Designing for Bottom-Up Adaptation to Extreme Heat

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Abstract

In the wake of global climate change, our world is projected to heat up and experience more extreme heat waves over the next few decades. Phoenix, Arizona, where this research was conducted, is one of the hottest locations on the planet and presents a testbed for understanding and addressing heat-related challenges. This paper focuses on adaptation as a design strategy that compliments existing approaches to mitigate human impact on the environment. We report on findings from a summer-long diary study that reveals how extreme heat impacts human lives, how participants cope with extreme heat. These findings motivated our critical making work themed around adaption, focusing on artifacts for visualizing, coping with, and utilizing extreme heat. In constructing these artifacts, we critically reflect on both the benefits and drawbacks of designing for adaptation and suggest hybrid approaches that mitigate human impact on and help people adapt to climate change.

Keywords

Extreme Heat, Adaptation, Sustainability, Critical Making

Introduction

In the wake of global climate change, our world is projected to heat up and experience more extreme heat waves over the next few decades [10].

If individuals cannot find successful ways to adjust to warmer temperatures, it could lead to social and structural disruption inside of the community, and, if extreme heat forces mass migration, could cause regional or international conflict.

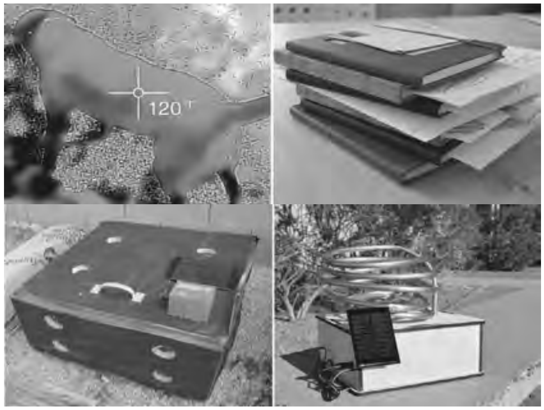

Figure 1. Data from our diary study of extreme heat: thermal camera image captured by a participant and participants' journals; and artifacts speculating on design for adaptation: a sensor-enabled hot composter and solar-powered chiller.

Phoenix, Arizona, where this research was conducted, is one of the hottest locations on the planet and serves as a testbed for understanding heat-related challenges. These range from the critical issues of heat vulnerability and heat mortality, to the marginalizing effects heat has on different socio-economic groups (e.g., stakeholders with limited access to cooling appliances or transportation). At the same time, heat also presents new opportunities for harvesting heat as a source of energy or more broadly energizing communities around the topic of climate change.

This paper focuses on a complimentary, albeit equally important set of research questions. How are human lives affected by extreme heat? What are the bottom up workarounds and coping strategies for living in extremely hot climates? And how can design intervene to address these challenges and harness heat for sustainable outcomes?

To answer these questions, we first conducted a longitudinal diary study asking seven Phoenix residents to document their experiences with heat over the course of the summer. Participants were asked to journal their routines, challenges, and workarounds in regards to heat from mid May through mid September. Themes from this study inspired our critical making activities to create physical artifacts as speculations on how design can support resilience in the face of extreme heat.

Research Contributions

This paper contributes insights into how humans adapt to extreme environments and critically reflects on how or if design should support these coping mechanisms. Our work is an important step towards 1) understanding bottom-up coping strategies and enhancing community resilience in the face of projected climate change; and 2) broadening the scope of research to include adaptation as part of the sustainability discourse. We continue by presenting the background and related work, including an overview of the extreme heat and existing relief efforts in Phoenix, AZ, and prior work across related areas. We then detail the methods and findings from our diary study, including 1) aspects of participants' daily lives affected by heat; 2) participants' coping strategies; and 3) barriers that hinder coping capacity. These insights motivate our critical making of artifacts themed around bottom-up adaptation: Thermochromic visualizations of extreme heat, low-cost solar cookers, a sensor-enabled hot composter, a solar-powered compression cooler, and a zine-style heat survival guide. We conclude by suggesting hybrid design approaches that both mitigate human impact on the environment and help people adapt to extreme conditions.

