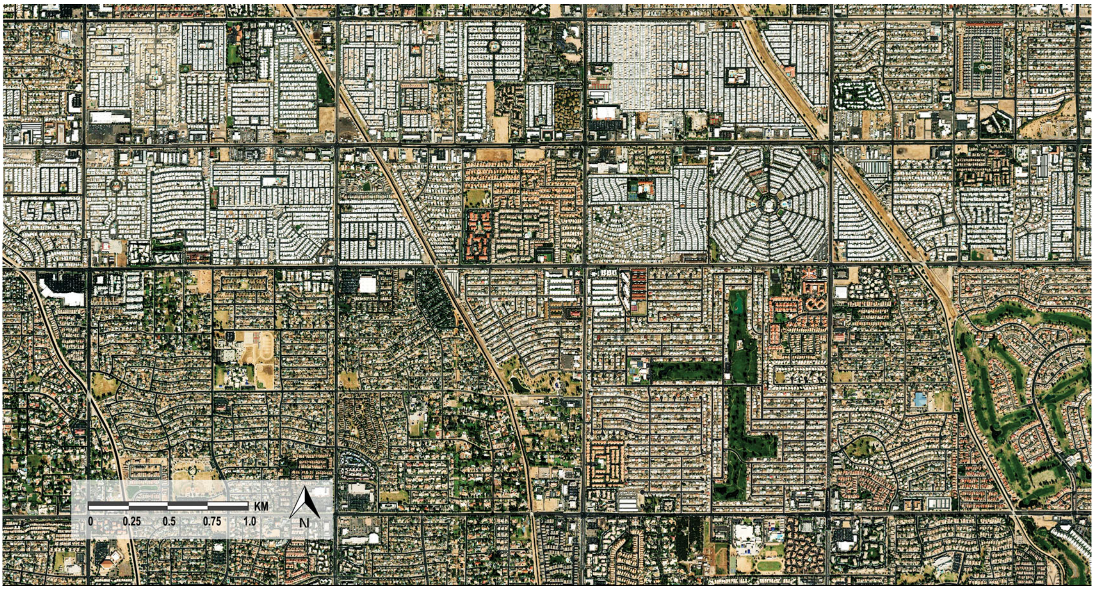

Figure 3 *Mobile home parks versus single-family residence communities in Mesa. Source: Maxar imagery from OSM Edit mode 2021.*

Table 1 *Frequency of indoor environmental heat deaths and deaths in trailers in Maricopa County, 2006 through 2018*

AC status	Indoor deaths	Deaths in trailers	Percentage of indoor deaths in trailers	Deaths not in trailers	Percentage of indoor deaths not in trailers
Not present	74	23	31	51	15
Present[a]	342	96	28	246	73
Unknown	51	11	22	40	12
Total	467	130	28	337	100
Reason for no AC					
Nonfunctioning	191	55	29	136	60
No electricity	34	11	32	23	10
Not in use	87	21	24	66	29
Total	312	87	28	225	100

[a]Among indoor deaths with AC present and known reason. *Note:* AC = air-conditioning. *Source:* MCPHD (2018).

Solutions 2017). The Phoenix metropolitan area (roughly contiguous with Maricopa County) is consistently ranked the hottest metropolitan area in the United States (Lada 2020) and is also among the fastest warming (Climate Central 2019). These climatic features make Maricopa County an ideal site for elucidating the underlying factors that exacerbate heat vulnerability, because these factors might be less visible in more temperate climates.

Within Maricopa County, our study unfolded across two sites. The first corresponds with the mobile home–dense area that we identified as having both low utility assistance receipt and high indoor heat-related deaths. The second, in South Phoenix, was identified in partnership with The Nature Conservancy. Despite primarily consisting of single-family homes and despite greater receipt of utility assistance, the neighborhood experienced a high number of indoor heat-related deaths. This article focuses on the former site due to our interest in mobile homes; however, we offer limited comparison with the South Phoenix site to contextualize some of our findings.

In Mesa, mobile homes comprise 26 percent of the housing stock in the intersecting Arizona Congressional District 4, representing the largest raw number and second highest proportion of mobile homes across U.S. congressional districts (ACS 2017).[3] The popularity of this affordable housing option is, perhaps, unsurprising given precipitously rising housing costs in Maricopa County (MHI 2020; Zillow 2020). The high density of mobile homes within Mesa, and the continuing demand for such housing, makes this site ideal for gathering rich data on urban mobile home residents that might not be obtainable in areas of less mobile home density.

