

# HUE

HEALTHY URBAN ENVIRONMENTS INITIATIVE



## FINAL REPORT

MARICOPA  
COUNTY



**ASU** Global Institute of  
Sustainability and Innovation  
Arizona State University

Healthy Urban Environments Initiative



This report highlights Healthy Urban Environments (HUE), a 4-year initiative (01/2019-12/2022) that supported thirty-three solutions-oriented, community-engaged projects using innovative approaches and partnerships to address issues of heat and air quality across Maricopa County.

### Lead Authors

Matthew Fraser, HUE Co-Director  
Charles Redman, HUE Co-Director  
Melissa Guardaro, HUE Assistant Research Professor  
Rachel Braun, HUE Postdoctoral Researcher  
Angela Grobstein, HUE Senior Project Manager

### Acknowledgements

The success of the Healthy Urban Environment initiative is based on broad participation and contributions from a range of participants. Most importantly, HUE acknowledges the generous financial support of the Maricopa County Industrial Development Authority (MCIDA) through Award #AWD00033817 and the guidance from MCIDA Executive Director Shelby Scharbach and MCIDA Business Development Officer Gregg Ghelfi. We acknowledge the vision of ASU President Michael Crow for convening key stakeholders to address the important challenges of urban heat and air quality in Maricopa County and the gracious assistance of ASU Associate Vice President Kristin Irwin in implementing our solutions center. In the next pages, we recognize the HUE leadership, the HUE project leads (who also contributed to this report), the other ASU contributing researchers, the external contributing researchers and HUE participating partners. Without the commitment, expertise and contributions from these individuals and organizations, HUE would not have been able to fulfill our charge to develop, demonstrate and deploy solutions that mitigate heat and improve air quality in Maricopa County, advance workforce development for future generations of Maricopa County residents, and translate solutions to heat and air quality a range of decision tools.

### Contact

A digital version of this report, as well as resources for the HUE-funded projects, can be found by scanning the below QR code or clicking the following link to the [HUE website](#).



Email: [hue.solutions@asu.edu](mailto:hue.solutions@asu.edu)

Healthy Urban Environments (HUE)  
Global Institute of Sustainability  
and Innovation  
Arizona State University  
P.O. Box 877904  
Tempe, AZ 85287-7904  
<https://sustainability-innovation.asu.edu/hue>

*Report Prepared: Spring 2023*



## HUE Contributors

### Leadership Team

#### Arizona State University

Charles Redman, *School of Sustainability*  
 Matthew Fraser, *School of Sustainable Engineering and the Built Environment*  
 Melissa Guardaro, *Global Institute of Sustainability and Innovation; Knowledge Exchange for Resilience*  
 Rachel Braun, *Global Institute of Sustainability and Innovation*  
 Angela Grobstein, *Global Institute of Sustainability and Innovation*

### Project Leads

#### Academic

#### Arizona State University

Anne Reichman, *Sustainable Cities Network*  
 Ariane Middel, *School of Arts, Media and Engineering*  
 Chingwen Cheng, *The Design School*  
 David Sailor, *School of Geographical Sciences and Urban Planning*  
 Deborah Salon, *School of Geographical Sciences and Urban Planning*  
 Hanna Breetz, *School of Sustainability*  
 Jennifer Vanos, *School of Sustainability*  
 Kamil Kaloush, *School of Sustainable Engineering and the Built Environment*  
 Katja Brundiens, *School of Sustainability*  
 Liza Kurtz, *Morrison Institute for Public Policy (formerly PhD Student in Global Health)*  
 Liza Oz-Golden, *Global Institute of Sustainability and Innovation*  
 Marta Berbés-Blázquez, *School for the Future of Innovation in Society, ASU (currently at University of Waterloo)*  
 Nathan Parker, *School of Sustainability*  
 Paul Coseo, *The Design School*  
 Pierre Herckes, *School of Molecular Sciences*  
 Ray Quay, *Decision Center for a Desert City*

#### K-12

Rachna Nath, *Arizona College Prep*

#### City/Government

David Hondula, *Heat Response and Mitigation, City of Phoenix; School of Geographical Sciences and Urban Planning, ASU*  
 Braden Kay, *Office of Sustainability & Resilience, City of Tempe*  
 Vjollca Berisha, *Maricopa County Department of Public Health*

#### Non-Profits

Emma Viera, *Unlimited Potential*

### Organizations

#### Academic

Arizona College Prep  
 ASU Landscape Construction III (class of 2021/2022)  
 Augustus Shaw Montessori  
 BASIS Charter Schools  
 Chandler Unified School District  
 Central Arizona-Phoenix Long-Term Ecological Research (CAP LTER)\*  
 Decision Center for a Desert City (DCDC)\*  
 Decision Theater\*  
 Desert Garden Montessori  
 Emerson Elementary School  
 Knowledge Exchange for Resilience (KER)\*  
 Paideia Academies  
 Sunland Elementary School  
 Sustainable Cities Network (SCN)\*  
 Tempe School District 3  
 Urban Climate Research Center (UCRC)\*

#### City/Government

Arizona Department of Environmental Quality (ADEQ)  
 Arizona Department of Health Services  
 City of Avondale  
 City of Chandler  
 City of Phoenix (Offices: Environmental Programs, Heat Response & Mitigation; Departments: Housing, Human Resources, Parks & Recreation, Street Transportation)  
 City of Scottsdale  
 City of Tempe (Office of Sustainability & Resilience, Human Resources Department)  
 Environmental Protection Agency (EPA)  
 Maricopa County Department of Public Health (MCDPH), Office of Nutrition and Active Living  
 Maricopa County Facilities Management Department  
 Salt River Landfill  
 United States Department of Agriculture (USDA)

#### Community-Based Organizations

Arizona Association of Manufactured Home & RV Owners (AAMHO)  
 CHISPA AZ  
 Foundation for Senior Living  
 Iglesia Episcopal de San Pablo  
 Patchwork Community Inclusion  
 Retail, Arts, Innovation, Livability (RAIL) Community Development Corporation (CDC)  
 Unlimited Potential  
 WERK | urban design

#### Corporations

3M Corporation  
 Crafco Inc.  
 Freeport McMoRan  
 GAF Materials Corporation  
 Gavan & Barker  
 Global KAI TEKI Center  
 Republic Services  
 Shade Industries

#### Non-Profits

American Forests  
 Arizona Center for Nature Conservation  
 Arizona Chapter  
 Arizona Sustainability Alliance  
 Healthy Babies Bright Futures  
 Local First Arizona  
 Phoenix Zoo  
 Pinnacle Prevention  
 Salt River Project  
 Trees Matter

\*ASU-based organizations



## Additional HUE Contributors

### Academic

Arizona State University  
College of Health Solutions  
Allison Poulos

Knowledge Exchange for Resilience  
Mary Munoz Encinas  
Patricia Solis

School of Geographical Sciences  
and Urban Planning  
Ashley Broadbent  
Lance Watkins  
Peter Crank (UCRC)  
Rababe Saadaoui  
Sara Meerow

School of Molecular Sciences  
Jesse Molar

School for Computing  
and Augmented Intelligence  
Matthew Huff  
Maya Muir

Global Institute of Sustainability  
and Innovation  
Monique Franco (CAP LTER)

School of Community Resources  
and Development  
Dave White

School of Life Sciences  
Mandy Kuhn  
Nancy Grimm

Watts College of Public Service  
and Community Solutions  
Sarah Bassett

College of Integrative Sciences  
and Arts  
Aaron Hess

Mary Lou Fulton Teachers  
College  
Steve Zuiker

School of Human Evolution  
and Social Change  
Paul Chakalian

School of Sustainable Engineering  
and the Built Environment  
Carlos Obando  
Jolina Karam  
Jose Medina

The Design School  
Alexandro Medina  
Allyce Hargrove  
Die "Kristen" Hu  
Kristian Kelley  
Jillian Edmonson  
Michael Mohr

School of Sustainability  
Adora Shortridge  
Andrea Córdova Cruzatty  
Grace Logan  
Florian Schneider  
Deepti Paul  
Janna Goebel

University of Arizona  
School of Landscape  
Architecture and Planning  
Ladd Keith

### K-12

Paideia Academies  
Alan Chamber  
Brian Winsor  
Victoria Garrison

BASIS Charter Schools  
Jershon Eagar

Arizona College Prep  
Abraham Troop  
Alex Kroumov  
Ashley Yang  
Daniel Wu  
Diya Nath  
Jacob Kaufman-Warner  
Kaitlyn Lai  
Nealin Banerjee  
Omina Nematova  
Sohani Sandhu  
Xieshi Zhang

### City/Government

AZ Department of Environmental  
Quality  
Amanda Luecker

AZ Department of Health Services  
Matthew Roach  
Carmen Tirdea

City of Chandler  
John Owens

City of Phoenix  
Mark Hartman  
Michael Hammett  
Mary Wright

City of Tempe  
Bonnie Richardson  
Robert Yabes

Maricopa County Facilities  
Management Department  
Chris McAbee

NOAA/National Weather Service -  
Phoenix  
Paul Iñiguez

### Non-Profits

Foundation for Senior Living  
Carrie Smith  
Katie Martin  
Megan Word

Phoenix Zoo  
Joe Wilkes  
Norberto Castro  
Steve Betts

Pinnacle Prevention  
Kenneth Steel

Retail, Arts, Innovation, Livability  
(RAIL) CDC  
Ryan Winkle

The Nature Conservancy  
Maggie Messerschmidt

Local First Arizona  
Nick Shivka

Unlimited Potential  
Ana Guzman  
Karla Torres  
Tawsha Trahan

### Community-Based Organizations

CHISPA AZ  
Masavi Perea

Patchwork Community Inclusion  
Agustin (Augie) Gastelum

The Sagrado Galleria  
Sam Gomez  
Selina Martinez

WERK | urban design  
Brian Sager  
Jesse Westad



**CONTENTS**

**1.0 HUE Vision ..... 5**

1.1 HUE Motivation ..... 5

1.2 HUE Objectives ..... 6

**2.0 HUE Action ..... 7**

2.1 Community Building ..... 7

    Southside Mesa Resilience Hubs ..... 7

    Making Visible the Invisible ..... 8

    Engaging Community Members for a Healthy South Phoenix ..... 10

    Mobile Cooling Center ..... 12

    Increased Heat Vulnerability in Mobile Homes ..... 13

    Waking up Wall Street ..... 14

    Heat Mitigation Strategies—Edison Eastlake ..... 16

    Enhancing Children’s Health and Well-Being—Paideia Academies ..... 18

2.2 Networking and Job Training ..... 20

    Arizona Heat Resilience Workgroup ..... 20

    Outdoor Worker Heat Safety ..... 21

    Teleworking for Ozone Reduction ..... 22

2.3 HeatReady ..... 23

    HeatReady Standards for Cities ..... 23

    HeatReady Schools ..... 25

    HeatReady Neighborhoods ..... 27

2.4 Decision Tools ..... 28

    Online Decision-Making Tool for Active Shade Management in the Southwest ..... 28

    Heat and Health Maps for Decision-Making in Tempe ..... 29

    Heat Vulnerability Map & Cool Solutions Webtool with ASU’s Decision Theater ..... 32

    Measuring the Urban Canopy and Cool Corridors ..... 33

    Advancing Decision Support for Tree and Shade Equity ..... 34

    Design Performance Scale-Up Evaluation Tool for Sustainable Business ..... 35

2.5 Monitoring and Future Scenarios as Basis for Solutions ..... 36

    Thermal Assessment of Natural and Engineered Shade in Tempe ..... 36

    Building Targeted Real-Time Warning Systems for Extreme Heat in Households ..... 38

    Crowdsourced Heat and Indoor Air Study ..... 39

    Evaluating Electric Vehicle Adoptions Affect on Air Quality for Low-Income Households ..... 40

    SenseHydro ..... 42

2.6 Materials ..... 43

    Photocatalytic Solar Panels to Control NOx ..... 43

    Benefits and Costs of Reflective Parking Lot Coating for Mitigating Heat ..... 45

    Phoenix Zoo Parking Lots ..... 48

    Sustainable Asphalt Roofing Technology Solution for Heat ..... 50

    Cool Ramadas ..... 52

    ECO PHX Project ..... 54

    Novel Approaches for Dust Control ..... 56

**3.0 HUE Impact ..... 58**

3.1 Community Impact ..... 58

3.2 Institutional Response ..... 59

3.3 HeatReady Cities, Schools, and Neighborhoods ..... 60

3.4 Decision Theater ..... 60

3.5 Infrastructure and Technology ..... 60

3.6 Extreme Heat Toolkits ..... 61

3.7 Media Coverage ..... 65

**4.0 Changing the Narrative to a New Perspective ..... 69**



## 1.0 HUE Vision

As cities across the globe continue to increase in population, concentrating critical infrastructure and financial investments, they become more vulnerable to the effects of extreme weather events that are intensifying due to climate change. In short, urban growth and climate change are on a collision course. Nowhere is this more obvious than in cities in hot, arid climates, where public health, outdoor comfort, and future economic development are being seriously challenged. Accordingly, the Healthy Urban Environments Initiative (HUE) focused on solving local problems, but always with a trajectory toward national and international application.

Arizona State University established HUE as a solutions-focused research, policy, and technology incubator designed to rapidly test, develop, and deploy heat mitigation and air quality improvement strategies and technologies in collaboration with practitioners and community members to create a healthy city and population across Maricopa County. Deploying a regenerative operational model that uses technology and policy outcomes to fertilize future research and development, HUE translated air quality and urban heat-related research into policy action, novel technology, and commercialized intellectual property.

In partnership with Maricopa County and harnessing the tremendous power of ASU's entrepreneurship and innovation infrastructure, HUE accelerated the translation of research from development to deployment, testing, and commercialization of new emission and pollutant control and heat mitigation technology.