Background and Related Work

This section draws on multidisciplinary literature to paint a broad picture of extreme heat in Phoenix and the relief efforts on the ground. We position these challenges and workarounds within a broader discourse on global climate change.

Extreme Heat

Phoenix, AZ is arguably the hottest city in the United States and one of the hottest on the planet. As early as mid May, the average daily temperatures exceed 100F (with lows often staying above 85F) and remain that high through September [10]. On average, it is over 100F for 107 days a year, making Phoenix the hottest large city in the US [ibid]. Even short-term exposure to this type of heat stresses the human body, with effects ranging from mild discomfort, to shock, fatigue, collapse, or even death [9]. Existing on-the-ground relief efforts in Phoenix are aimed at alleviating factors that contribute to heat vulnerability, with initiatives ranging from heat refuge and hydration stations, to wellness checks, factsheets, and awareness campaigns [14, 15].

The extreme heat experienced in Phoenix for nearly a third of the year is relevant within the broader context of global climate change. As the earth's surface temperatures are projected to increase over the next few decades [2], many areas are expected to experiences more extreme heat waves [21]. Even if these trends stabilize, heat already effects parts of world and there is an urgency to consider adaptation as well as mitigation strategies [2, 12]. Heat has marginalizing effects on low income groups and can lead to political and economic tensions around resources. Adaptation is therefore a critical component of addressing climate change peacefully In this paper, we study bottom-up coping in Phoenix using ethnographically-informed fieldwork, an approach that is different from existing quantitative studies (e.g., mortality statistics or GIS data [1]).

Sustainability and Interaction Design

Eco-feedback research visualizes consumption and aims to nudge human behavior towards reducing impact on the environment. Examples range from low-power energy monitoring platforms [16], to persuasive representations of desirable behaviors [7], adaptive indoor temperature settings [3], and higher-level reflections on eco-feedback design principles [7] to name a few.

In addition to these mitigation approaches, recent work has also examined perceptions of and adaptations to climate change [6, 4]. For example, Knowles, et al. identified barriers for political mobilization towards cutting fossil fuel emissions [13]. Recent research has also considered adaptations to extreme weather patterns, namely the effects of cold weather on youths in Northern Finland [29]. For hot weather, Ryan explored the possibility of using wearable technology to help individuals adapt to the altering weather caused by climate change [19]. Co-design methods have also been applied to develop mobile technologies that support adaptations to climate change in the Pacific [29]. We contribute to this body of work on adaptation by focusing specifically on the problem of heat.

Methods

We began with a summer-long diary study to gain grounded insights into how human lives are affected by extreme heat. Study insights focused critical making activities and led to the prototyping of artifacts around the theme of adaptation.

Diary study: Drawing on prior sustainability research that examines everyday practices [e.g., 27], our diary study focused on heat-related experiences amongst participants who regularly spend time outdoors. We reached out to a local bicycle advocacy organization and a library to recruit seven participants (3 male, ages mid 20s to late 50s) who rely on biking and walking as a mode of transportation even in the summer months. An initial group meeting introduced participants to the project and invited them to document heat-related experiences in Phoenix from mid May through mid September.

The participants were provided with journals, and instructed to describe their experiences however felt most natural, as per prior work that validated free-form, paper-based data collection [28]. In addition, participants were asked to mail the researchers a weekly postcard detailing one heat-related experience from that week (Fig. 2).