Data and Methods for ECR

Building on prior heat-related health research, we employed the CR framework by leveraging contextual data from administrative and secondary sources and a wide array of primary data gathered by our multidisciplinary research team. The CR framework does not explicitly compel the inclusion of public stakeholders or people with lived experience as coproducers of knowledge, however (NSF 2019). Nonetheless, we leaned heavily on the CG tradition in our problem identification, question development, and data collection and interpretation, collaborating with partners both within and outside of the university. What emerged was a hybrid research design, as shown in Figure 1, that we termed the ECR approach.

Our core collaborators were UAN, the MCPHD, and The Nature Conservancy, all of whom offered early data, insights, and expertise and, subsequently, acted as equal partners in study design and implementation. Leveraging our university ties and our collaborators' grounded knowledge of the local community, we collectively identified additional collaborators to assist with particular aspects of study implementation, based on either their strong ties to the study sites (i.e., CG) or their expertise in areas not represented among existing partners (i.e., CR). The Center for the Future of Arizona, The Salvation Army, and Paideia Academy aided in participant recruitment and were identified due to their deep social embeddedness in the study sites and their shared goal of improving community health and well-being. Heliosun and For Energy aided in collecting data on mobile home energy efficiency and were identified based on their domain expertise. We also enlisted the help of several research assistants who attended Arizona State University while also residing in the respective sites.[4]

Beyond the data shared by UAN and the MCPHD, we gathered additional contextual data from several sources. County demographic data come from the ACS (2013–2017, five-year estimates) and ESRI Demographics Data (2018) using Community Analyst. Data on the outdoor environment include remotely sensed land surface temperature data from the U.S. Geological Survey (Landsat 8 Level-2 provisional surface temperature product, June–August 2019). Land cover classification data come from the Central Arizona–Phoenix Long-Term Ecological Research project, which uses 2010 National Agriculture Imagery Program imagery with a 1-m spatial resolution and an object-based image classification technique.[5]

We also analyzed heat resilience programs available to local residents using data gathered from a comprehensive Web site search of federal, state, and county governments; utility companies; and nongovernmental organizations. Together with our community partners, we compiled an asset inventory of known programs and actors offering such programs. While researching these programs and actors, we identified commonly used terminology that was then leveraged to conduct broader searches to locate additional data points until saturation was reached. We categorized each program according to its primary objective—receipt of financial support, direct changing of a condition, or longer term investment in overarching conditions—and then cross-classified each program according to its eligibility criteria, viability, and availability.

Regarding primary data, we recruited participants using a CG approach; namely, we collaborated with the Center for the Future of Arizona, The Salvation Army, and Paideia Academy, with additional assistance coming from the MCPHD, who provided flyers in English and Spanish. Recruits were offered a $95 gift card and access to their data in return for participation, and they were informed that they could opt out of any portion (or all) of the study at any time. In total, fifty-six households (twenty-five in Mesa and thirty-one in South Phoenix) took part. Data were collected between June and August 2019.

First, heat sensor kits were prepared and deployed, which included four sensors that recorded indoor temperatures. One HOBO-brand sensor was placed in the room where respondents spent a majority of their waking hours. It recorded temperature data at five-minute intervals for up to eighty-five days, was approximately wallet-sized, and contained a small display that allowed respondents to see the temperature.[6] Three Thermochron iButtons were placed in other rooms where respondents spent a meaningful amount of time, whether awake or asleep. These sensors, which recorded temperature data at hourly intervals, were approximately the size of a house key and did not include a display. Sensor kits with complete data were ultimately collected from twenty-one (84 percent) Mesa respondents. Results reported herein (in Fahrenheit) encompass readings from the HOBO-brand sensors.[7]

Second, home energy audits were conducted for nineteen (76 percent) Mesa respondents. Audits were offered in collaboration with two private business partners, Heliosun and For Energy, who generously offered them at a deeply discounted rate, which was assumed by our research team to offer them at no cost to respondents. The audits followed the standard operating procedures at the respective businesses and assessed factors like square footage; roof, floor, and exterior wall insulation; window and exterior door efficiency; and cooling mechanical capacity. Of focus here, audits also included a blower test, wherein large quantities of air are blown into a residence to measure leakage. Nineteen Mesa respondents received home energy audits, but five respondents were unable to receive the blower test because the required equipment would not fit inside their door. Results reflect the fourteen (56 percent) Mesa respondents able to receive the blower test.