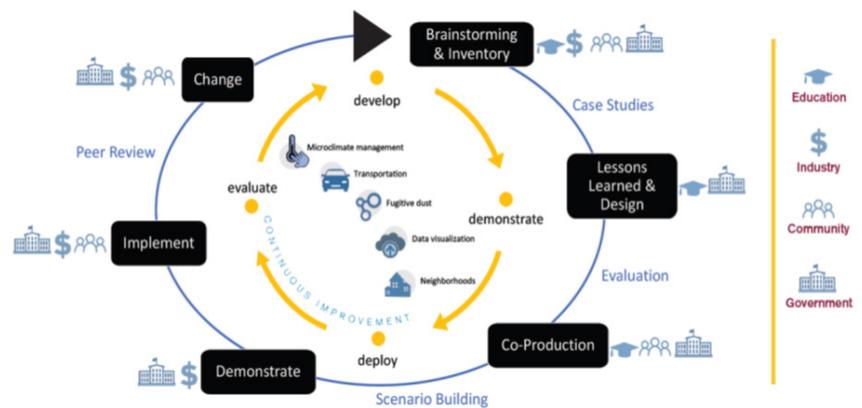
Leveraging ASU's Decision Theater and its suite of state-of-the-art modeling and decision-making tools, HUE researchers promoted a cooler environment throughout Maricopa County by using an integrated development model for strategic planning and growth. By connecting the data and concerns of various sectors of industry—e.g., tourism, agriculture, energy, transportation, and construction—HUE fostered co-creation and decision spaces for key stakeholders and leaders to examine scenarios for future planning and to implement changes with sustainable, measurable impact. Throughout, HUE empowered communities and individuals through awareness-raising and tools for building resilience to heat and air quality hazards.

### 1.1 HUE Motivation

In addition to the HUE Vision, the motivation for a solutions-focused initiative was to help shift the narrative with regard to the trajectory of Maricopa County. External media often portrayed Phoenix as a sprawling urban agglomeration suffering from poor air quality and unbearably hot summers where it is so hot one can fry an egg on the pavement. By developing, demonstrating and documenting solutions to urban heat and air quality, HUE seeks to shift the narrative to highlight how Maricopa County is promoting thermal comfort,

effectively managing air quality, and building collaboration and knowledge sharing between stakeholders. With this, Maricopa County and HUE are leading the way in solving the challenges arising from extreme environmental conditions, climate change and population migration to urban centers in hot, arid regions of the country and around the world.

To produce actionable results focused on solutions (rather than focusing on knowledge generation), HUE efforts included a significant focus on demonstrations, stakeholder engagement and education, and workforce development. HUE is founded on an iterative approach as illustrated in Figure 1, where continuous improvement and co-development of knowledge leverages the knowledge base of local communities, the ability to implement solutions at scale from municipalities and businesses, and the innovation and technology development of our university.



**FIGURE 1**

Translating vision into action.

### 1.2 HUE Objectives

HUE set out with four main objectives, which were all accomplished through various pilot projects undertaken by ASU researchers and local organizations throughout the Valley. Those objectives were to:

- launch a public-private partnership that establishes Phoenix as a model for proactive, evidence-based research in thermal comfort and air quality management
- develop programs that identify individuals, cities, and communities as “resilient” for either heat, air quality, or both
- create a nationally recognized, coordinated research policy and technology incubator with deep connection between users, customers, and businesses to push market transformation
- distribute urban environment “toolkits” that provide strategies to mitigate urban heat and improve air quality

## 2.0 HUE Action

This section provides an overview of the various inter- and transdisciplinary projects that HUE supported (33 total) over its four-year span. Readers will progress through three broad categories: individuals and communities (section headings “Community Building” and “Networking and Job Training”), standards-setting and decision-making (“HeatReady” and “Decision Tools”), and materials and built environments (“Monitoring and Future Scenarios as Basis for Solutions” and “Materials”). The interwoven nature of these categories demonstrates HUE’s recognition of the holistic approach necessary to prepare Maricopa County for today’s climate pressures and those to come. To view more details for each project, please visit the HUE Projects webpage: [sustainability-innovation.asu.edu/hue/projects](https://sustainability-innovation.asu.edu/hue/projects).

### 2.1 Community Building

For neighborhoods to be better connected within and across regions, they must evolve and reflect communities’ functions and needs; these include an efficient design to connect residents to local amenities and transit, less street pavement, landscaping that improves cool landscaping with low water use, and more multiuse, functional features. To accomplish this, HUE researchers worked closely with neighborhood associations, city planners, and residents to analyze interventions and generate substantial design improvements that create the next generation of neighborhoods in arid environments. From Resilience Hubs to naturalized landscapes, from mobile cooling centers to alleyway transformations, HUE explored various ways to improve cooling and thermal comfort across the Valley—and built relationships with and among community members in the process.

#### Southside Mesa Resilience Hubs

HUE researchers co-developed a strategic plan for a necklace of resilience hubs in west Mesa. Most of the time, resilience hubs operate as community centers, but they can spring into action during a disturbance such as a heat wave, power outage, or pandemic. The hubs can also provide centralized recovery resources after a disturbance. With the help of additional funding from the EPA’s Environmental Justice Small Grants program, the project team implemented the demonstration projects recommended in the [Heat Action Planning Guide](#) to assist in increasing thermal comfort for residents while establishing the foundation for resilience hubs in the neighborhood.

Through community meetings, HUE researchers introduced the concept of a resilience hub and discussed neighborhood needs. A series of different engagements—including community meetings at a trusted community space, pláticas (conversations with residents at various popular food vendors), ASU @ Mesa City Center neighborhood council meetings, corridor economic development meetings, and the Better Block Southside Mesa project—helped to establish project goals. The resilience hub project’s overarching goal was to enhance the neighborhood’s economic vitality, to work together on various

#### Key Takeaways

- Heat-vulnerable neighborhoods require place-based, community-led inputs on solutions.
- The development of a resilience hub in Mesa based on community input will help assist with community projects, including heat interventions, while also supporting residents during times of disruption.

**Project Team:**

- *Melissa Guardaro*  
HUE & Knowledge Exchange for Resilience (KER), ASU (Lead)
- *Mary Munoz Encinas*  
HUE, ASU
- *Ryan Winkle*  
Executive Director, RAIL CDC
- *Agustin (Augie) Gastelum*  
Founder, Patchwork Community Inclusion
- *Sarah Bassett*  
Public Service and Community Solutions, ASU

**Key Takeaways**

- Historical environmental injustices shape the distribution of environmental amenities and harms in the City of Phoenix.
- Arts-based approaches can serve to make visible the air pollution affecting communities in the South of Phoenix.
- Visual displays of environmental quality indicators may catalyze community dialogs on social and environmental determinants of health.

community projects (including heat interventions), and to prevent displacement, especially of longtime residents and those whose families have lived in the community for generations.

The strategic plan for a resilience hub in Southside Mesa represents one of the first grassroots-driven resilience hubs in the country. Most importantly, the Southside Mesa resilience hub project will help build community capacity, shift power dynamics, increase the shared health of the community, and provide access to relief services in emergency situations. The pathway to creating a resilience hub is of interest to other groups wishing to establish a mutual aid society in their community and prepare for disruptions. These resilience hubs served as a living laboratory and a pilot project for a network of resilience hubs in Maricopa County.

**Making Visible the Invisible**

Poor air quality is one of the main environmental health concerns affecting residents in South Phoenix. Substantial evidence links marginalized urban areas with high levels of extreme heat and air pollution and negative health outcomes. Relative to the rest of Phoenix, South Phoenix has been and continues to be disproportionately affected by the adverse health effects stemming from a legacy of systemic injustice and segregationist planning and zoning practices.

The motivation behind this project was to create an art installation to display concentration of particulate matter as a way of raising awareness and fostering community conversations to catalyze broader forms of engagement and action around existing and pervasive health inequities. Working with The Sagrado Galleria, an arts-based community organization in South Phoenix, the team constructed and installed a 12-foot obelisk on Central Avenue for all traveling the South-Central corridor to see (Figure 2). Community groups and minority-owned businesses in South Phoenix conceived, designed, and fabricated the obelisk.

As a celebrated artistic and cultural landmark whose mission goes beyond promoting the arts, The Sagrado Galleria was uniquely situated to carry out this project. The Sagrado Galleria functions as a meeting point for artists in the community and is also a sought-after partner in local development projects that center the voices of longtime community residents.

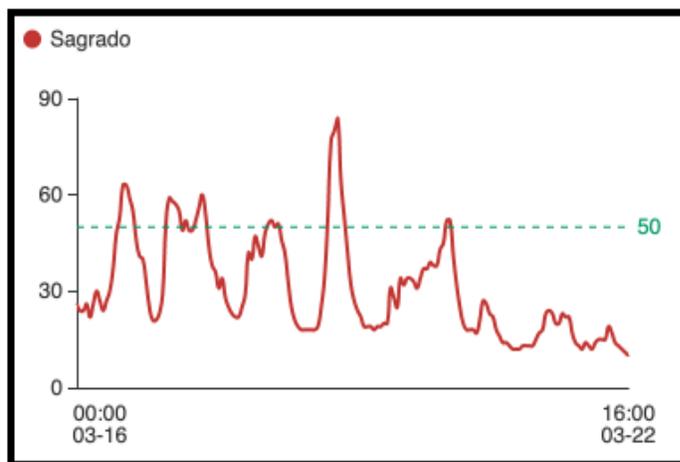
**Project Team:**

- *Marta Berbés-Blázquez\**  
Future of Innovation in Society, ASU (Lead)
- *Grace Logan*  
Sustainability, ASU
- *Sam Gomez*  
Co-founder and Executive Director, The Sagrado Galleria
- *Selina Martinez*  
Design Empowerment Phoenix, The Sagrado Galleria
- *Monique Franco*  
CAP LTER, ASU

**FIGURE 2**

Obelisk placed outside of The Sagrado Galleria to monitor air quality. (Credit: AZ Central)

This project straddles the HUE themes of Demonstration and Education. As a demonstration project, the installation sought to show the value of art as a medium for scientific communication and a catalyst for broader engagement. The insights obtained through the targeted community engagements will inform the design of future environmental art installations around South Phoenix and beyond. As an education project, this installation promoted two-way learning, where researchers better understood community concerns in relation to air pollution, and where residents became more aware of air pollution's impacts and, further, have come to see themselves as agents of change in designing solutions. Finally, because the art installation has its own air quality sensor for particulate matter (PM1, PM2.5, and PM10) and nitrogen dioxide, it feeds data into and becomes part of the [network of sensors](#) that ASU has deployed in South Phoenix, with the guidance of Prof. Jennifer Vanos.

**FIGURE 3**

Sensor reading example (week of 3/22/23).

*\*Currently at the University of Waterloo (School of Planning and Faculty of Environment)*

### Key Takeaways

- There is a need for consistent messaging a variety of touch points and message delivery tactics—more frequent and bite size seems most impactful—to increase understanding and encourage action or change.
- Every community is different; however, trust is something that we all need to work every day to achieve. It is important to listen and act on short-term and long-term goals.

#### Project Team:

- *Emma Viera*  
Executive Director,  
Unlimited Potential  
(Lead)
- *Dr. Ana Guzman*  
Director of Community  
Health, Unlimited  
Potential
- *Juana Silva*  
Lead Community Health  
Worker, Unlimited  
Potential
- *Minerva Velarde*  
Community Organizer,  
Unlimited Potential
- *Karen Anaya*  
Social Media Coordinator,  
Unlimited Potential
- *Tawsha Trahan*  
Director of Environmental  
Justice, Unlimited  
Potential
- *Masavi Perea*  
CHISPA AZ

#### Partner Organizations:

- Maricopa County Health  
Department
- ASU School of  
Sustainability

### Engaging Community Members for a Healthy South Phoenix

In conjunction with ASU and the Maricopa County Department of Health, local nonprofit Unlimited Potential analyzed Maricopa County heat index maps and identified two areas with high heat index, high morbidity, and/or high mortality: Old Town in Avondale and South Phoenix. After identifying these communities, the team conducted a [heat readiness assessment](#) by walking the areas, holding community conversations, and engaging municipalities officials and community partners. The project team used every opportunity to talk with residents about what they need and want to see in their community.

The research team held twenty-seven in-person, one-hour workshops in 2022 in three different cities (Avondale, Phoenix, and Mesa\*). These involved diverse participants (such as high school students, barber shop students, church members, nursing students working in cooling centers, and families and friends at people's homes) and settings (such as in parks and on campus at Unlimited Potential). The team also adopted new approaches to publicizing their work, such as by using social media, resulting in over 100,000 views and 850 shares in 2022. A series of weekly podcasts is in the works, and community health workers have also implemented five-to-ten-minute climate and health sessions during their weekly meetings, which have an average of 50+ people on the line.

Unlimited Potential has incorporated this work into their monthly health fairs and other events that they either host or attend, such as the 2022 Rio Salado community cleanup and booth event and the Phoenix Food Day event (October 22, 2022). They have also distributed over 10,000 pieces of asthma and air pollution information at multiple locations, such as senior centers, health fairs, grocery and other local stores, graduation events, cooling centers, and weekly food distributions.

The team's experience highlighted the need for consistent messaging and the use of a variety of touch points and message delivery tactics — more frequent and bite size seems most impactful — to increase understanding and encourage action or change. Phoenix neighborhoods are incredibly diverse, and this project demonstrates that engaging with each community is vital to understand local resident priorities, establish trust, and ensure effective co-development of solutions. With this engagement, we can raise community awareness of extreme heat and air quality and ensure success through resident involvement.

\*Heat ready assessments were conducted in two of the workshop cities.



**FIGURE 4**

Fred Campbell Park  
101 E. Lawrence Blvd  
Avondale, AZ 85323

### Demonstration Projects

City of Avondale:

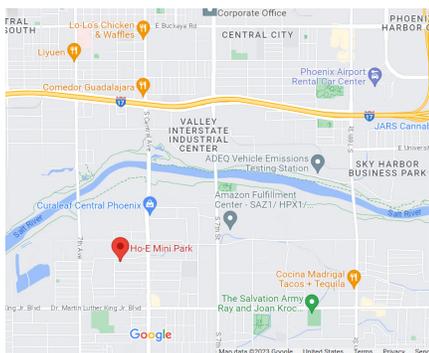
Community members overall reported pride in their city and were primarily interested in improving parks and green spaces where families could gather. After receiving this feedback, community health workers drove through Avondale neighborhoods, selected three parks in need of attention, and presented their findings to the City of Avondale Sustainability Office.

Fred Campbell Park (Figure 4) was selected for improvements. Luckily, the City of Avondale already had 20-30 trees available and agreed to do a community event in November 2022 in conjunction with a tree planting. The community event included a native plant giveaway, music, healthy local food, and a community art project. The local Boys and Girls Club and STAR (Stand Together and Recover) West, whose center backs up to the park, were recruited to help. Members were excited to participate, leading to another event held in February 2023 where the artist presented the work created by the community.

South Phoenix:

Community members' number-one priority was safety; they were mostly concerned about neighborhood blight, poor-quality housing and high costs, unsheltered people, and unresponsive city officials.