Participants completed semi-structured interviews at the end of the study (about 2 hours), reflecting on their summer experiences. During the interviews, participants read parts of their journals as prompts and discussed the written events in greater detail with the interviewers. In addition, participants were asked to complete a card sorting exercise to reflect on the extent to which aspects of their lives— food, sleep, commute, relationships, etc.—were effected by heat. Participants were also asked to sketch their ideal urban location and speculate on ways that heat could be used

to improve their lives. Participants were compensated $10 for every two mailed postcards, $10 for each hour of their time during the interviews, and an additional $30 for completing the entire study. Audio from the interviews was transcribed and analyzed along with the journal entries, photographs, and postcards.

Prototyping artifacts: The construction of physical artifacts is a longstanding method in design research, whereby engagement with materials reveals opportunities and constraints for future work [e.g., 8, 22]. Given the grounded account of extreme heat from our diary study, prototyping of artifacts was employed as a method to envision how design might support bottom-up adaptation to extreme heat Our prototyping focused on three themes: 1) visualizing; 2) coping with; and 3) productively utilizing extreme heat. The resulting artifacts materialize new design opportunities and challenges presented by extreme heat.

Extreme Heat: Impacts and Coping Strategies

This section details key findings from our diary study of participants' experiences with heat in Phoenix. On average, participants wrote 8-12 diary entries over the course of the summer, with most writing more entries at the beginning of the study, and one person making a journal entry every single day. The data falls into one of three high-level themes: 1) Heat's impact on daily lives; 2) participants' coping strategies; and 3) challenges that hinder coping.

Extreme Heat and Participants' Daily Lives

Before detailing how heat affects particular aspects of participants' daily lives, it is worth noting some of the general ways they describe the summer conditions.

You don't walk outside and adjust, you walk outside and essentially get punched in the face. -P5

For all participants, a Phoenix summer involves, as P1 best put it, *"sweating while doing next to nothing outside"*. We continue by detailing how the extreme heat impacts specific aspects of participants' daily lives.

Contact with hot materials: In addition to the high daily temperatures, participants routinely come in contact with uncomfortably—and often dangerously—hot materials. Examples include having to *"maneuver around the metal seatbelts and car door handles"* (P4), testing the pavement before taking out pets because "*they'll have possible burns on the concrete"* (P5), or common electronics overheating when left outside even for *"not even five minutes"* (P2).

We have a concrete wall and in the summer, that wall heats up. We don't have a headboard on the bed so right up against the wall. You can feel the heat from the wall in the summer. -P5

Lack of cold water. In addition to these interactions with hot materials and objects, participants also struggled to find cold water. All participants commented on uncomfortably warm water in pools and faucets: cooling water systems are not common in Phoenix homes, and all participants reported that their "cold" faucets and most pools were never actually cold.

All the plumbing runs overhead. All the piping is in the attic, and the attic is 120 degrees. Getting a cold shower in the summertime is actually a bit of a challenge. -P1

Mid July through August, a lot of the pools are like bathwater and it's just in the sun. -P7

The above comments reflect the challenge of accessing cold water for drinking, showering, or swimming.

Appetite and diet: To varying extents, heat impacts all of the participants' food habits during the summer. Logistically, participants are unable to bike with frozen items (e.g., *"ice cream's pretty much a no-go, unless I happen to be driving"*, P1), and cold items require insulated bags whether shopping by car or bike (e.g., *"if I didn't bring my insulated bag, then I wouldn't buy any cold foods"*, P2). Participants also reported a decrease in appetite (e.g., *"I would definitely say smaller, and I think it's also because I feel so dehydrated"*, P4). Cooking behaviors change as well, with most participants opting for colder foods, not using the oven, or not cooking at all (e.g, *"I didn't use the stove or the oven"*, P3; "*We did cold foods more than not, or went out"*, P2).

Exercise: During the peak heat, participants avoid hiking, running, walking, swimming, or biking outdoors, which leads to changes in their exercise routines. Three of the participants switch to working out indoors, while others limit their workouts.