Third, we designed, tested, and deployed a semi-structured survey, which was completed by twenty-

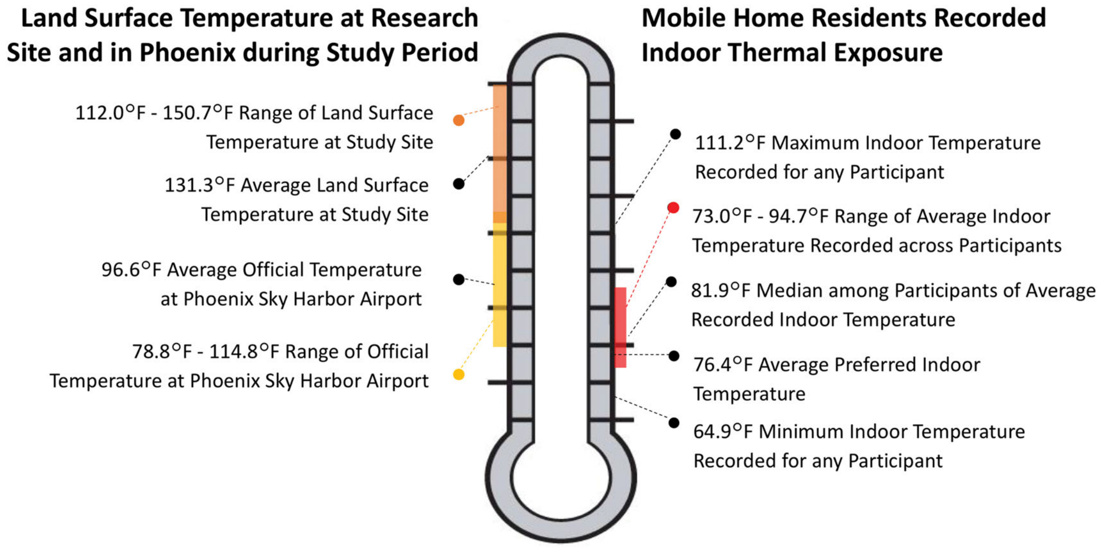

Figure 4 *Recorded indoor thermal exposure and land surface temperature metrics for Mesa respondents, July through September 2019.*

three (92 percent) Mesa respondents. In August 2019, respondents were contacted via their preferred mode of communication to complete an online survey, which included both closed-choice and open-ended questions. The survey, developed based on past heat-related health studies conducted by the team, contained 126 questions, divided into the following categories: perceptions of heat vulnerability, heat-related health concerns, heat mitigation devices and strategies, utility relationships and billing, heat-related cost concerns, and individual and household sociodemographic information. Completed surveys were translated from Spanish to English as needed.

Finally, in February 2020, we returned to the Mesa site to present preliminary findings. Although this presentation characterized responsible CG, we also recognized it as an important opportunity to learn what findings resonated most and to identify anything that our data collection, although extensive and engaged, might have missed. As such, we practiced engaged participant observation (Robey and Taylor 2018). A known research assistant sat as part of the audience and transcribed attendees' statements during and after the presentation and made note of what presentation elements elicited physical reactions (e.g., head nodding).

Coproduced Results

We first describe respondents' indoor heat exposure and discuss the physical and psychological consequences of such exposure. Then, we leverage our ECR approach to unpack the factors that render mobile home residents uniquely vulnerable, breaking these causes down categorically according to exposure, sensitivity, and adaptive capacity (Chow, Chuang, and Gober 2012).

Indoor Heat Exposure: Far beyond Comfortable

As depicted in Figure 4, the temperature inside of respondents' mobile homes was often much warmer than their average preferred temperature. Six respondents recorded maximum indoor temperatures above 100° and had an average minimum indoor temperature of 76.4°—that is, their indoor temperature, at its lowest, was at the maximum comfort threshold. Indoor temperatures were also highly volatile; comparing minimum and maximum indoor temperatures for each respondent, the average difference was 20.8°. These findings are all the more concerning in light of survey results indicating that a majority of respondents spend nearly twenty-four hours per day indoors.