Community health workers visited three primary areas of concern (a park; an unkept alleyway near the park; and an old and neglected mobile home park). They selected the park, at 128 West Illini Street (Figure 5), as the area where a project would have the most impact.



**FIGURE 5**

Ho-E Mini Park  
128 W. Illini Street  
Phoenix, AZ 85041  
(Credit: GoogleMaps)

The park is small but well used, particularly by young children. A street on the north side of the park, which partly runs along an industrial area and mobile home park, had become a dumping ground for all sorts of garbage and debris. It was overgrown, unsafe, and unsightly. Children from the mobile home park cross this road to reach the park and, according to community members, the city had not responded to calls to clean the street up.

Unlimited Potential, CHISPA Arizona, community members, and the City of Phoenix Parks and Recreation department collaborated on a cleanup day in September 2022. Participants filled four trailers (plus pickup beds) with trash, debris, weeds, and other materials.

The team established a city contact for additional outreach, should there be more garbage dumping, and is working to create a neighborhood association to adopt the park. Ideally, the existence of an association will improve the chances of securing funding for additional improvements.

HUE researchers also provided resources to community members regarding an existing alleyway program, which offers an opportunity to gate off an alley if 50% of the neighbors agree and offered staff to support outreach efforts if desired.

### Key Takeaways

- People outdoors or in spaces without functioning cooling are very vulnerable to negative health impacts from extreme heat.
- Jenny's Trailer is a green-energy, mobile trailer that travels to where people are, rather than requiring people to travel to where cooling is.
- For more about Jenny's Trailer and its impacts on the community, please visit [tempe.gov/heatrelief](http://tempe.gov/heatrelief).

#### Project Lead:

- *Liza Oz-Golden\**  
HUE, ASU

#### Partner Organization:

- *City of Tempe, Human Resources Department*



**FIGURE 6**  
Jenny's Trailer.

*\*Currently at the City of Phoenix (Planning & Development Department)*

### Mobile Cooling Center

HUE partners at the City of Tempe searched for more innovative solutions for heat relief for the homeless. Tempe already offers heat relief solutions across the city, including heat relief stations located in community centers. Jenny's Trailer, a collaboration project in partnership with Tempe's Homeless Outreach Prevention Effort (HOPE), expanded upon these solutions in novel ways. Jenny's Trailer is a cooling center in a travel trailer.

HUE researchers worked to ensure the trailer design would fulfill the mission to provide a welcoming and sustainable location for unhoused individuals to escape the heat. HUE's former project manager, Liza Oz-Golden, worked with students from ASU's Engineering Projects in Community Service (EPICS) program and City of Tempe staff to create a quality space that people would want to visit. Local solar experts with Sun Valley Solar Solutions ensured that the renewable energy system would be able to keep the space cool during hot summer months without negatively impacting the environment. The City of Tempe—in particular, the Human Services Department—supported the project with homelessness expert knowledge and experience. The department operated the trailer in parks and selected neighborhoods throughout the city.

HUE had two main priorities. The first was to create a mobile cooling center that serves the people where they are and to consider that those experiencing homelessness may have mobility issues and other physical and social barriers that prevent them from accessing municipal services. The trailer has a comfortable and inviting interior and also provides shaded, enjoyable outdoor seating under an awning (Figure 6).

The team's second priority was to create a mobile cooling trailer that does not impact air quality. The cooling center design substituted the polluting generator with a greener solution: solar panels were installed to support the large battery that Sun Valley Solar Solutions had mounted in the trailer. Rewiring of the trailer with the new system thus enabled clean energy for the air conditioning, lights, refrigerator, and awning operations and for expanding the pop-out. Figure 6 illustrates the solar panels on top of the trailer's roof. On a sunny day and with fully charged batteries, the trailer can operate for five to six hours with the support of the solar panels.

The trailer offers air conditioning, Wi-Fi, and cold water. HOPE provided social, housing, and work-related resources, with a goal of visiting with repeat clients and helping to end homelessness in Tempe. The city plans to operate the trailer year-round and use it around neighborhoods and communities that experience power outages.

**Key Takeaways**

- Research from the Maricopa County Department of Public Health (MCDPH) has found that mobile home communities in Maricopa County are disproportionately impacted by extreme heat.
- As part of a project to raise awareness of heat illness, safety tips, and community resources, a [Heat Toolkit](#) developed by MCDPH was distributed to residents of mobile home communities.
- View more about the project, including proposed solutions by the Mobile Home Community on the Maricopa County [Heat Season Solutions and Activities page](#).

**Project Team:**

- *Vjollca Berisha*  
Sr. Epidemiologist, MCDPH (Lead)
- *Gail LaGrander*  
Active Living Specialist, MCDPH
- *Teresa Sosa*  
Salud en Balance Lead, Iglesia Episcopal San Pablo
- *Aaron Gettel*  
Epidemiologist, MCDPH
- *Tony Bishop*  
Epidemiology Data Analyst, MCDPH
- *Emily Walsh*  
Epidemiology Contractor, MCDPH
- *Jessica Whitney*  
Epidemiology Data Analyst, MCDPH
- *Eileen Green*  
President, AAMHO
- *Patricia Solis*  
Executive Director, KER, ASU

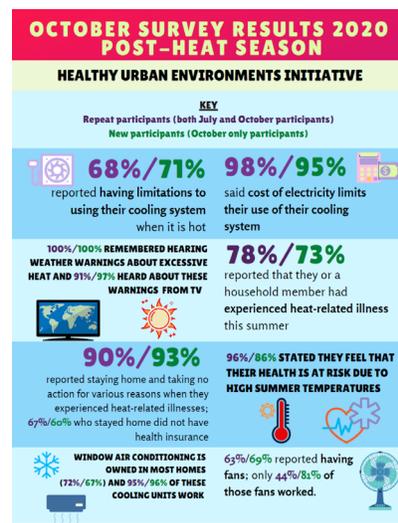
**Increased Heat Vulnerability in Mobile Homes**

Each year, 100 residents of Maricopa County on average die from heat, and more than 1,700 residents suffer heat-associated injuries. Between 2016 and 2020, this average climbed to 207 deaths and 2,000 injuries. Nearly 26% of these heat deaths occur indoors, and 35% of the indoor deaths occur in trailer/RV/mobile homes ([Berisha, 2021](#)). The Greater Phoenix area, in particular, is one of the largest urban areas in the US to experience extreme heat. Mobile home communities are disproportionately impacted; the Maricopa County Department of Public Health sought to discover why this is so.

HUE researchers aimed to reduce the number of heat deaths among residents living in mobile home communities by raising awareness of heat illness/deaths and providing community resources to assist with utility cost and repairs. The specific objective of this project was to capture and identify behavior modification in relation to heat exposure, safety tips, and use of heat resources, as well as to measure the changes that occur throughout the summer.

In 2020, MCDPH and partners initiated an awareness-raising campaign among residents of a selected mobile home community. The campaign distributed a Heat Toolkit that provided information on heat illness, heat safety tips, and community resources.

To learn more about trailer/mobile home residents in relation to extreme heat, HUE researchers designed and implemented a community survey comprising two phases: pre-heat season and post-heat season. Residents who completed the survey did so over the phone with a community health worker. During pre-heat season, residents received resources in the form of a Heat Toolkit. Post-heat season analysis explored whether the Toolkit impacted the residents' heat perception, knowledge, coping mechanisms, barriers to cooling, and knowledge and use of community resources (Figure 7).



**FIGURE 7**  
October 2020 survey results infographic for repeat and new participants.

### Key Takeaways

- Alleyways are underutilized spaces that can be transformed into pedestrian-friendly walkways by addressing concerns such as shading during the day and illumination at night.
- A weeklong demonstration at an alleyway in downtown Chandler provided an opportunity to showcase potential cool corridor transformations and collect community input.
- Practices that can boost community engagement\*: (1) involving different populations (e.g., non-English speakers, minority groups, the elderly); (2) using various modes of outreach (e.g., workshops, email lists, flyers); (3) increasing number of engagement events; (4) incentives to show appreciation; and (5) partnerships with local, community-based organizations.

#### Project Team:

- *Deborah Salon*  
Geographical Sciences  
and Urban Planning, ASU  
(Lead)
- *Rababe Saadaoui*  
Geographical Sciences  
and Urban Planning, ASU
- *Kenneth Steel*  
Pinnacle Prevention
- *John Owens*  
City of Chandler

### Waking up Wall Street

Vibrant alleyways are beneficial to health, community development, and the environment. Transforming dark, unsafe, unattractive, and underutilized alleyways such as Wall Street, an alley in downtown Chandler, into a livable public space presented a unique opportunity for people and businesses to thrive. By encouraging walkability, promoting social interaction, and implementing creative street design elements, the “Waking up Wall Street” project became a true asset to Chandler’s community. This conversion also aligned with the City of Chandler’s goals to enhance its downtown identity and Maricopa County’s efforts to mitigate heat and improve air quality.

To inform and improve the alleyway’s redesign project, a demonstration week (“A Week of Wall Street”) took place from March 17-23, 2022. This mini-transformation event was an opportunity to (1) showcase and test street design ideas, such as temporary shade structures, seating areas, creative spray chalk art, and mural art; (2) foster positive relationships with community members while gathering feedback; and (3) raise awareness about pedestrian-friendly places (Figure 8). Data collection methods included surveys and focus groups, which were conducted online and in person during the event to increase community participation and get feedback from hard-to-reach populations. Overall, about 100 people shared their perceptions of the Wall Street alleyway, assessments of the proposed design elements, and thoughts about how to create pleasant places to walk.



**FIGURE 8**

Photos from the Week of Wall Street event.

Though Wall Street is frequently used to access main streets such as Frye Road and Chicago Street, results showed that Chandler's residents and visitors viewed the alleyways as an unpleasant, unsafe, and uncomfortable place to walk, especially at night and/or during summer months. Factors fueling these perceptions included lack of shade, lack of lighting, and car traffic. Given the region's hot, desert environment, the general public recognized shade as a critical element to create a cooler public area to walk and proposed the addition of natural shade through trees and vegetation and/or shade structures, such as umbrellas and shade sails. In addition, Wall Street's lack of lighting increased perceptions of unsafety and limited the use of the alleyway for recreational purposes. The community suggested that nighttime ground and/or string lighting would be helpful to make the alleyway more dynamic and welcoming. The findings also showed that additional landscape design elements were needed to transform the alleyway into a pedestrian-friendly space. These elements included public water fountains, stamped concrete pathways, street crossings, underground utility lines, and highlighting the city's history and culture through art.

In addition to their valuable input on the Wall Street project, focus group participants shared best practices to boost community engagement (see project's 'Key Takeaways'). These strategies could be applied to future projects in Chandler and other cities for meaningful community engagement.

### Key Takeaways

- Decisions made during the design and construction neighborhoods can have implications for residents' experiences with heat and airflow.
- ASU researchers compared the results of different designs for a neighborhood redevelopment plan in Phoenix to determine how considerations like building height and vegetation placement can affect thermal comfort.
- Best practices for neighborhood design include variable height buildings, consideration of orientation to maximize shade, and strategic use of vegetation to create cool corridors.

#### Project Team:

- *David Sailor*  
*Geographical Sciences and Urban Planning, ASU (Lead)*
- *Peter Crank*  
*Urban Climate Research Center, ASU*

#### Partner Organizations:

- *City of Phoenix, Housing Department*

### Heat Mitigation Strategies—Edison Eastlake

The Edison Eastlake neighborhood is the subject of a substantial public housing redevelopment initiative being led by the City of Phoenix. The neighborhood is part of a HUD \$30 million Choice Neighborhood Community redevelopment effort to revitalize a low-income, distressed neighborhood of 577 old and obsolete public housing units and vacant lots. In partnership with the City of Phoenix Housing Department and other stakeholders, HUE researchers used microscale atmospheric models to evaluate the microclimate implications of various neighborhood redesigns for the Edison Eastlake project. This redevelopment effort incorporated heat mitigation solutions recommended by the Arizona State University team with goals such as reducing heat impacts, and providing cooler pathways to transit nodes. HUE researchers supported these goals by using a combination of in situ measurements and ENVI-met modeling to explore the neighborhood's airflow and heat transfer dynamics across both the baseline and the new proposed redesigns.

This approach enabled practitioners and researchers to better understand various proposed designs' thermal impacts in both space and time in comparison with the existing design. The project team used simulation outputs to engage with local city officials, community members, and other partners and stakeholders (such as The Nature Conservancy) to improve the decision process for this and future development efforts.

The redevelopment project consisted of a neighborhood redesign, including the expansion of Edison Park in the north, the extension of the park along the western edge of the neighborhood, and the deployment of a new neighborhood configuration intended to provide residents with an improved thermal environment.

Simulations were used to (1) simulate the neighborhood in its current configuration, using local observations to validate the model accuracy, and then (2) use the validated model to test various design alternatives, quantifying the impacts of these designs on neighborhood air temperatures and thermal comfort metrics.

Simulation results revealed several best practices with respect to neighborhood design:

- Designs should include a variety of building heights (e.g., 2-4 story) to provide more shade and facilitate vertical air mixing.
- Outdoor courtyards should be oriented to maximize shading by buildings. If north-facing orientation is not possible, artificial shade structures or vegetation should be used
- Vegetation augmentation should focus on use of cool corridors along high pedestrian traffic routes to provide local cooling and shading.

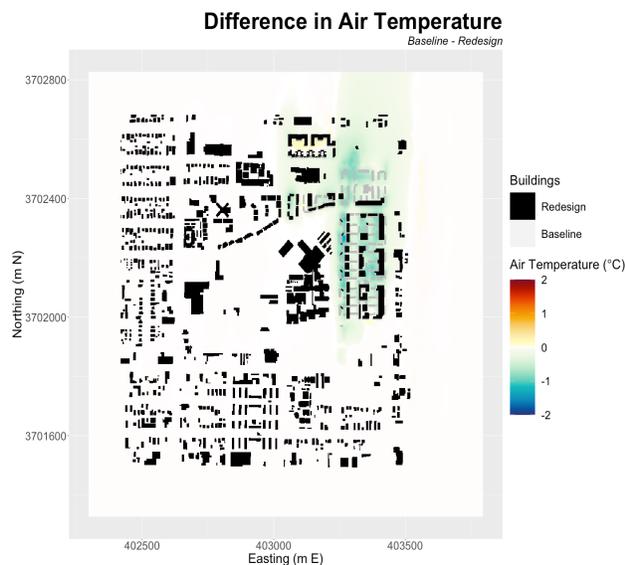
In addition, the simulations found that neighborhood redesign could result in neighborhood-wide cooling on the order of 0.2 °F. However, pockets of cooling as large as 3-4 °F were observed within the vegetated corridor. New construction and exposed units had modest (~ 0.5 °F) warming on the south and east sides. Despite bias errors in the model, the predicted magnitude of changes in temperatures are trustworthy and the evaluated neighborhood redesign shows promise for improving thermal comfort of residents.