I guess I don't go on long rides over the summer. I don't go on rides over usually about five miles or so just because it's hard to carry enough water to make sure that you're going to be able to get there. -P5

I just end up not running. I tried swimming. I still work out with the trainer. We still do that, but we—usually, when it's nice out we work out outside, which is also very nice. -P7

Social interactions: Participants reported that the weather impacted their social lives. For some, extreme heat led to less social gatherings (e.g., "*there were some days where I was like it's too hot to do anything"*, P3). For others, travel distance is limited during the hotter months. Participants also noted that social events often have lower attendance:

It's a real trick to make sure that everybody wants to go out. Nobody really wants to go out and ride around in the heat. - P5

Health: All participants reported experiencing various physical symptoms that they directly attributed to heat. These range from mild headaches, nosebleeds, feeling disoriented, and other side effects of dehydration (P1, P3, P5), to allergies from being exposed to circulating air indoors (P2, P6), or full-on heat strokes (P7). In addition, all participants noted that they encounter more people who are sick over the summer than during other seasons.

Mood: Participants reported that heat has psychological effects on their lives. To varying extents, all participants observed feeling more *"cranky", "lethargic", or "crabby"* over the summer ("*people are short-tempered, they're lethargic*", P6).

Just having to run outside to the car to take the trash out type thing. It just definitely puts everybody in a cranky mood. -P4

Everybody is crabby the last week of May and then they're crabby the first week of October, 'cause it's still hot and we still have triple digits like next week. -P7

To summarize, this section detailed how extreme heat— both in terms of exposure to high temperatures and hot materials—effected participants' water access, diet, exercise, social lives, health, and mood.

Coping Strategies

Here, we describe participants' coping mechanisms for the presented challenges. These include minimizing exposure, as well as different strategies for adapting to the heat.

Staying indoors: Participants spent significantly more time indoors in the summer months, especially during daylight hours. To save money on air conditioning, participants insulated their homes by closing the window shades (P2, P3, P4); putting wooden doors over the windows (P6); or using fans (P2, P3). Participants also seek out public spaces that are air conditioned, including movie theatres, restaurants, or grocery stores. In addition, they tend to alter bicycle commutes to include indoor stops.

Costco has, in the back of the store, a produce room and a dairy room, and those are colder than the rest of the stores. You can walk in. You learn those. -P1

Changing routine: To maximize time spent indoors during the hottest parts of the day, all participants change their routines. Most notably, when they have the flexibility, they opt to run errands and leave their homes during early mornings or late evenings. For example, participants would grocery shop at night (e.g., *"I'd do grocery shopping at night, which I generally don't like* *to do"*, P3) and batch multiple tasks into a single car trip (e.g., "*since it's hot, we just try to hit all three stores in one day"*, P3).

Leaving the city: Finally, all participants escape the heat by leaving Phoenix for at least some part of the summer. Trips range from weekend get-aways to Flagstaff (a cooler city in Northern Arizona), to longer-term vacations in the Pacific Northwest or the East Coast.

It's just like a great burden's been lifted off your mind when you get the temps that aren't destroying you as soon as you walk out every single day. -P6

Adapting to the eat

When staying indoors or traveling is not an option, participants employ various adaptations to the environment: hydration, clothing, shade, and productively utilizing heat.

Hydration: Participants emphasized hydration as the most important strategy for coping with exposure to heat. All participants travel with a water bottle and many rely on different types of reminders to drink water (e.g., " *I do have to remind myself, 'cause I feel like even as much water as I'm drinking it's still not enough"*, P7). Given the predominantly warm tap water, some participants refill their bottles with cold water in restaurants, or refrigerate or freeze their water containers at home.

Clothing: All participants rely on protective clothing to shield from the sun. Examples range from sunglasses and hats (all participants), to long-sleeve shirts purchased at thrift stores (P1), shoes that insulate from the hot cement (P4), sunsleeves (P6, P1), and UPF clothing (P5).

I'll apply sunscreen but it seems to quickly wear off of me and I have to reapply it, and I never remember, so I've decided that physical barrier is probably the best bet. -P5

In addition, participants often apply cold water to various articles of their clothing—bandanas, shirts, helmets—to cool off.