Health Consequences: Sensitivities beyond Mortality

Survey results indicate that respondents experienced physiological and psychological health consequences from indoor heat exposure. When asked whether they were ever uncomfortably warm in their home (five-item Likert scale), zero respondents reported never, whereas 62 percent reported often or very often. Heat exposure led 86 percent of respondents to feel more tired than usual and 80 percent to have more trouble sleeping than usual. Additionally, 60 percent of respondents had experienced symptoms of heat exhaustion within the past five years. Heat exposure was also tied to more severe physiological consequences. According to Alice, she had difficulty breathing when it became too hot in her home.[8] Similar breathing difficulties were reported by Sandy, who stated that the heat interacted poorly with her chronic obstructive pulmonary disease, causing her to go to the hospital. Perhaps the most alarming physiological consequences were reported by Howie, who recounted experiencing two strokes attributable to indoor heat exposure.

Psychologically, approximately 86 percent of respondents reported that indoor heat made them unable to enjoy normal household activities, and nearly two thirds reported experiencing higher than average difficulty thinking. Further, two thirds of respondents reported experiencing heat-induced anxiety. According to Greta, an anxiety attack brought on by the heat awakened her during the night. More severe psychological consequences were not limited to anxiety. One respondent, Nancy, indicated that indoor heat exposure caused depression, leading her to seek medical treatment.

The link between indoor heat and health consequences could also be indirect. Painfully, one attendee of our presentation stated that she was aware of residents committing suicide due, in part, to feeling desperation while unable to manage their summertime indoor heat exposure (Thompson et al. 2018). These tragic deaths are not attributed to indoor heat in official statistics, meaning that the figures that inspired our research might be underestimates.

Individual Contributors to Sensitivities

Prior research finds that a variety of sociodemographic characteristics are associated with increased heat sensitivities. Older adults are more susceptible to the effects of heat exposure (Naughton et al. 2002). Among respondents, 50 percent were either sixty-four or older or living with someone who was and 75 percent were either sixty or older or living with someone who was. These rates vary substantially from the age distribution of Maricopa County, wherein only about 15 percent of residents are sixty-five or older (ACS 2017).

A second heat sensitivity factor is racial or ethnic minority status (Klinenberg 2002; Naughton et al. 2002). Because our sample sizes for individual racial and ethnic minority groups are small, we draw interpretations from the racial composition of the site relative to the number of indoor heat-related deaths. Site residents were disproportionately White compared to the entire county yet were also disproportionately likely to fall victim to indoor heat-related death—implying that nonminority status is not a protective factor for mobile home residents.

Low income and low educational attainment are also associated with heat sensitivities (Chow, Chuang, and Gober 2012). The median household income in Maricopa County was about 250 percent greater than that of respondents, at least half of whom earned less than $25,000 annually. Respondents' low incomes were largely a function of fixed-income payments due to retirement, disability, or, less commonly, unemployment. This steadily low income stream was a significant barrier to managing heat exposure, whether respondents opted not to lower the temperature on or even run their AC due to utility cost concerns (50 percent) or whether they were unable to afford necessary AC repairs (33 percent) or energy efficiency solutions (75 percent).

Educationally, nearly 43 percent of respondents had earned a high school diploma or equivalent or less and only about 10 percent had earned a bachelor's degree or higher. Beyond the relationship between education and income, low educational attainment could present distinct challenges by fostering a decreased ability to navigate information bottlenecks or engage in self-advocacy. Nearly 90 percent of respondents did not use billing plans that smoothed costs, and about three fourths had not participated in a utility assistance program. Additionally, our engaged participant observation found no evidence of collective activism among our respondents; although they recognized that the burden of managing indoor heat exposure was a commonality, proposed solutions (or barriers) were framed individually.

Finally, health comorbidities exacerbate heat sensitivities (Klinenberg 2002; Naughton et al. 2002; Kenny et al. 2010). Although substance use is positively correlated with poor heat-related health outcomes, only two respondents reported ever using alcoholic beverages as a means to cool off. On the other hand, preexisting health conditions were salient. Nearly 20 percent of respondents reported that at least one household member was unable to move freely without assistance, and one respondent cited this as a primary reason for being unable to improve his or her home's energy efficiency.