**FIGURE 9**  
East Edison Model Domain.



**FIGURE 10**  
Observations in East Edison Lake.



**FIGURE 11**  
Modeled cooling in Edison Eastlake.

**Key Takeaways**

- Outdoor playgrounds provide a valuable environment for children’s learning and play but may not be safe or usable spaces during warm and hot weather due to low shade and minimal vegetation.
- Playground redesign that is focused on shade and nature-based elements (e.g., wood) can protect children from exposure, reduce risk of burns, and increase use of space.
- A playspace redesign using nature-based solutions is currently underway at Paideia Academies, a local school in the Valley.

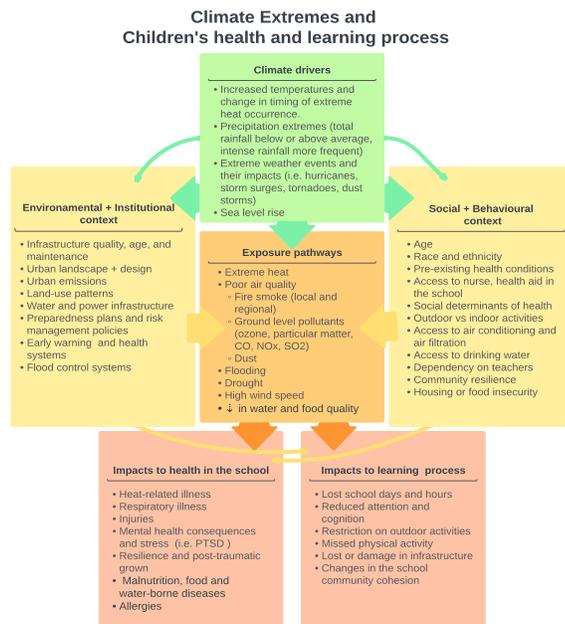
**Project Team:**

- Jennifer Vanos  
*Sustainability, ASU (Lead)*
- Paul Coseo  
*Design, ASU*
- Janna Goebel  
*Sustainability, ASU*
- Steve Zuiker  
*Teachers College, ASU*
- Allison Poulos  
*Health Solutions, ASU*
- Chingwen Cheng  
*Design, ASU*
- Aaron Hess  
*Integrative Sciences and Arts, ASU*
- Brian Winsor  
*Director, Paideia Academies*
- Alan Chambers  
*Outdoor Education Coordinator, Paideia Academies*
- Victoria Garrison  
*Curriculum Director, Paideia Academies*

**Enhancing Children’s Health and Well-Being—Paideia Academies**

In 2019, ASU researchers and Paideia Academies ambitiously set out to address the challenges of schoolyard exposures to heat and air pollution and to manage stormwater through revitalizing their playspaces as natural play and learning environments (see [Paideia Project Roadmap](#)). In 2021, after data collection, co-creation of designs with the community, funding challenges related to COVID-19, and various iterations of plans, the school broke ground to create a natural play and learning environment (NPLE). The schoolyard is now a more naturalized landscape full of compelling, nature-based play and learning opportunities ready to be discovered by children. In these spaces, children are surrounded by hills, gardens, bioswales, native plantings, trees, orchards, climbing vines, rocks, and streams that help them discover nature while they play and build social, cognitive, and motor skills. Importantly, the infrastructure provides abundant shade that grows more each year; hedges for protection from heat, traffic pollution, and noise; and bioswales to manage stormwater runoff from South Mountain. A new school garden sanctuary provides food and additional learning experiences.

These outdoor environments are also part of the school’s environmental and sustainability curriculum. A lot has been learned around long term monitoring that can also be leveraged for learning and adapting plans based on school needs. The greatest impacts have been using environmental data, and analysis from the school, paired with literature and school-based needs, to make decisions around outdoor



**FIGURE 12**  
Climate Extremes and Children’s health and learning process.  
(Credit: Gisel Guzman)



*Partner Organizations:*

- *City of Phoenix, Office of Environmental Programs; Office of Heat Response and Mitigation*
- *Healthy Babies Bright Futures*
- *Trees Matter*
- *Arizona Sustainability Alliance*
- *United States Department of Agriculture (USDA)*
- *Central Arizona-Phoenix Long-Term Ecological Research (CAP LTER)*
- *Environmental Protection Agency (EPA)*

designs and usage that are safe and impactful. MaRTy data, for example, has been helpful in decision making for what activities to organize in different locations at the best time of day. All the various researchers in the project (as well as teachers, maintenance staff, etc.) have learned a lot from each other's methods and ways to enact change. We are continually learning both from the school and from each other. As the school evolves and the designs take fuller effect, we hope to be able to use the real-world evidence to drive more change yet are just waiting patiently as plants grow and we all keep adapting to new changes to heat and air pollution. Further, the data dashboard (coming soon) will allow for more ease of interaction with the data by community members.

Two ASU faculty partners involved with Paideia (Steve Zuiker, Janna Goebel) are also researchers working on a state-wide survey of school garden leaders. Researchers can confidently say that Paideia's garden and wider outdoor infrastructure rank among the top 5% across Arizona school campuses (participating in the survey) based on the characteristics of school gardens reported by over 300 garden leaders across the state. Moreover, Paideia's efforts to comprehensively integrate outdoor opportunities into academic learning via their "Take It Outside" initiative is a force multiplier of the established benefits of outdoor play, outdoor education, and garden-based learning in particular.

Overall, Paideia has provided a prominent example of sustainable infrastructure implementation that yields educational and ecological benefits among complex environmental, social, and infrastructural challenges. We have found overall that students are enjoying the new designs and are more active overall, especially in the back bioswale. This work, which now includes six seasons of student data (spring and fall 2019, 2021, and 2022), has also led to multiple publications, including a new book, "[The Impact of Extreme Weather on School Education: Protecting School Communities](#)," which is forthcoming in Summer 2023. In addition, this project won the [2022 METIS Sustainable Infrastructure Award](#) (in the ecological category), and an [EPA Rainworks Challenge Grant](#). ASU researchers will continue to collaborate with Paideia Academies on long term data collection (to observe changes) and additional drone imagery.

### Key Takeaways

- Various stakeholder organizations, including municipalities and nonprofits, work on issues related to extreme heat in the state of Arizona; coordination and sharing of best practices can help with addressing extreme heat.
- In regular meetings during the summer months, stakeholder organizations shared updates, resources, and new knowledge gained in their work addressing heat-related issues.
- To learn more about this workgroup, view past presentations, and sign up to attend future meetings, please visit the [AZ Heat Resilience Workgroup website](#).

## 2.2 Networking and Job Training

Programming that educates the public, especially the most at risk, on heat-health safety, illness prevention, and extreme-heat preparedness is a common thread in all the funded projects. The HUE team contracted for a worker safety brochure to be developed for widespread dissemination throughout the county in both English and Spanish. HUE researchers explored alternative worker arrangements, such as teleworking, that could reduce air pollution before the pandemic necessitated this shift. And HUE supported a regional, now statewide, heat resilience working group from its inception; the group is now a nationally recognized best practice for working across sectors and silos to manage extreme-heat effects.

### Arizona Heat Resilience Workgroup

Created in the spring of 2020, the Arizona Heat Resilience Workgroup convened stakeholder organizations to monitor National Weather Service forecasts, share best practices for heat mitigation and adaptation, and encourage collaboration and coordination of heat responses and innovations. The group met monthly in cooler months and bimonthly from May through October. A cooling center subgroup focusing on coordination, planning, and strategic placement met monthly. Participants included municipalities, health departments, nonprofits, the faith community, academia, and utility companies.

At each meeting, after the weather forecast, speakers from a range of sectors and professions added to the knowledge base, encouraged sharing ideas within Maricopa County, and captured the attention of federal agencies and other regions tackling heat. Members of this group were part of the NOAA Roundtable on heat resilience in the US Southwest, informing policy and sharing the region's innovative work. Members were also involved in the Phoenix Extreme Heat Tabletop Exercises, hosted by NOAA, to identify critical gaps in response to extreme heat, with an emphasis on improving outcomes for the most at-risk groups and to prioritize short- and long-term solutions at various scales.

#### *Workgroup Steering Committee:*

- *Melissa Guardaro*  
*HUE & KER, ASU*
- *Anne Reichman*  
*Director of SCN & Project Cities, ASU*
- *Mary Wright*  
*Office of Heat Response and Mitigation, City of Phoenix*
- *David Hondula*  
*Director of Heat Response and Mitigation, City of Phoenix;*  
*Geographical Sciences and Urban Planning, ASU*
- *Paul Iñiguez*  
*Science Operations Officer, NOAA/*  
*National Weather Service - Phoenix, AZ*
- *Braden Kay*  
*Office of Sustainability & Resilience Director, City of Tempe*
- *Ladd Keith*  
*Landscape Architecture & Planning, University of Arizona*

**Key Takeaways**

- A wide variety of job types can expose workers to heat, including delivery drivers who are constantly moving between their vehicles and delivery locations.
- HUE developed brochures and accompanying websites, in English ([brochure](#) and [website](#)) and Spanish ([brochure](#) and [website](#)), to provide resources and tips for staying safe while working in the heat.

*Project Lead:*

- **Liza Kurtz\***  
Global Health, ASU  
(Graduate Student)

**Outdoor Worker Heat Safety**

A wide variety of workers are exposed to heat; beyond the commonly thought of outdoor workers – construction, landscape, and farm workers, for example – are delivery drivers and warehouse workers. Based upon a review of heat-health informational materials, HUE researchers developed brochures in English and Spanish, along with an accompanying website, to provide resources and tips for staying safe while working in the heat.

**Self checkup**  
Staying hydrated by drinking water is a critical part of staying safe in the heat. One easy way to monitor your hydration is by checking the color of your urine when you pee. While or light yellow urine shows hydration, while darker yellow means you need to hydrate.  
Use this **urine color chart** to assess if you're drinking enough fluids to stay hydrated.

**Hydrated**  
If your urine matches these colors, you are hydrated.

**Dehydrated**  
If your urine matches these colors, you are dehydrated and need to drink more fluids.

**Severely Dehydrated**  
If your urine matches these colors, you should consult a doctor immediately!

Precaution: Certain medicines and vitamin supplements may change the color of your urine. The colors in this chart should only be used as a guide.

**How hot is too hot?**  
There is no magic number that is "too hot." While it's always a good idea to keep an eye on the temperature, **you are the expert.** If you feel too hot, you are too hot.  
Here are just a few things that could make you hot outdoors or on the job:  
Direct sunlight  
Enclosed spaces  
Pavement

Scan this QR code to view more **tips and tricks.** We also encourage you to add your own by emailing [HUE.Solutions@asu.edu](mailto:HUE.Solutions@asu.edu).

**Staying safe in heat**  
**A guide for workers**  
Stay hydrated  
Cool off often  
Take it slow

For additional resources, visit [adobe.ly/2Z6GQZl](http://adobe.ly/2Z6GQZl), or scan the QR code with your smartphone camera.

**Some of the resources you'll find:**

- Someone is too hot – what do I do?
- Getting and giving tips for beating the heat.
- Free heat safety consultations.
- Learning to work in the heat.
- Work and rest period recommendations.
- Heat safety training and apps.
- Heat safety resources for on the job and at home.
- Reporting unsafe working conditions.

ASU Global Institute of Sustainability and Innovation  
Arizona State University  
Healthy Urban Environments Initiative HUE

HUE is grateful for the support that it has received from the Maricopa County Industrial Development Authority (MCIIDA) Award #AWD0003817.

**What can you do?**  
It's crucial to be proactive about staying cool. Be extra cautious and hydrate and take breaks often throughout the day, even if you don't feel overheated. Staying cool is easier than trying to cool off after you are already too hot.

**Stay hydrated**  
Plenty of water and electrolyte drinks will help replenish salt and water lost while sweating. **Hydrate before you are thirsty.**

**Cool off often**  
Take frequent breaks when it's hot. This means at **least 10 minutes in a cool environment.** An enclosed space without air conditioning like a delivery truck is not enough to cool off.

**Take it slow**  
Human bodies are amazing and can learn to work in the heat – but it takes time. As temperatures rise, **give your body time to get used to the heat.** This means taking more breaks, drinking more water and being more careful than you think you need to be.

**Learn the signs**

**Heat exhaustion**

- Faint or dizzy
- Excessive sweating
- Cool, pale, clammy skin
- Nausea or vomiting
- Rapid, weak pulse
- Muscle cramps

**Heat stroke**

- Throbbing headache
- No sweating
- Body temperature above 103° F/ hot, dry skin
- Nausea or vomiting
- Rapid, strong pulse
- May lose consciousness

If you or someone else has **heat exhaustion**:

- Move to an air-conditioned place.
- Drink water and apply cool water to skin or clothes.
- Tell a supervisor.

If you or someone you are working with has **heat stroke**:

**Call 9-1-1 immediately.**

**Know your risk**  
There are many reasons you might be at greater risk of heat illness:

- Being new to the job.
- Having heart or lung problems.
- Taking common over-the-counter or prescription medications.
- and age are just a few

If you have one or more than one of these risk factors, it's extra important to have a plan to stay cool.

The National Weather Service has developed a tool called **HeatRisk** that helps you understand the temperature forecast and judge your risk.

Learn more at [www.nws.noaa.gov/wh/heatrisk](http://www.nws.noaa.gov/wh/heatrisk) or scan the QR code with your smartphone camera.

The information and resources provided in this pamphlet are not intended or implied to substitute for professional medical advice, diagnosis or treatment.

**FIGURE 13**  
Outdoor Worker Heat Safety Brochure.

\*Currently a Research Analyst at the Morrison Institute for Public Policy, ASU



**Key Takeaways**

- Not only do employers have an interest in teleworking at least some of the time (90% of the workforce survey respondents), but teleworking can help the region meet air quality goals.
- Employers must address significant teleworking barriers, such as impact on advancement, team building, and ease of collaboration.
- Technology-related issues, such as minimum skills required to telework, additional IT support, and space and equipment management, highlight the need for formal trainings and easily accessible resources.
- Equity concerns persist and must be addressed. Moving forward post-pandemic, employers should formalize teleworking eligibility criteria.