Shade: In addition to clothing, all participants seek shade as a coping strategy. For example, P1 uses an umbrella for longer walks, P7 cools off in a walkway shaded by a bridge, while P3 enjoys shaded patios.

I stood there waiting for the train. That was just one of those hot days, there's no shade or anything like that so I was just standing in the sun and that was probably one of the most acute heat experiences I think of the entire summer. -P5

Productively utilizing heat: Finally, participants discussed ways to utilize the heat for productive purposes. Air drying clothes outside was the most common practice (P5, P1, P2, P3, P5), followed by gardening desert-tolerant plants (P3, P7). Participants also commented on the longevity of materials and products as afforded by hot, dry climates, including longer-lasting roads, and less rust on cars and bicycles (P1, P6). In addition, participants speculated on ways they could use thermal energy in the future, ranging from thermal cooking (P5), solar-powered electricity in the home (P1), a backyard food dehydrator (P2), buildings that utilize convection cooling (P5), and the use of heat to grow plants to create shade (P3).

In summary, this section described the mechanisms by which participants cope with extreme heat, ranging from ways of minimizing exposure to strategies for adapting to the temperatures.

Barriers for coping

This section details three types of barriers that participants identified as hindering their ability to cope with extreme heat.

Money: All participants noted the financial challenges associated with staying cool over the summer. These range from the cost of air conditioning (e.g., *"we basically bleed money trying to keep our house cool"*, P2), to the price of protective clothing ("*It's hard to find proper clothing to deal with heat and for it to be cheap"*, P5), or the expense of travel to leave the city ("*cause you have to have money to do all those things"*, P6).

I think that there's definitely a socio-economic issue with dealing with heat because it's much—and AC, AC is expensive. There are those kind of aspects that you need to pay to remain cooler. You need to pay something and it's very tricky. P5

Figure 2. Visualizing extreme heat: screenprinting with thermo-chromic ink and a paint-based heat visualization

In addition to the costs of coping with heat as discussed by P5, summers also hurt the job market, as noted by P7:

Everything shuts down here. She [niece from out of town] would be competing with my 35-, 40-year-old friends for jobs because they lose jobs in the summer. It's very bad for people in the service industry here. P7

Public awareness: In addition to the expenses associated with staying cool, participants also noted lack of public awareness about the environment as a barrier for coping.

I think that a lot of the problems with the environment that we've had here is from people coming in from outside and they want to have what they have in other places. They've got the grass they're watering. They're building lakes and ponds. I think it's completely changed the environment in the past 20 years because of that. -P7

Infrastructure: Finally, participants cited several ways that urban planning could improve coping capacity: more public water fountains (e.g., "*more available water at trailheads*", P5), better shading at bus stops (e .g., "*a trellis with some vines on it. It's gonna create some shade in the summertime*", P3), or more desert-appropriate landscaping with native plants that use less water (all participants). Nearly all participants also commented on the growing population and urban development in Phoenix as a contributing factor to the heat:

I definitely think it's more people, more development. I don't know if there's more freeways, but I think it's a combination of the environment and just the buildup of civilization here. -P2

Like most of the other participants, here P2 suggests that the influx of people and the resulting development may have exacerbated the area's trend towards hotter weather. To summarize, this section discussed money, awareness, and infrastructure as factors that potentially hinder participants' (and other residents') ability to cope with extreme heat.

Adaptation as a Theme for Design

While some of the behaviors unearthed in the diary study are not surprising (e.g., staying indoors or leaving the city during summer months), our study also revealed unexpected ways that extreme heat impacted the participants and inspired creative workarounds. We found, for instance, that heat presented unique physical constraints (e.g., anticipating when everyday materials would be too hot to touch; re-routing commute to access cold water or shade); as well as psychological effects that led participants to change their eating habits, schedules, and social interactions. Understanding how people cope with and adapt to extreme heat—from the mundane to the extraordinary behaviors— is a critical first step towards designing for this space.