Social Dimensions of Adaptive Capacity

Consistent with prior research, social factors also contributed to respondents' heat-related health vulnerability. Living alone, as do slightly more than half of our respondents (but only one fourth of Maricopa County residents), poses an increased threat (Naughton et al. 2002; Harlan et al. 2013; ACS 2017). Social isolation also matters (Klinenberg 2002). Of the 42 percent of respondents who reported having no choice but to leave their home because the temperature inside was too hot, 57 percent reported going to the home of a friend, relative, or neighbor. Thus, nearly one fourth of respondents did not rely on their social network during a high-threat period, implying that they might be socially isolated.

Neighborhood collective efficacy also matters for heat vulnerability (Klinenberg 2002; Browning et al. 2006). Nearly 86 percent of respondents agreed or strongly agreed that they would be willing to help their neighbors (five-item Likert scale); however, nearly one fourth reported that they interacted with their neighbors never, seldom, or several times a month. Thus, although respondents expressed a high degree of collective efficacy, this did not necessarily translate into robust social bonds. Another point warrants mention: During our presentation, several attendees mentioned that "snowbirds" arrive at the park during winter and depart before summer begins, leaving the park much less densely populated during the summer (and, therefore, precipitously decreasing the absolute potential for social contact).

Prior research also links indoor heat vulnerability to neighborhood sociodemographic characteristics (Harlan et al. 2006; Uejio et al. 2011; Harlan et al. 2013; Hondula et al. 2015). Much of this research does not query the associated causal mechanisms, making it unclear whether the relationship is causal or merely a function of the spatial clustering of high-vulnerability individuals. Research that does explore causal mechanisms (e.g., Klinenberg 2002; Browning et al. 2006) emphasizes both social isolation and collective efficacy.

Physical Environmental Factors of Adaptive Capacity

Certain housing features pose a greater heat threat, including lacking functioning AC, living in a single-room occupancy dwelling, and living on the top floor of a housing structure (with mobile home residence heretofore unaddressed; Klinenberg 2002; Naughton et al. 2002). Regarding AC use, slightly less than half of Mesa respondents used central AC, and slightly less than one third used a window AC unit. These figures contrasted starkly with those of South Phoenix, wherein only one respondent used a window AC unit and the rest relied on central AC. Additionally, our engaged participant observation revealed that respondents struggled to repair broken AC units due to the cost of repairs relative to their low fixed incomes. They also lamented difficulty in finding repair companies that were both inexpensive and reliable, implying a trade-off between cost and repair quality.

The energy efficiency of mobile homes also mattered for indoor heat exposure. Mobile home building codes were first instituted in 1976, with periodic updates since (Arizona Housing Alliance and Mobile Home Working Group 2017). Although we did not collect the year that respondents' dwellings were built, ACS data show that as many as 65 percent of mobile homes in Maricopa County could have been built prior to 1990; thus, even before durability is considered, energy efficiency might be suboptimal. Results of the blower tests underscore this point. According to our auditors, an energy-efficient home will have leakage of less than or equal to 1,500 cubic feet per minute. Only four respondents received readings under this threshold, and one home demonstrated near constant air transference between the inside and the outdoors.

The energy inefficiency of respondents' mobile homes was exacerbated by the energy inefficiency of the mobile home park, consistent with prior research showing locational disparities in heat exposure (Harlan et al. 2006; Smargiassi et al. 2009). Referring back to Figure 4, the outdoor temperature at the park was, on average, 16.5° higher than the highest meteorological temperature recorded over the same time period. This makes sense given the lack of physical environment–related adaptive capacity features found throughout the site: Only 12.07 percent of land cover was vegetated, and two thirds of land was covered by buildings or roads.

Programmatic Factors of Adaptive Capacity

An important mediator between individuals and the environment is the adaptive capacity of the programmatic landscape that, herein, encompasses heat resilience programs in Maricopa County. Several conclusions derive from our analysis of these programs, visually depicted in Figure 5. First, a majority of heat resilience programs function to directly change a condition or invest in long-term conditions, whereas relatively few programs are focused on the receipt of financial support. Nonetheless, our respondents expressed a dire need for financial support to build heat resilience.