*Project Team:*

- *Rebecca Sanders*  
Geographical Sciences and Urban Planning, ASU (Lead)
- *Amanda Luecker*  
Associate Transportation Planner, Arizona Department of Environmental Quality
- *Robert Yabes*  
Principal Planner, City of Tempe

**Teleworking for Ozone Reduction**

“Teleworking” refers to working from a location outside of the main office, whether from a satellite office or from home. It has been promoted as a way to reduce emissions, save employees commuting costs and time, and increase work-life balance. Until recently, teleworking was perceived as a privilege; rarely was it offered across an organization.

Before the COVID-19 pandemic normalized teleworking, HUE researchers explored attitudes and barriers to teleworking among City of Tempe employees. The team’s goal was to develop resource materials for other municipalities wishing to explore teleworking. As the pandemic hit, the project shifted to understanding the evolving experiences of a remote workforce and focused on best practices. While the COVID-19 pandemic created a natural experiment with teleworking, this project revealed weak points in the system that need to be tackled to ensure successful future teleworking efforts.

Final products include one set of reference tips for managers, another for employees, and a generic teleworking assessment tool to help prospective teleworkers think through various aspects of their work and address potential challenges. More and more organizations are offering a teleworking option; this research offers an evidence-based framework to ease the transition to alternative working arrangements.

**Teleworking Tips for Employees**

**TELEWORKING FUNDAMENTALS**  
**Assess whether teleworking is right for you.** Successful teleworkers are:

1. Able to work with minimal direct supervision
2. Organized in their work practices
3. Able to plan for their work (with some managerial input)
4. Able to meet schedules and deadlines
5. Effective with time management
6. Effective communicators
7. Comfortable with technology



Image credit: Valley Metro

**Review your agency’s teleworking policy and related IT policies.** These policies likely include information and guidelines related to:

1. Eligibility,	6. IT support, information security, and data privacy, and
2. Scheduling,	7. Equipment usage and expenses, e.g. for printing access and cost.
3. Timekeeping,	
4. Dos and don’ts of teleworking,	
5. Workspace requirements,	

**Ensure that you have participated in any required teleworking orientations or technology assessments.** For example, you will likely need to be able to perform the following actions to successfully telework:

1. Connect to your agency’s VPN,
2. Open and use your agency’s collaboration software (such as Microsoft Teams),
3. Use your camera and microphone for meetings,
4. Create, accept, and open calendar appointments,
5. Download files from a server or web.

There may be additional position-specific functions that you need to be able to perform; check with your manager to make sure that you know all that will be required of you.

If you have a question that is not answered by your agency’s policy or training, discuss it with your manager and document the discussion in writing.

**FIGURE 14**  
A set of references for teleworking employees.

### 2.3 HeatReady

One of the challenges limiting progress on extreme-heat resilience is the lack of systematic tools, frameworks, and accountability and management structures available to institutions for setting goals and evaluating their progress. Compared to other environmental hazards like air quality and flood control, which are addressed via dedicated regulatory structures and government agencies, heat governance typically happens in a much more ambiguous setting. Progress is primarily realized when governance leaders voluntarily dedicate attention and resources to the problem—an approach at odds with increasing recognition of heat as a major challenge to our health, quality of life, and economic vitality. HUE researchers worked to change this at multiple scales through creating the interlinked HeatReady Standards for Cities, Schools, and Neighborhoods. The combined implementation of these standards amplified efforts to create a healthier, cooler future for Maricopa County.

#### HeatReady Standards for Cities

The goal of creating HeatReady Standards for Cities was to help local governments recognize and accelerate efforts to identify, prepare for, mitigate, track, and respond to urban heat dangers. ASU researchers began developing concepts for HeatReady Standards as early as 2018, in partnership with the City of Phoenix. The HeatReady portfolio of action has engaged more than 75 experts to develop criteria for recognizing and certifying municipal governments' efforts. Local leadership increasingly mentions HeatReady as an aspirational theme of efforts to cool the places where Maricopa County residents live, work, learn, and play and thereby protect residents when hot weather occurs.

HUE researchers, in collaboration with multiple cities in the Southwest, developed and pilot-tested a first tier of HeatReady Standards for Cities during the project period (Figure 15). While the COVID-19 pandemic was a significant interruption to project activities, the research team nevertheless gathered valuable feedback about how to improve the certification process to (1) appropriately balance the administrative burden on city staff completing the application while (2) simultaneously providing a sufficiently rigorous and meaningful tool to compel action. The project team also had productive dialogue with regional leadership from the National Weather Service and other regional and national partners about mechanisms for sharing the standards with a broader audience. The HeatReady Standards for Cities include 21 separate action items across three broad domains: Adaptation Actions (those that help people cope with heat), Mitigation Actions (those that make the city cooler and more comfortable), and Internal Actions (those that support decision-making by city staff) (Figure 16). The HeatReady Standards for Cities framework was used

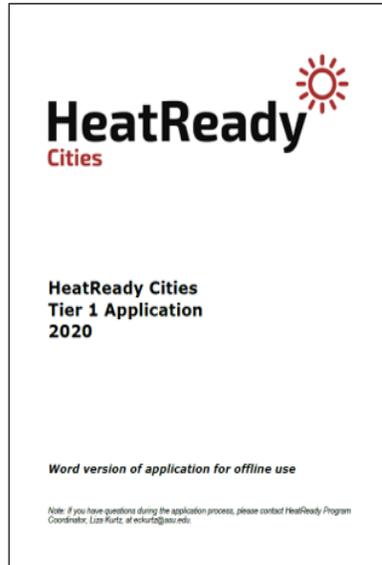
#### Key Takeaways

- Municipalities may not have dedicated policies and frameworks for addressing extreme heat. Heat may affect multiple departments in a municipality but is often not the responsibility of a single department.
- The HeatReady Standards for Cities include action items that help people cope with heat (adaptation), make cities cooler (mitigation), and support city staff in decision-making (internal actions).

**Project Team:**

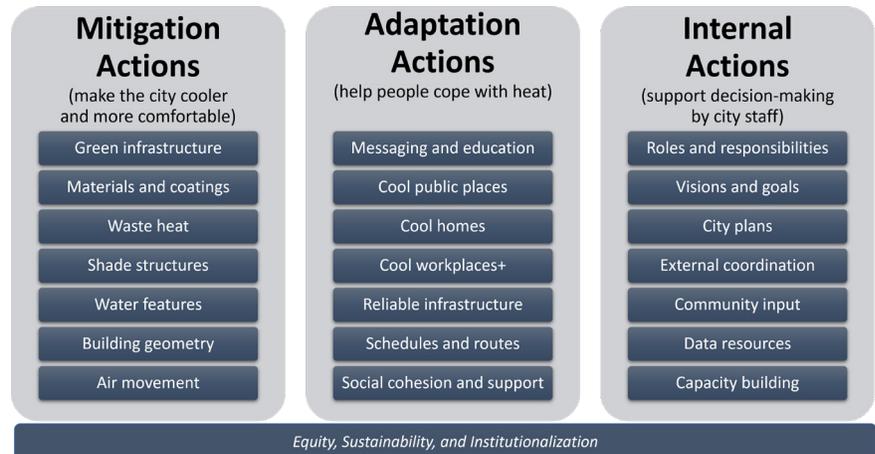
- **David Hondula**  
Director of Heat Response and Mitigation, City of Phoenix; Geographical Sciences and Urban Planning, ASU (Co-Lead)
- **Elizabeth “Liza” Kurtz**  
Public Policy, ASU (Co-Lead)
- **Paul Coseo**  
Design, ASU
- **Ray Quay**  
DCDC, ASU
- **Sara Meerow**  
Geographical Sciences and Urban Planning, ASU
- **Mark Hartman**  
Chief Sustainability Officer, City of Phoenix
- **Michael Hammett**  
Chief Innovation Officer, City of Phoenix
- **Braden Kay**  
Office of Sustainability & Resilience, City of Tempe
- **Paul Iñiguez**  
Science Operations Officer, NOAA/National Weather Service – Phoenix, AZ
- **Paul Chakalian**  
Human Evolution and Social Change, ASU (Graduate Student)
- **Vjollca Berisha**  
Sr. Epidemiologist, MCDPH
- **Matthew Roach**  
Arizona Department of Health Services
- **Maggie Messerschmidt\***  
The Nature Conservancy

by multiple municipalities in Maricopa County to help enhance the heat-related components of the Maricopa County Multi-Jurisdictional Hazard Mitigation Plan in 2021 and is being used operationally by the City of Phoenix’s new Office of Heat Response and Mitigation.



**FIGURE 15**

Cover sheet of Tier 1 Application for HeatReady Cities Certification.



**FIGURE 16**

Conceptual framework for HeatReady Standards for Cities.

\*Currently a Sr. Resilience Consultant at Arup

**Key Takeaways**

- Schools are critical neighborhood places for students, parents, and communities, but heat can negatively impact children’s health and learning.
- Recommendations for creating HeatReady schools were developed with feedback from a group of stakeholders, including school staff, teachers, community health professionals, and parents.
- For more information on the final 30 recommendations for creating HeatReady Schools, please see this article, and for more information about how to become a HeatReady School, please visit the [HeatReady Schools website](#).

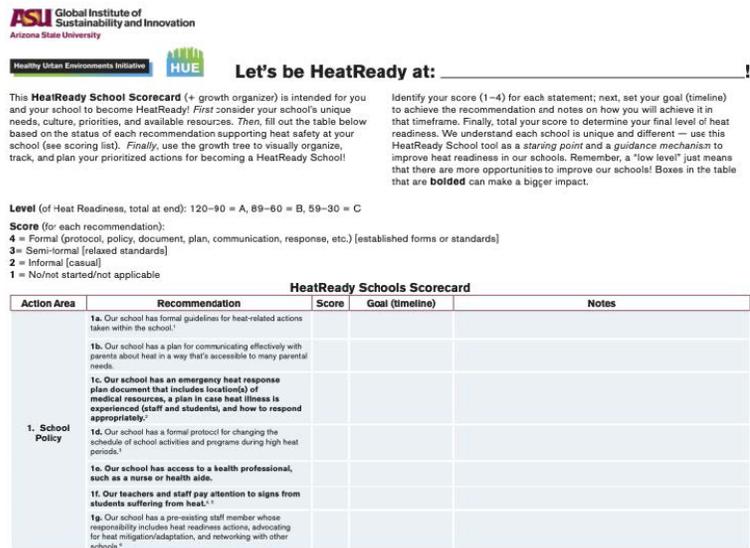
**HeatReady Schools**

Schools are hubs for their surrounding community, connecting parents, teachers, children, and families. School heat conditions, preparedness, and policies thus impact all aspects of the community. However, only minimal attention has thus far been paid to formalizing school heat preparedness to mitigate high temperatures and ensuing health and educational concerns.

With a view to school heat readiness and child heat vulnerability, HUE researchers engaged key stakeholders to understand current heat perceptions, reactions, and actions to gauge the effectiveness of heat preparedness conditions present in Phoenix’s school environments. Key findings highlighted that heat safety resources are available but not fully utilized within schools and that students are negatively impacted by extreme heat, whether direct or indirect, both inside and outside the classroom.

HUE researchers generated a compendium of 30 final recommendations based on five action areas (training, prevention, school policy, community, and environment) that are important in creating a HeatReady School. From these recommendations, they developed resources to guide schools in working toward heat safety, risk management, and adaptive capacity. These include a HeatReady School Scorecard (Figure 17), a [HeatReady Decision-Making Tree](#) and [Basket](#), HeatReady Teacher Training, and a bilingual K-12 Summer Emergency Preparedness Course. An academic paper, “[HeatReady Schools: A Novel Approach to Enhance Adaptive Capacity to Heat Through School Community Experiences, Risks, and Perceptions](#),” published in *Climate Risk Management*, details the methodology for building the HeatReady Schools rubric.

**FIGURE 17**  
HeatReady School Scorecard.



**Project Team:**

- *Jennifer Vanos*  
*Sustainability, ASU (Lead)*
- *Melissa Guardaro*  
*HUE & KER, ASU*
- *Mary Munoz Encinas*  
*HUE, ASU*
- *Adora Shortridge*  
*DCDC, ASU*
- *David Hondula*  
*Heat Response and*  
*Mitigation, City of*  
*Phoenix; Geographical*  
*Sciences and Urban*  
*Planning, ASU*
- *Dave White*  
*Community Resources*  
*and Development, ASU*

**Partner Organizations:**

- *Paideia Academies*
- *Tempe School District 3*
- *Emerson Elementary*  
*School*
- *Sunland Elementary*  
*School*
- *Augustus Shaw*  
*Montessori*
- *Desert Garden Montessori*
- *Trees Matter*
- *City of Phoenix, Office*  
*of Heat Response and*  
*Mitigation*

The HeatReady Schools program built trust and open communication with schools, parents, and community members; helped to identify the school's unique needs; fostered frequent communications and reminders; and identified a HeatReady Champion.

Through this research, we have improved our understanding of how people perceive and react to heat emergencies, as well as what actions are taken at the school level to mitigate their effects. Based on interviews with key stakeholders, we have gauged the effectiveness of existing heat preparedness actions at schools in the Phoenix area. Our thirty final recommendations are providing important "HeatReady" actions that can be applied or adapted for various school contexts and/or climate regions. In 2022, we reached a total of 32 schools and community centers utilizing HeatReady Schools resources, a number that continues to grow. We have also created a HeatReady Schools growth tree and rubric, share numerous resources with our members, and have developed multiple training resources for schools to leverage (e.g., Bilingual K-12 Summer Emergency Preparedness course, HeatReady Teacher Training). These trainings also support work within HeatReady Neighborhoods, within which schools are a critical player for heat readiness. All schools have also received a new "HeatReady Schools Toolkit".

Heat affects school children's health and learning, even though children perceive heat as less severe than adults do. Heat is difficult to manage, and teachers and nurses are already overwhelmed with ongoing school activities—yet simple actions from the HeatReady Schools program, when implemented, protect children from heat, keep them in the classroom, and minimize health issues and losses to learning.

### Key Takeaways

- While extreme heat is present across the Valley, individual neighborhoods have different needs and ideas about what types of heat resilient efforts are most appropriate for their specific location and community.
- Through the HeatReady Neighborhoods project, community members and organizations worked toward developing self-defined strategies for long-term mitigation of heat and extreme heat emergency preparedness in their community.