Above all, our findings present clear opportunities to design for adaptation. Environmental science literature has highlighted adaptation as a viable strategy for addressing climate change [2, 12, 19]. The theme of adaptation seeded our critical making work and the resulting artifacts span three categories: 1) visualizing, 2) coping with, and 3) utilizing extreme heat. Drawing on critical making literature [18, 20], we continue by reflecting on the insights uncovered during our materially-oriented work.

Visualizing Extreme Heat

Our first materially-oriented exploration is inspired by the subset of our diary study findings that reveal many day-to-day challenges presented by extreme heat. The findings reveal that participants face interactions with warm tap water and uncomfortably hot materials (e.g., maneuvering around the black seatbelt and steering wheel of a hot car), and experience adverse effects on their appetites, moods, social lives, and in many cases, personal health. These rich experiences are hard to communicate using quantitative metrics or digital sensors, and in our maker sessions, we wanted to investigate how extreme heat might be visualized beyond numeric data. We focused on screenprinting with thermochromic and UV- sensitive inks to creatively express heat and UV exposure.

Screenprinting is a flexible technique for replicating stencil-based images across a variety of mediums—paper, fabric, plastic, wood, etc. When coupled with inks that change color based on temperature or UV levels, the versatility of screenprinting makes it an ideal method to visualize temperatures of everyday materials or UV radiation in outdoor spaces. We worked with thermochromic pigments [24]— colored powders that become translucent at particular temperatures (86F in the pigments we worked with), and solar drops [ibid], which conversely change from being translucent to an opaque color in the presence of UV radiation. Our final ratios consist of: 2 teaspoons of transparent extender base [26] and 40-60 solar drops for the UV-sensitive inks; and 1 tablespoon of opaque screenprinting ink with 2.5 teaspoons of thermochromic pigment for the heat-sensitive ink.

Low-cost UV and thermal sensing: Inspired by earlier artistic uses of thermochromic paints [e.g., 11], we developed two concept ideas for our screenprinting inks. The first is a UV exposure indicator, printed on a vinyl sticker and placed outdoors to warn passerbys when sun protection is necessary. This idea is informed by the fact that all of our participants rely on UV-protective clothing, while non-natives to the region have been known to underestimate the effects of the sun. Our second concept is a printed "thermometer" which can be visualize when materials or objects become uncomfortably hot (Fig. 2). This idea has a variety of practical applications as inspired by our field data—e.g., showing whether the pavement is safe for pets, or when surfaces such as public benches or playgrounds are too hot to touch.

Figure 3. Coping with extreme heat: Phoenix survival guide cover and Hazards section

Reflection: Our engagement with temperature and UV-sensitive screenprinting inks led us to imagine how emergent technologies might draw attention to the problem of extreme heat more broadly. For instance, low-cost, printed indicators might be coupled with image processing on mobile phone cameras to infer and monitor local temperatures on a scale that is not feasible with specialized digital sensors.

Coping with Extreme Heat

Our participants cited a range of coping strategies to stay cool—from wearing protective clothing to altering commute to access shade and cold water. At the same time, they also discussed a general lack of public awareness about the dangers of and coping strategies for extreme heat. Inspired by these findings, our second set of artifacts explores how design might enhance local coping capacity and fill gaps in public knowledge.

Solar powered chiller: We wanted to examine how design might address the lack of portable cooling in extremely hot climates. Using Amontons' Law of Pressure-Temperature (the pressure of a gas at fixed volume is directly proportional to the gas's absolute temperature), we developed a prototype consisting of a DC air compressor connected to a copper tube that is sealed with an end valve. The air compressor, which can be powered by a solar battery, pumps air into the copper tube. Once a desired pressure is reached, the end valve is used to rapidly release the air, thereby decreasing the pressure and resulting in a temperature drop. In our initial tests, we submerged the copper tube into 750ml of water, and effectively reduced its temperature by 4F.