Second, most programs have strict qualification requirements that our respondents were unable to meet due to their tenure in a mobile home. For instance, eligibility for most programs is limited to direct customers of the county's two main utility providers, Arizona Public Service and Salt River Project. Our data collection revealed that many mobile home residents are not direct utility customers but, rather, get billed by the mobile home park as the direct customer. Among programs that do not require a direct utility relationship, those that require alterations to the land (which mobile home residents rent) render this group ineligible (Rumbach, Sullivan, and Makarewicz 2020). Further, housing with wheels (even if immobilized or covered) is ineligible for many programs (interview, S. Morgan, Arizona LIHEAP coordinator, Phoenix, AZ, 2019). Finally, respondents noted technical barriers to implementation that transcended cost and eligibility requirements, including, for instance, reports that mobile homes could not bear the weight of solar panels.

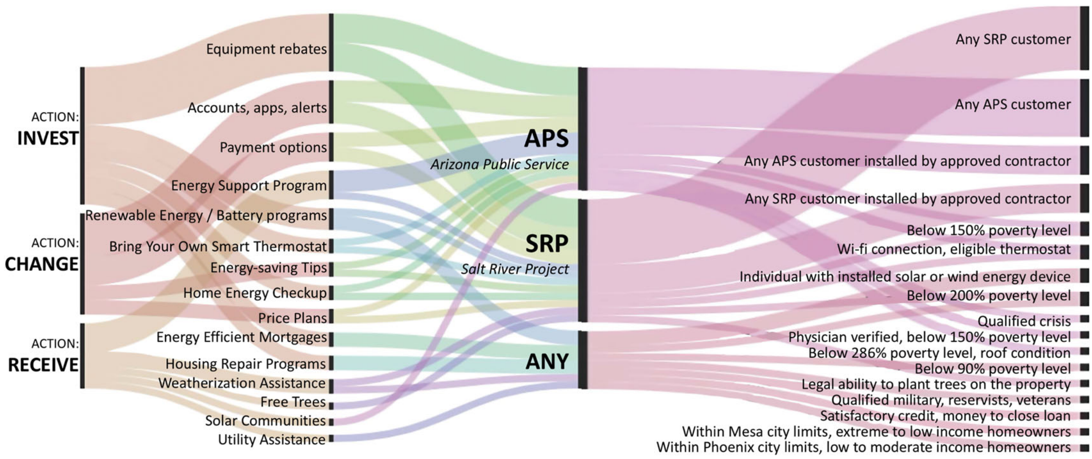

Figure 5 *Options for utility customers to change, invest, and receive energy program benefits in Maricopa County. Credit: Carlos Aguilar.*

Discussion and Conclusion

Our research sought to explain a heretofore unrecognized social problem within Maricopa County, brought to light through our community partnerships and, especially, our collaborative mapping; namely, mobile home residents are disproportionately likely to perish from indoor heat. To gain leverage on this problem we employed a novel ECR approach, integrating cross-disciplinary scholarship and techniques, forming a convergent team, and collaborating equitably with community partners and residents with lived experience at each stage of the research process.

Our findings both affirm and extend prior research at the nexus of heat and health. Even as we corroborate many of the factors long associated with heat vulnerability, we also illuminate new factors (e.g., the local programmatic landscape) previously overlooked in many analyses. Our process of coproduction with community partners—who were both experiencing and responsible for the gap made visible through this work—also made apparent the tight interrelationships between factors contributing to heat vulnerability. Finally, we highlight the need for greater attention to mobile homes in heat research, where residents face unique challenges, including energy-inefficient dwellings, an environment developed without due attention to heat impacts, and ineligibility for programs that would foster greater heat resilience.

For us, the story of indoor heat-related deaths in mobile homes is one of precarious individual and social factors, leading to and interacting with dangerous physical environmental factors, all existing within a void of programmatic support. Our respondents faced a vexing bind: They lived in mobile homes because they were affordable, but affordability brought with it a number of steep, hidden costs that were exacerbated by the outdoor physical environment. Despite their high vulnerability, mobile home residents are rendered essentially invisible to nongovernmental organization actors, utility providers, and governments because available resilience solutions address either economic or environmental factors, thus encouraging programmatic silos unable to address the multiple jeopardies that this group epitomizes.