#### Project Team:

- *Melissa Guardaro*  
HUE & KER, ASU (Lead)
- *Ryan Winkle*  
RAIL CDC
- *Augie Gastelum*  
Patchwork Community Inclusion
- *Mary Munoz Encinas*  
HUE, ASU
- *Adora Shortridge*  
DCDC, ASU
- *Sarah Bassett*  
Public Service and Community Solutions, ASU
- *Jennifer Vanos*  
Sustainability, ASU
- *David Hondula*  
Heat Response and Mitigation, City of Phoenix; Geographical Sciences and Urban Planning, ASU

### HeatReady Neighborhoods

Previous research has carefully identified vulnerable neighborhoods through mapping socioeconomic, health, and landscape-level data to locate extreme-heat problematic locations. Research is limited on how and what type of community-level resilience efforts are most appropriate, especially in under-resourced neighborhoods. The [Nature's Cooling Systems \(NCS\) research](#) highlighted the need for community-based solutions that are contextually and culturally appropriate.

HeatReady Neighborhoods extended upon HUE's HeatReady Cities and HeatReady Schools projects to optimize a community's assets, or "resource shed." A HeatReady Neighborhood is one that is prepared for extreme-heat emergencies and works toward long-term heat mitigation solutions that increase residents' thermal comfort.

The HeatReady Neighborhoods rubric (Figure 18) guided neighborhoods in personal, household, and collective heat emergencies and utilized evidence-based solutions in creating cool zones and pathways in anticipation of a hotter future environment. Using a mixed-method approach, HUE researchers identified the following thematic areas: Equity/Inclusion, Neighborhood Cohesion, Education/Activism, Emergency Preparedness, Physical/Landscape-Level Interventions, and Funding. Each thematic area consists of statements along a good-better-best continuum. The HeatReady Neighborhoods rubric is a comprehensive list of possible interventions from which communities can select priorities under each theme. Becoming a HeatReady Neighborhood is an iterative, evolving, and intersectional process, and it is best for neighborhoods to tackle at least one action item from each category to achieve a balanced and robust program.

The HeatReady Neighborhoods rubric provided a benchmark for communities wishing to infuse cooling strategies at the household and community scales. This new knowledge of what communities wish to see assisted municipalities in formulating neighborhood services plans, heat emergency protocols, and long-term mitigation strategies at the hyperlocal scale. It is important to note that while this project was grassroots driven, the final rubric did not absolve municipalities from offering support and provisioning services. Further, communities that implemented the HeatReady Neighborhoods rubric could use it as a pillar for establishing a local resilience hub and as a leverage point when advocating for heat interventions with cities and philanthropic organizations.



**FIGURE 18**  
HeatReady Neighborhoods cover page.

### Key Takeaways

- Designing urban features to increase shading can help lower experienced temperatures and increase outdoor comfort.
- A simulation tool allows users such as City staff, developers, and the general public in Tempe to model the performance of different types of shading.

## 2.4 Decision Tools

When addressing issues of extreme heat and poor air quality in Maricopa County, stakeholders need to make critical decisions about when, where, and how to address these hazards. Numerous HUE projects sought to improve aspects of this decision-making process so that stakeholders could make informed and effective decisions. These HUE projects led to the development of a new suite of tools that can assist decision-making on various topics, including tree planting and shade installation. Furthermore, these projects and tools can increase communication around heat and air quality hazards by providing a wider audience with the means to explore data and solutions.

### Online Decision-Making Tool for Active Shade Management in the Southwest

Mean Radiant Temperature (MRT), which takes into account shading, heat emitted from surfaces, and air temperature, can be a better indicator of human thermal comfort than air temperature alone. While understanding the impacts of infrastructure on human thermal comfort can help inform the design process, it is not feasible to take direct measurements of MRT for all proposed design ideas. Therefore, ASU researchers are developing an online simulation tool that models the impacts of different designs on MRT and, subsequently, human thermal comfort. Users can pick locations, shade types and size, and ground cover conditions to generate MRT at different times of day and compare to a hypothetical non-shaded location. The tool will allow city planners, architects, and the general public to quickly and easily understand the impacts of proposed designs on human thermal comfort.

#### *Project Team:*

- *Ariane Middel*  
Arts, Media and Engineering, ASU (Co-Lead)
- *Braden Kay*  
Office of Sustainability & Resilience Director, City of Tempe (Co-Lead)
- *Katja Brundiers*  
Sustainability, ASU
- *Paul Coseo*  
Design, ASU
- *Bonnie Richardson*  
Principal Planner, City of Tempe

**Key Takeaways**

- Heat exposure and vulnerability varies spatially within municipalities, thereby creating areas with higher needs for implementing heat-related solutions.
- Heat and health data need to be integrated as early as possible in the planning process and defended with reliable data (both instrument-based and people-based data) through to when planning documents are approved by City Council.
- Providing desk-top ready data to inform decision-making can help to create cooling in areas experiencing the worst impacts of heat exposure, reflecting a city-wide practice of creating equitable urban cooling.

*Project Team:*

- *Braden Kay*  
Office of Sustainability & Resilience Director, City of Tempe (Co-Lead)
- *Paul Coseo*  
Design, ASU (Co-Lead)
- *Katja Brundiers*  
Sustainability, ASU (Co-Lead)

**Heat and Health Maps for Decision-Making in Tempe**

Heat is unevenly distributed throughout neighborhoods in municipalities; likewise, many city departments may not have roles related to heat. Understanding how to connect municipalities with heat-related information and data for the purpose of improving conditions for residents is a step toward creating more livable communities. A partnership project between ASU researchers and the City of Tempe sought to address these issues. The overall goals of the project were to establish a citywide practice of equitable urban cooling while providing desktop-ready data on heat, health, and equity to inform decisions on investing in equitable urban cooling infrastructure. “Equitable urban cooling” means to create the most cooling in those areas that are experiencing the worst impacts of heat and have high levels of vulnerability due to structural inequities and injustices.



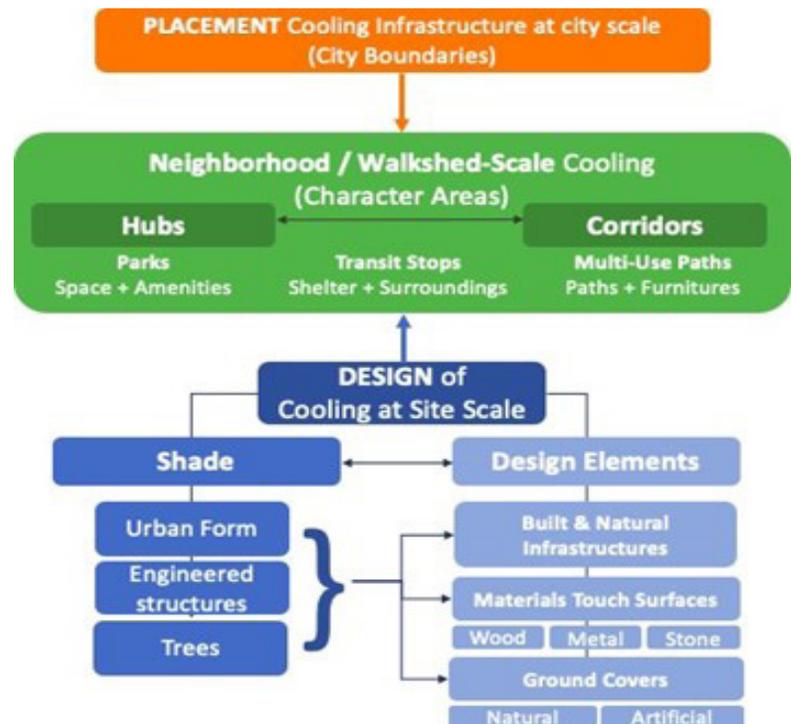
**FIGURE 19**

HUE work was combined with prior streams of applied research focusing on establishing a city-wide practice of heat planning and heat management through aligning equity values with city practices and emergency management with community engagement.

With the support of city staff and ASU researchers (total 25), the HUE-funded project co-created new heat data with the support of NASA DEVELOP students who processed raw data from 2017-2020 and approaches to overcome hurdles to decision-making and implementation of equitable urban cooling.

A key aspect of this project’s explicit process design were regular and focused meetings with City staff and ASU researchers to exchange information, build trust, and find convergent narratives as the foundation of creating effective relationships and shared understandings of the challenges and opportunities. This work centered around listening sessions to ensure that 1) departmental priorities and values were integrated into content, 2) cross-departmental and interdisciplinary collaboration facilitated, and 3) key gaps in heat planning and decision making addressed through identified overlaps and complementarities in approaches.

Figure 20 presents the approach to work towards equitable urban cooling. This starts at the top with identifying the hottest areas and high levels of heat vulnerability on the city scale in order to determine where to place cooling infrastructures to achieve equitable urban cooling. Next, these infrastructures are specified for the neighborhood level, like the City’s Character Areas, and broken into hubs (e.g., parks) and corridors (e.g., shaded walkways) that connect these hubs, building a cool ‘walkshed’. Each of these infrastructure elements is then designed to further ensure cooling, especially at the site-scale (e.g., playground in a park) and touch scale (slide in the playground to ensure thermal comfort and prevent heat injuries like burns). In this three-step process, instrument-based heat data is to be combined with the lived experience of people coping with heat on a daily basis. The latter requires careful community engagement and demonstrated follow-up on what was heard.



**FIGURE 20**  
Graphic to describe process for heat planning decision-making ranging from placing infrastructures at the city-scale to designing it at the site- and touch-scales.

Hurdles to achieving these project goals included increasing communication about residents' experiences with heat, understanding decisions related to infrastructure placement and design, and synthesizing the wide variety of datasets related to heat.

The most significant result from this partnership was the inclusion of the Equitable Urban Cooling Practice in the City of Tempe Council's approved Climate Action Plan Update. This project contributes data, information, and graphic content for another project, the Cool Kids project. The Cool Kids project develops a series of modules to raise participants' knowledge of systemic injustices as they relate to heat inequity (e.g., colonization, segregation, and trauma). One of the modules is on "Heat Equity and the Promise of a Collective Movement for Urban Cooling."

Lastly, the NASA DEVELOP team has also created a story map for Tempe titled "[Establishing Heat Priority Scores for Tempe, Arizona.](#)" The story map provides a great overview of the heat, health and equity data from the DEVELOP team. It is a powerful tool for communication and building shared literacy. The story map is also an example of what "desktop ready" data means as the NASA Develop team worked closely with the City's GIS Manager to ensure integration with the City's information infrastructure and existing datasets. This influenced the structure of the "desktop ready" showcase for heat and health data and information integration. The Showcase presents examples of heat data for each of the three levels described in the Equitable Urban Cooling Approach (see Figure 20), explains how this data can be integrated with other data and provides access to meta-data.

### Key Takeaways

- A wide variety of projects and solutions addressing heat have been tested and developed but communicating this knowledge to a wider audience remains a challenge.
- Working with ASU's Decision Theater, HUE developed the [Heat Vulnerability Map & Cool Solutions webtool](#) that allows regional stakeholders to explore extreme heat solutions developed by HUE and other groups.
- The webtool also allows users to identify regions where implementation of solutions is most appropriate, based on factors such as vulnerability variables, temperatures, and existing infrastructures.

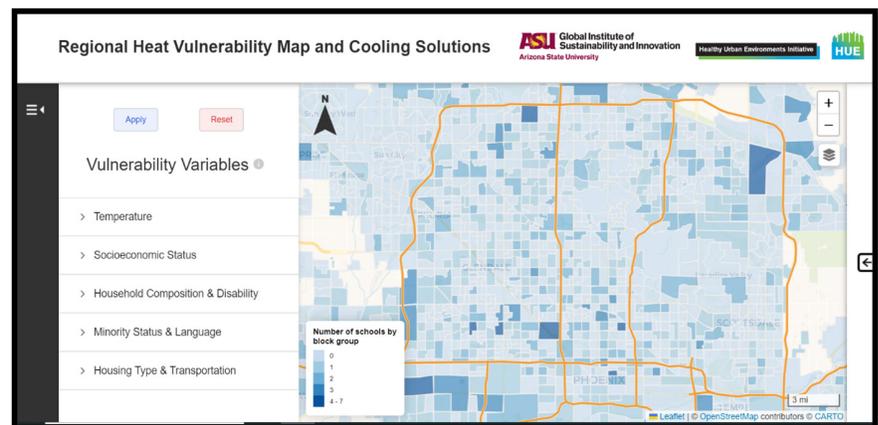
### Project Team:

- *Paul Coseo*  
Design, ASU (Co-Lead)
- *Katja Brundiers*  
Sustainability, ASU (Co-Lead)
- *Rachel Braun*  
HUE, ASU
- *Braden Kay*  
Office of Sustainability & Resilience, City of Tempe
- *Melissa Guardaro*  
HUE & KER, ASU

### Heat Vulnerability Map & Cool Solutions Webtool with ASU's Decision Theater

HUE researchers have tested and deployed a wide range of research and solutions aimed at both adapting to and mitigating extreme heat in Maricopa County. However, stakeholders with an interest in addressing these issues in the region, including municipalities, nonprofits, researchers, and concerned community members, may have a difficult time finding the many tested projects related to extreme heat. Furthermore, stakeholders such as municipalities may find it difficult to identify areas that are most in need of heat-related solutions and actions. These regions may exist at the intersection of vulnerable communities and types of infrastructure that can be changed, upgraded, or built.

To address this compounding problem of identifying potential actions to address extreme heat, especially in the areas where solutions are most needed, HUE researchers developed a heat vulnerability map and cool solutions webtool in partnership with ASU's Decision Theater (Figure 21).



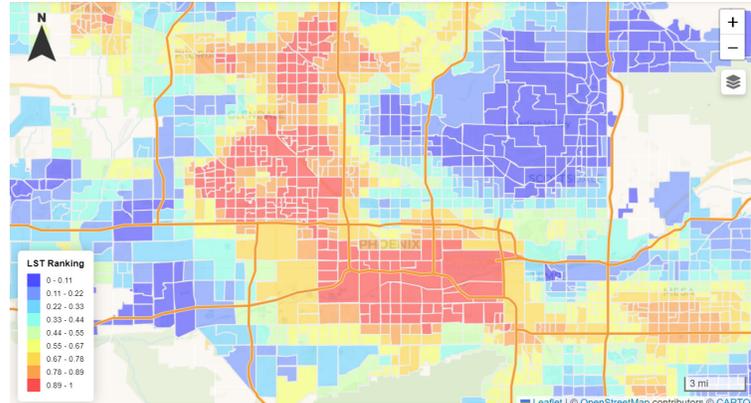
**FIGURE 21**

The Data Dashboard view. Vulnerability variables can be adjusted with sliders on the left and Topics can be chosen on the right.