Heat survival guide: In parallel, we examined how design can reconcile the gap in public knowledge and share the insights embedded in the native or street-educated culture of Phoenix. "Phoenix, a survivor's guide" is designed to provide local knowledge and resources to the uninitiated in surviving the extremes of the desert climate (Fig. 3). The survival guide is intended as a low-cost, DIY style, self-printed zine to be distributed amongst vulnerable populations.

Figure 4. Utilizing extreme heat: solar cooker made from repurposed materials and hot composter deployed outside

Structured with minimal text and bold graphics and photos, the design suggests the importance of observing one's surroundings for the abundance of resources available to any engaged citizen. The content draws on additional field visits to two homeless shelters, a conversation with a homeless family, and photographs of municipal resources available within the Phoenix metropolitan area. Information is structured in order of importance: Hazards, Water, Food, Shelter, and Transportation.

Reflection: Developing these prototypes led us to more deeply engage with the coping strategies employed by our participants as well as the challenges for disseminating this local knowledge. Constructing the chiller sensitized us to the difficulties of accessing cold water in extremely hot climates. At the same time, the construction of this artifact materializes future possibilities, whereby design can intervene and enhance coping capacity through portable cooling. The survival guide led us to more broadly consider how coping techniques might be annotated and shared. This approach could also scaffold social networks aimed at not only disseminating practical information, but also enhancing community members' social wellbeing. With participants' moods and social lives being negatively affected by extreme heat, these sharing mechanisms might provide psychological support amongst community members.

Utilizing Extreme Heat

Despite the many challenges presented by extreme heat, our participants also identified numerous ways for creatively and productively harnessing thermal energy. Our final set of prototypes more broadly examines how extreme heat can be harnessed to improve people's lives. Inspired by the fact that extreme heat impacts food and cooking habits, especially given participants' reluctance to use the stove over the summer, we constructed artifacts for solar cooking and heat composting.

Low-cost solar cooking: While there is no shortage of available solar cooking designs [e.g., 25], we aimed to 1) use only simple household or repurposed materials; 2) develop easy and fast assembly methods; and 3) cook real food to validate our designs. We experimented with several set-ups, including a modified ten-inch can; a box lined with mirrors; and a cone cooker made from a car windshield insulator. The designs were tested in the winter, with outside temperatures of 62F, and resulted in food temperatures of about 115F. The set-ups were used to heat up a layer of precooked rice, chopped tomatoes, corn, and cheese, which was uniformly melted in each of the cookers. Working and cooking with these simplistic designs in the winter led us to envision the feasibility of summer-time solar cooking, when outdoor temperatures would be 40F higher.

Hot composting: In parallel, we explored hot or "Berkley" composting, a method that relies on a high temperature and moisture level to rapidly break down organic matter in the course of several weeks [17]. The process is catalyzed by a ratio of 1 part nitrogen to 3 parts carbon in the compost matter, which needs to be "turned" or mixed when the bin's temperature falls below the desired range of 130-150F. We prototyped a sensor-enabled hot compost bin: A wooden box with mesh-covered holes for ventilation, and a thermocouple and a soil moisture sensor routed inside. Data from the sensor is processed by the Arduino micro-controller (Fig. 4). A display mounted on the lid shows current temperature and indicates when the contents should be turned or watered. The system is powered by a solar panel, with all electronics encased in a waterproof acrylic box. Moving forward, our prototype could be coupled with an information guide such that it could be assembled and used by non-experts.

Reflection: Harnessing heat with our artifacts led us to think more broadly about inverting some of the heat-related challenges into opportunities: e.g., utilizing heat to cook meals, compost waste, dry clothes, cultivate plants, dehydrate food, or extend the lifespan of products such as cars or bicycles with less exposure to road salt or humidity. Practically speaking, harnessing thermal energy in these ways could help alleviate some of the financial challenges that were revealed in our study. More importantly, these approaches could build communities around an optimistic and resilient view of extreme heat.