Although the ECR approach was beneficial for uncovering a pressing social need and understanding its complexities, there necessarily remain some limitations. The CR framework demanded breadth of inquiry, whereas the CG approach demanded depth of inquiry, resulting in a lower sample size. Further, our site was selected based on visualizations derived from data convergence, structuring which mobile home community was engaged. Although the "average" mobile home resident is represented by our study, mobile home residents and parks are sociodemographically heterogeneous (MHI 2020). As such, and particularly in light of the intricate relationship among environmental data, communities of interest, and research processes (Wang et al. 2020), findings might vary for dissimilar groups of mobile home residents or dissimilar parks. This leads us to caution that one-size-fits-all solutions might be untenable.

The ECR approach was, nonetheless, essential for producing actionable findings within Maricopa County. Greater local awareness of mobile home residents' heat-related challenges, made possible through our extensive community partnerships, inspired local stakeholders to develop information flows and interventions targeted toward this group. We are also developing a heat resilience toolbox for use in mobile home communities alongside our initial partners and newly engaged community stakeholders, scientists, students, and volunteers.

Beyond these interventions, our research foreshadows a pressing need to grapple with scale (Solís, Vanos, and Forbis 2017). Mobile home residents have little control over many of the factors that make them vulnerable—factors like advanced age, health comorbidities, and low fixed-income payments. Consequently, solutions must move up the decision-making and accountability scale to account for the costs of heat at a community level. Mobile home park residents could be supported in collectively advocating on their own behalf. Mobile home park owners—many of which are large, well-resourced corporations with out-of-state owners (Reagor 2020)—should also share accountability for providing a healthy environment for residents. Utility companies and local governments also bear some responsibility for the health and well-being of consumers and residents within their purview, even if mobile home residents do not constitute a majority of their customers or constituency. This points to another issue of scale mismatch (Solís, Vanos, and Forbis 2017): Mobile home parks cut across utility and municipal boundaries, rendering the challenges associated with living in these parks simultaneously everyone's problem and no one's problem.

If mobile home residents remain invisible, people will continue to die. With more than 20 million Americans living in manufactured housing and mobile homes (MHI 2020), facing the threat of rising temperatures and other environmental changes, the stakes are high. We encourage key local and national stakeholders—including scientists—to break down existing silos and recognize their agency for offering tenable solutions. We also provide a model for geography in demonstrating the theoretical, methodological, and data configurations necessary to undertake ECR. In doing so, we underscore the benefits of this approach for novel problem identification and deep, democratic knowledge building, with the goal of amplifying the impact of our disciplinary strengths and developing transformative solutions. ■

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Notes

[1] To protect privacy, dots were automatically generated within each ZIP code using ArcGIS. We clarify that we did not fully engage a public participation geographic information systems (GIS) approach (Robinson 2010; Robinson, Block, and Rees 2017), and our use of GIS analysis was limited. In doing so, we underscore that even simple mapping and interpretation, done alongside community partners, can catalyze discovery and generate actionable insights.

[2] Data presented span 2006 to 2018 to reflect what was available to us at the time of community engagement. Adding data from 2019 raises the proportion of indoor heat-related deaths in mobile homes to 29 percent, and in 2019 specifically 40 percent of such deaths occurred in mobile homes (MCPHD 2020). The MCPHD uses the term *trailers* as synonymous with mobile homes. We maintain their language in the presentation of their data.

[3] For an interactive map of mobile homes in Maricopa County, visit https://bit.ly/3bZXMtZ.

[4] We underscore the fact that we, as researchers, did not "create" all of the partnerships in this research; rather, we engaged long-standing partnerships (e.g., the UAN), and we gathered and joined together with actors already familiar with one another and working in the same domain to achieve a specific, shared goal.

[5] The land surface temperature (LST) data have an error of –0.56 K ± 0.76 K (band 10 LST) and –2.16 K ± 1.64 K (band 11 LST; Cook et al. 2014), and the land cover classification data have an overall classification accuracy of nearly 92 percent (Li et al. 2014). These respective accuracy rates fall well within accepted ranges.

[6] The five-minute time interval was selected to provide a sufficient resolution of daily thermal change while balancing the demands of a months-long data collection period, including data storage and battery limitations.

[7] Although the indoor (i.e., out of direct sunlight) placement of these sensors circumvents many of their associated accuracy concerns, they were also tested and calibrated prior to deployment to ensure optimal accuracy (Hubbart et al. 2005).

[8] All names are pseudonyms.

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