This webtool maps social vulnerability variables identified by the Center for Disease Control (CDC); land surface temperature comparisons; and infrastructure locations, such as schools, parking lots, and mobile home communities, to allow stakeholders to compare and contrast needs and existing infrastructure in different locations. It then synthesizes various solutions to extreme heat developed by numerous entities, including but not limited to HUE, public health departments, local municipalities, and local community organizations (Figure 22). The webtool organizes and presents these solutions in a way that allows users to understand the basic premise and applications of the research while inviting them to explore comprehensive reports if they are interested in replicating the solutions. While there were

**FIGURE 22**

The customizable map shows variances in heat across the region.



many goals in developing this tool, one major focus was on creating a functional resource that invites further exploration and communication around approaches to addressing extreme heat in Maricopa County.

### Key Takeaways

- Shading for pedestrians can vary widely throughout the metro Phoenix region; a lack of shading can increase temperatures in many areas.
- The best places for planting trees to increase shading and cooling along “cool corridors” were determined using a combination of environmental and social characteristics in each area.
- Find out more about the City of Phoenix’s progress toward increasing the tree and shade canopy along critical “cool corridors” as a part of the [Tree and Shade Master Plan](#).

### Measuring the Urban Canopy and Cool Corridors

Stakeholders addressing extreme heat have limited finances, time, and personnel; their shared goal is to maximize the impact of their actions given these constraints. For example, one issue facing Maricopa County is the unequal amount of shading and trees in various parts of the county. Some neighborhoods and regions have substantially more trees, leading to more shade and improved thermal comfort for pedestrians. Stakeholders wishing to improve the distribution of shading and trees across the county may seek to plant more trees. However, the major issue that arises is determining where to plant a finite number of trees for maximum impact.

The “Cool Corridors” project identified these regions of maximum impact by using innovative methodology combining the environmental and social characteristics of various areas. In particular, the project categorized one mile stretches of the road network in the City of Phoenix by using a “cool corridor prioritization score.” High-priority areas included those with low car availability, high pedestrian traffic, low amounts of shade, high surface temperatures, and vulnerable surrounding communities. Results of this work were then used to determine the highest-priority street segments within different council districts and across the entire city. The City of Phoenix is using results from this work to further evaluate the suitability of these high-priority areas for tree planting.

#### Project Team:

- *David Hondula*  
Heat Response and Mitigation, City of Phoenix; Geographical Sciences and Urban Planning, ASU (Lead)
- *Mark Hartman*  
Chief Sustainability Officer, City of Phoenix

**Key Takeaways**

- Exposure to heat is unevenly and inequitably distributed in Maricopa County; a history of underinvestment in certain neighborhoods has resulted in fewer trees in these neighborhoods and limited access to the benefits trees provide.
- Web-based data tools can help determine which neighborhoods most need trees – based on factors such as existing tree cover and vulnerability indicators – to create heat-resilient communities.
- To learn more about trees maps for metro Phoenix, please visit this current [Tree Equity Score map for Metro Phoenix](#) created by American Forests.

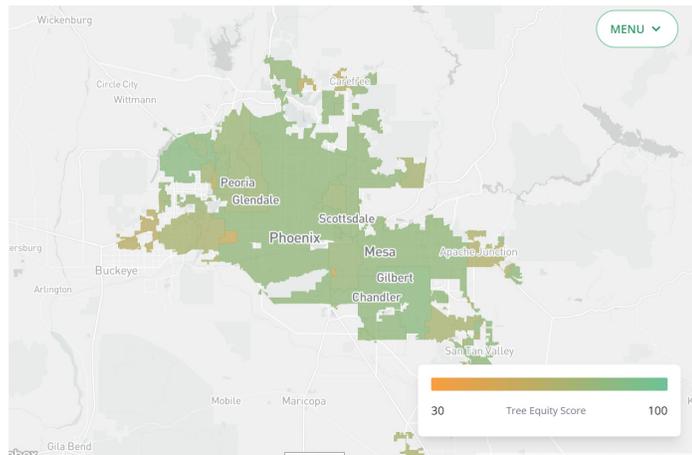
**Advancing Decision Support for Tree and Shade Equity**

As noted, tree coverage and shading are not distributed evenly across Maricopa County. Many municipalities and organizations have a goal of increasing tree coverage, and therefore shading, across the region. To support these goals, ASU researchers collaborated with American Forests to create a Tree Equity Score Analyzer for Maricopa County (TESA-MC). The TESA-MC is an online, publicly accessible webtool that synthesizes numerous datasets related to trees that can help advance goals related to increasing tree coverage. It enables users to make better decisions about the most appropriate locations for tree planting activities in the region and includes the following functionalities:

- within each jurisdiction in Maricopa County, identification of all pedestrian corridors not meeting shade targets in the Maricopa Associations of Governments (MAG) [Active Transportation Plan Toolbox](#)
- realistic, two-dimensional simulation of tree planting in eligible areas (e.g., public right of way) and calculation of anticipated changes in shade coverage and tree equity scores
- automated recommendations and comparisons for tree planting or shade structure projects to meet user-defined goals and specifications within a given area
- cost-benefit analysis for user-specified tree and shade scenarios.

**Project Team:**

- *Ariane Middel*  
Arts, Media and Engineering, ASU (Lead)
- *Amy Frazier*  
Geographical Sciences and Urban Planning, ASU
- *David Hondula*  
Heat Response and Mitigation, City of Phoenix; Geographical Sciences and Urban Planning, ASU
- *Chris David*  
Vice President of GIS and Data Science, American Forests
- *Eric Candela*  
Director of Local Government Relations, American Forests
- *Isaac Newton Kwasi Buo*  
Tartu University, Estonia (visiting scholar at ASU)



**FIGURE 23**  
Screenshot from American Forests Tree Equity Score Analyzer.

**Partner Organizations:**

- City of Tempe
- City of Scottsdale
- City of Avondale
- The Nature Conservancy
- Arizona Chapter
- Arizona Sustainability Alliance
- Trees Matter

### Key Takeaways

- Developing a user-friendly and stakeholder-driven decision-making tool requires engaging stakeholders throughout the research process is critically important.
- Evaluating integrated sustainable development outcomes of a business requires a comprehensive understanding of interconnected scales through systems design.
- Allowing meaningful engagement with stakeholders requires flexibility and an adaptive process of research design and re-design.

#### Project Team:

- *Chingwen Cheng*  
Design, ASU (Lead)
- *Nick Shivka*  
Senior Sustainability  
Program Manager, Local  
First Arizona (LFA)

### Design Performance Scale-Up Evaluation Tool for Sustainable Business

Our built environments are designed through deliberate decision-making processes that are influenced by complex factors including desirable outcomes for achieving sustainability, resilience, and justice goals. [Local First Arizona SCALE UP](#) (Sustainable Communities Accessing Lending and Expertise Upon Performance) engages with local businesses entities to develop visions and actionable projects that address sustainable development goals. With an aim to fill the gap in the co-design process engaging communities and stakeholders to develop strategies together, ASU researchers designed a comprehensive environmental design decision-making tool that aims to address urban heat and thermal comforts in the built environments that achieve sustainability, resilience, and justice goals considering local-specific climate and context. This project utilized resources from the Decision Theater to engage with stakeholders to co-develop the decision-making tool. The novelty of this project lies in the process itself. Instead of an expert- and product-driven project, this project was community-centered and user-driven, and the outcomes are customized by stakeholders. Stakeholders can understand holistic systems design and assess pros and cons based on their needs and priorities on sustainability and resilient goals.

Local First Arizona hosted two cohorts for the SCALE UP program on January 11–February 18 and March 1–April 8, 2022, in which ASU researchers were involved and connected with stakeholders. A hybrid hands-on workshop was conducted with stakeholders in Phoenix and Tucson areas in July 2022 to co-develop the decision-making framework that fits their business needs. Local First Arizona (LFA) published [reports of the SCALE UP program](#), its cohorts and ASU's partnership. The ASU research team developed a prototype decision-making tool using environmental, social, and economic sustainability framework and building-in indicators co-designed with the business owners and Local First Arizona stakeholders throughout the months of September and October. The prototype tool in an excel file format was delivered to LFA in November along with a user's manual briefly illustrating the purpose of the tool, how to use the tool, and how to read the results. Future funding would be most beneficial to test the tool with business owners from the SCALE UP program and evaluate the effectiveness of this tool in enhancing the knowledge of sustainable development and willingness for taking actions toward sustainability goals to further address environmental justice and community resilience.

### Key Takeaways

- Pedestrians moving through the Valley are exposed to direct sunlight, hot surfaces, and heat radiating back from buildings.
- Different shading types (trees, umbrellas, buildings) have different abilities to create shade and cooling. See related publication: [50 Grades of Shade](#).

#### Project Team:

- Ariane Middel  
Arts, Media and Engineering, ASU (Lead)
- Florian Schneider  
Sustainability, ASU

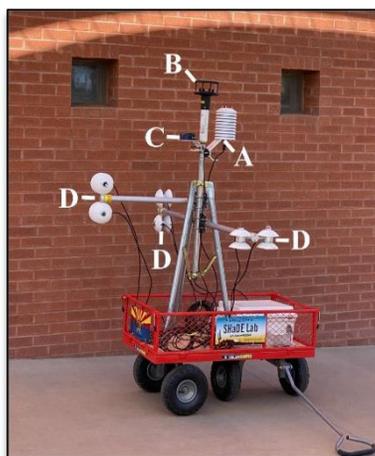
## 2.5 Monitoring and Future Scenarios as Basis for Solutions

Although regional and national groups monitor heat and air quality throughout the Valley as a whole, both indoor and outdoor environmental conditions can vary widely throughout the region. More targeted and localized monitoring systems may therefore help protect individuals from these environmental hazards. Furthermore, understanding how current conditions can impact future scenarios can help make decisions related to mitigating heat and air quality issues. HUE researchers tested some of these monitoring systems in different environments and with different segments of the population. These HUE projects focused on characterizing the effectiveness of these monitoring types and on raising awareness of the different environmental conditions that exist throughout the Valley. Other projects sought to characterize future conditions given ongoing work in the region.

### Thermal Assessment of Natural and Engineered Shade in Tempe

As any resident of Maricopa County can easily tell you, standing in the direct sunlight on a hot summer day is much more unpleasant than standing in the shade. Likewise, standing in the middle of a dark asphalt parking lot is much more unpleasant than standing in the middle of a grassy park. Quantifying these differences in pedestrians' thermal comfort can contribute to developing infrastructure that provides maximum comfort in extreme-heat conditions.

This project extended the “right tree in the right place” guiding principle of Tempe’s Urban Forestry Plan to “right shade in the right place”. In collaboration with the City of Tempe, this study tested the efficacy of various shade types to inform guidelines and best practices for shade deployment. ASU researchers used an innovative method for understanding not just temperature and shade but also pedestrians’ comfort level as related to heat. MaRTy – a mobile weather station that measures Mean Radiant Temperature (MRT) – was used to assess the performance of natural and engineered shade in over 100 locations in Tempe (Figure 24). Measurements of MRT, which more closely relates

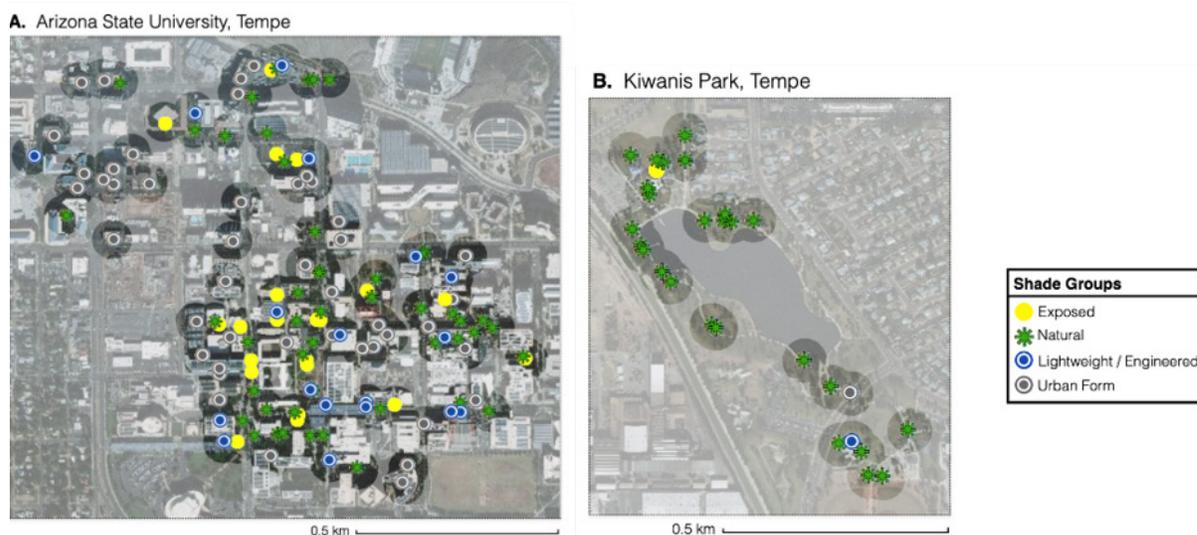


**FIGURE 24**

The mobile human-biometeorological instrument platform MaRTy. A) temperature/humidity probe, B) WindSonic horizontal wind speed/direction sensor, C) GPS sensor, D) three 4-Component Net Radiometers to measure shortwave and longwave radiation in 6 directions (up/down, left/right, back/front).

to thermal comfort than either air temperature or shading alone take into account heat felt from surfaces, such as pavement and buildings, shading provided by structures such as trees and shade sails, and air temperature.

Researchers concluded that not all environments and structures contribute in the same manner to thermal comfort. In particular, shading from urban forms, such as buildings, was most effective at lowering MRT, while shading from trees varied widely based on the type of tree. Insights from these quantification efforts can help with developing infrastructure that protects and provides relief to pedestrians.



**FIGURE 25**

Aerial view of study areas in the City of Tempe: A. Downtown Tempe including the Mill Avenue District (to the north-west) and Arizona State University's Tempe Campus (to the south-east); B. Kiwanis Park.