Discussion and Implications

Our diary study of participants' lives in one of the hottest cities on earth reveals extreme heat's broad impact on human lives. To adapt, participants alter their routines and travel to minimize outdoor exposure to extreme heat, and keep track of hydration, switch to protective clothing, seek shade, and find ways to utilize heat for productive purposes. These coping mechanisms, which are sometimes hindered by infrastructure and lack of money or public awareness, suggest adaptation as a viable design strategy to support community resilience.

Supporting Bottom-Up Adaptation Through Design

We see adaptation as a complimentary trajectory for sustainable HCI, much of which tends to focus on mitigating environmental impact [7, 13]. As we noted earlier, there is an urgency to consider adaptation in addition to mitigation to support community resilience in the face of climate change, even if global trends stabilize [2, 12]. The second part of this paper thus set out to concretely identify design opportunities by making and reflecting on artifacts themed around adaptation to extreme heat.

Drawing on insights from our diary study, our artifacts materialize ideas for visualizing, coping with, and utilizing extreme heat. In line with prior literature, whereby researchers' work with physical materials reveals new insights [e.g., 18, 20], making our prototypes enabled us to deeply engage with the heat-related challenges experienced by our participants and imagine solutions rooted in the physical world. For instance: screenprinting with temperature-responsive inks led us to envision how communities might draw attention to thermal infrastructure disparities across neighborhoods; assembling a heat survival guide challenged us to consider broader mechanisms for gathering and sharing local coping knowledge; and our solar cooking and composting applications inspired us to think about productively utilizing heat to improve human lives. While our artifacts are not intended as fully-functional devices per say, the key takeaways could be incorporated into future systems and deployed with stakeholders.

Adapting to What?

While enabling communities to better cope with existing conditions can significantly improve human lives, it is also worth considering what it is that we are trying to adapt to. In our diary study, for instance, the participants understandably adapted to existing infrastructures (e.g., unshaded roads; meals and social interactions scheduled around the corporate 9-5 workday, etc.). Participants' coping strategies, and the artifacts we created, necessitate a reflection on the broader systems that transpired these challenges: the car-centric southwestern culture, or broader yet, the existence of Phoenix, originally a mining town, as a large dessert metropolis in the post-industrial era. Notwithstanding the obvious drawbacks of focusing on adaption alone (e.g., accepting the status quo), there are real dangers in framing adaptation discourse around "sustaining the unsustainable" [23]. Moving forward, we see adaptation as merely a part of the solution, with future systems taking on hybrid and systemic approaches.

Hybrid mitigation-adaptation approaches: The diary study reveals several grounded examples whereby participants' coping strategies also minimize their impact on the environment. For example, air-drying clothes utilizes heat and reduces electric power consumption; insulating homes (e.g., covering windows) lowers indoor temperatures and improves energy efficiency. Some of our designed artifacts also reflect these ideas: a solar cooker utilizes heat while minimizing fuel and electricity consumption; like-wise, a hot composter takes advantage of environmental conditions to convert waste into a useful material. Practically speaking, new systems can facilitate other adaptation-mitigation behaviors: e.g., solar dehydrating to preserve food; or harvesting heat-loving plants to create shade and improve efficiency of air-conditioned spaces. On a higher level, hybrid systems could reframe routine household activities to utilize thermal energy while reducing human impact on the environment.

Conclusion

Motivated by climate change projections that suggest increasing temperatures over the next few decades, our work aimed to understand how design could support bottom-up adaptation to extreme heat. Our diary study revealed the human challenges and workarounds for living in an extremely hot environment. These findings served as prompts for critical making and reflection on junctures where design can intervene. Above all, we hope that our work energizes the ISEA research community around design that both mitigates our impact on and helps us adapt to the environment.

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