### Key Takeaways

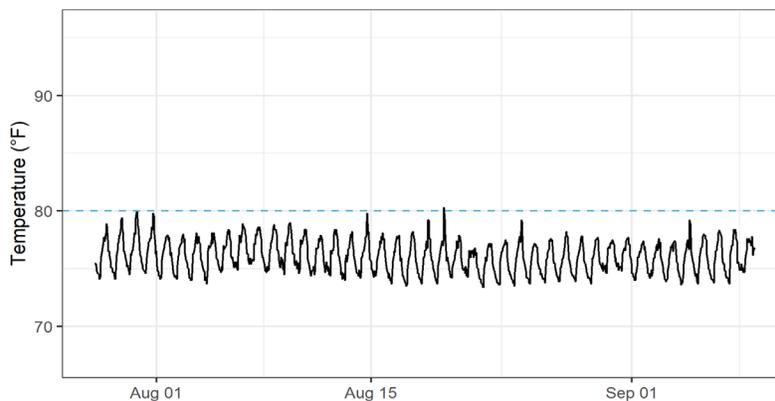
- Extreme indoor heat in insufficiently cooled homes presents a threat to health and well-being.
- This pilot study tested a system that monitored indoor temperatures in homes in Maricopa County in order to issue alerts when temperatures passed a certain threshold.

#### Project Team:

- **David Hondula**  
Director of Heat Response and Mitigation, City of Phoenix; Geographical Sciences and Urban Planning, ASU (Lead)
- **Lance Watkins**  
Geographical Sciences and Urban Planning, ASU
- **Matthew Roach**  
Epidemiologist, Arizona Department of Health Services
- **Carmen Tirdea**  
Epidemiologist, Arizona Department of Health Services
- **Carrie Smith**  
COO, Foundation for Senior Living
- **Katie Martin**  
Home Improvements and Community Services, Foundation for Senior Living
- **Megan Word**  
Chief of Community Engagement, Foundation for Senior Living

### Building Targeted Real-Time Warning Systems for Extreme Heat in Households

In Maricopa County, a significant portion of heat-related deaths occur because of indoor exposure. Researchers conducted a pilot study in ten households in Maricopa County to test a system that issues alerts when dangerously hot conditions are detected inside the home. These alerts would trigger wellness checks by neighbors, family members, or other support personnel. Results from the study indicated that participants generally had a positive experience with the pilot test. Every participant said that they knew someone who would benefit from such a system, and no one expressed concerns related to inconvenience or privacy. Participants had a wide range of preferences for indoor temperatures that would trigger an alert, ranging from 80°F to 99°F. Several participants asked for more specific guidance from the public health community regarding recommended thresholds. While all participants had access to central air conditioning, indoor temperatures were highly variable, both with respect to the mean between participants and to hour-to-hour and day-to-day variability. Participants had differing opinions about the organization or institution that would be most appropriate to provide such a service. About half of the study participants thought that an emergency management or public health organization could operate this service, but the other half thought that it would be best managed by individuals. Overall, this study provided useful feedback for designing interventions to address indoor exposure to heat in Maricopa County.



**FIGURE 26**

Indoor temperatures from one participant in a pilot project for a real time indoor temperature alerting system. In this household, indoor temperatures reached or exceeded the user-defined threshold of 80°F two times during the study period.

### Key Takeaways

- Atmotube wearable monitors proved fit for use in a personal heat and particle exposure study
- Preliminary data clearly stresses the need for indoor air quality monitoring in homes
- A lesson plan on particle pollution, incorporating sensor use, was developed.

#### Project Team:

- *Pierre Herckes*  
Molecular Sciences, ASU  
(Co-Lead)
- *Dr. Jershon Eagar*  
High School Chemistry  
Teacher, BASIS Schools  
(Co-Lead)

### Crowdsourced Heat and Indoor Air Study

This project aimed to investigate exposure to both heat and air pollution (fine particulates), and the differences between indoor and outdoor exposure. The goal was to have students act as “citizen scientists,” providing them with low-cost air pollution and temperature sensors to make measurements in their homes and daily lives (by carrying the sensors) to assess their exposure. An additional objective was to develop a teaching module to enhance the students’ understanding and awareness of air and heat issues.

ASU researchers began with a detailed market survey of sensors, the selection of sensors, and extensive testing to determine which would be used. The Atmotube sensors proved to be highly portable, provided consistent measurements, and were chosen for the study. However, when the project began recruiting its first student cohort, substantial logistics challenges were encountered in the post-COVID era, including supply chain issues and the lack of availability of good quality sensors like the Atmotubes. Alternative additional sensors were tested but failed to meet project needs. Finally, when the sensors became available again, at a substantially higher cost, the summer/heat period was missed, and the focus shifted towards a smaller cohort and PM2.5 in the absence of heat. The scientific insights were interesting, albeit preliminary. When students carried a sensor on them at all times, vs. using an in-house monitor, or compared to the air quality monitoring network data, we saw on aggregate that for active students, the network showed a reasonable exposure range but did not capture substantially higher indoor concentrations in some individuals’ homes. The indoor home environments showed substantial variability with some homes having at times alarming PM2.5 levels, stressing the need for indoor air pollution mitigation measures. Future research will address these issues. The main outcome, however, is that the sensors proved to be efficient and fit for exposure studies. The protocols for having individuals carry the sensors, checking them on their cellphone, and having a matching sensor left in their house, proved to work, and future, larger-scale studies can build upon this. A summer deployment will allow for heat measurements to be included.

The development of a teaching model that incorporates the sensors for citizens (high school students, grades 9-12) has been completed. A lesson plan was developed that includes four lessons, a PowerPoint presentation to instruct teachers and students as well as student and teacher notes. These materials were also included in a module for a college level environmental chemistry lab class.

### Key Takeaways

- Electrification of transportation is expected to reduce local air pollution for all locations within Maricopa County.
- Air quality benefits of electrification are expected to be higher in disadvantaged communities because they start with worse pollution.
- Rapid adoption of electric vehicles in more than the passenger sector are needed to improve air quality.

#### Project Team:

- *Nathan Parker*  
*Sustainability, ASU (Lead)*
- *Danae Hernández-Cortés*  
*Future of Innovation in Society, Sustainability, ASU*
- *Hanna Breetz*  
*Sustainability, ASU*
- *Andrea Córdova Cruzatty*  
*Sustainability, ASU*
- *Deepti Paul*  
*Sustainability, ASU*

### Evaluating Electric Vehicle Adoptions Affect on Air Quality for Low-Income Households

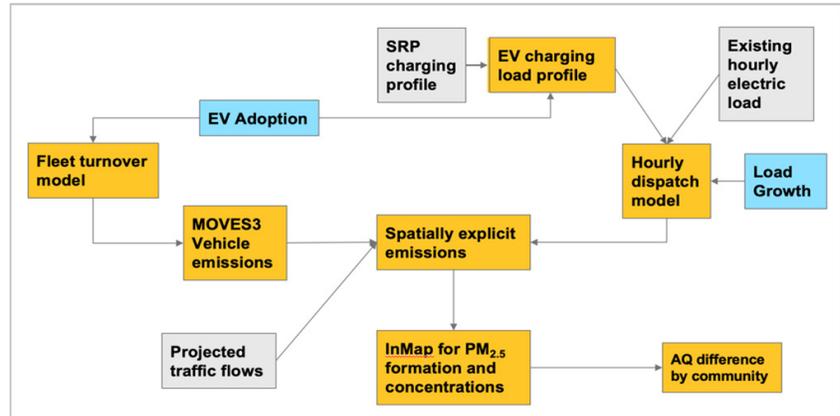
Electric vehicles (EV) are considered a key technology solution for decarbonization and urban air pollution, as they do not emit contributors to ozone and fine particulate emissions as compared to internal combustion vehicles. However, quantifying improvements in local air quality impacts is challenging, because it depends on a variety of technical and environmental factors, including season, driving patterns, vehicles replaced, and proximity to power plants that will power the EVs. Estimating their impact is critically important for policymakers to understand how air quality would be changed by EV adoption and design policies for the largest benefit.

To estimate the air quality impacts of EVs and inform local policymaking, our team of ASU researchers analyzed the impact of EV adoption scenarios on air pollutants in Maricopa County. We particularly focused on air quality impacts for low-income and minority communities, which are disproportionately burdened by poor air quality due to their proximity to highways and industrial zones. EV adoption may have mixed effects for these communities; on the one hand, emissions will be reduced near high traffic roads, but on the other hand, emissions may be increased near natural gas power plants, which also tend to be sited near vulnerable communities. Examining these effects requires an integrated analysis of traffic flows, marginal emissions from power generation, the distribution of pollution in the environment, and spatial patterns of urban socioeconomic and demographic characteristics. In addition, it requires the development of various scenarios for EV adoption and charging.

To develop these scenarios and identify air pollutants of greatest concern, our team conducted meetings with local governments and stakeholders. The existence of continuous working groups within the Sustainable Cities Network (SCN) and Arizona Thrives made these discussions possible and inclusive of a wide range of communities and perspectives. These conversations highlighted two vehicle segments where analysis was needed: (a) personal vehicles, and (b) local heavy and medium duty fleets. We focused our initial modeling work on personal vehicles, since several local governments and utilities are already setting deployment goals and developing infrastructure programs for these vehicles. In continuing work, we will also pursue analysis of heavy and medium duty fleets that operate within the region. New policy options are being discussed to allow these fleets to generate NOx credits, which made this segment even more policy-relevant than we thought at the beginning of the project.

We modeled a scenario in which EVs grow to 30% of new light duty vehicle sales by 2030. This resulted in the electrification of 12% of light-duty vehicle miles due to the rates of fleet turnover. We used the MOVES3 traffic flow model to estimate the impact on vehicle emissions and an electricity dispatch model to estimate power plant emissions,

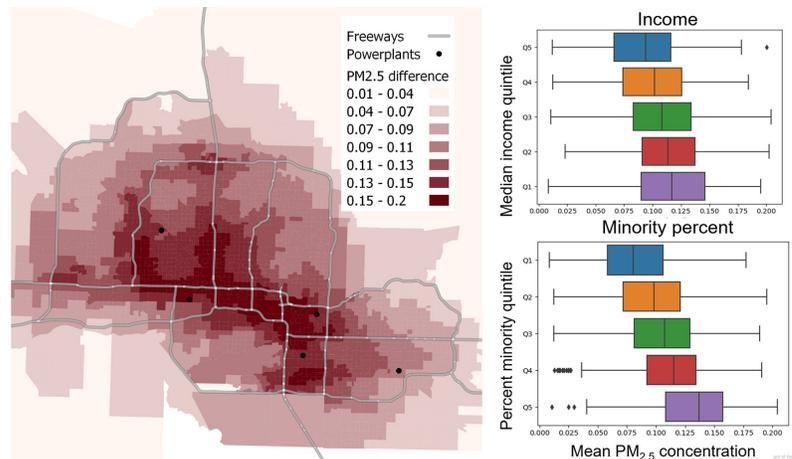
resulting in spatially explicit estimates of net emissions changes. For PM2.5, we further used InMap to estimate how these changes in emissions translated into changes in ambient concentrations. Lastly, we analyzed the changes in emissions by income and minority quintiles to evaluate the relative impact on disadvantaged communities.



**Figure 27**  
Model diagram.

We found that within Maricopa County, vehicle electrification universally results in improved local air quality (Figure 28). Even in communities downwind from power plants, the additional pollution from power plants is offset by reductions from local vehicle emissions. The benefits of electrification are greater for disadvantaged communities who suffer from higher air pollution, supporting the argument for incentivizing adoption from an environmental justice perspective. However, we also found that the adoption of EVs has a limited impact on air quality compared to other fleet changes over time, particularly improvements in conventional vehicles due to tighter emissions standards on newer vehicles. These two factors together lead to 10% reduction in NOx emissions from vehicles and electricity generation in 2030 compared to 2021.

**Figure 28**  
Impact of electric vehicle adoption on PM2.5 pollution in Maricopa County in 2030 comparing no electric vehicle adoption with adoption reaching 30% by 2030. Map of improvements in mean PM2.5 concentrations due to adoption of EVs (left). Improvement in mean PM2.5 concentrations in census block groups grouped by median income (top-right) and minority percent (bottom-right).

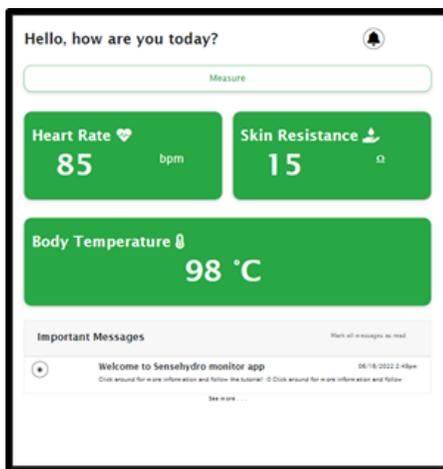


### Key Takeaways

- Successful breadboard prototype measures desired biometric data
- Device communicates data via Bluetooth for mobile device response.
- Ongoing research involves algorithm optimization and hardware integration.

#### Project Team:

- *Rachna Nath*  
STEM Coordinator  
and Educator, Arizona  
College Prep (Lead)
- *Jennifer Vanos*  
Sustainability, ASU



**FIGURE 29**

SensyHydro app homescreen.

### SenseHydro

Heat-related illness is a major issue in Maricopa County and other regions around the world that experience high summer temperatures and/or heat waves. One proposed solution is a wearable measurement (Hydrothermal Sensing) device that can alert users about potential indicators of their hydration levels and heat stress through biometric data. A team of developers from the Chandler Unified School District are developing a wearable wristband device that monitors heart rate, blood oxygen levels, body temperature, and skin resistance. This device sends data to an app on the user's phone that can then use algorithms to detect indicators of hydration level and heat stress. Such wearable products can offer individuals another method to protect themselves in high-heat environments by alerting them of such symptoms and suggesting precautions (e.g., drink water, go to a shaded area).

Various sensors have been tested to determine which would be most viable in terms of accuracy, energy cost, availability, and price. Test rigs are being constructed which will be used to collect a plethora of measurements at different wrist positions and pressures, providing the necessary data for developing the algorithm.

The prototype utilizes a low power nRF52840 Bluetooth Low Energy microcontroller, which interacts with the biometric sensors. The biometric sensors include a heart rate and SpO2 sensor (MAX30101/2), a body temperature sensor (MAX30205), an inertial measurement unit (LSM6DSL), and a skin resistance sensor utilizing a differential amplifier circuit. The microcontroller gathers the sensor data during set time intervals and communicates the data periodically to the user's phone or another central Bluetooth device, where the data can be processed through an algorithm to extract the desired results. The device is powered through a 400mAh Lithium Polymer battery, which allows it to actively report data for hours and can be further optimized to potentially last days or weeks before needing to recharge. A working breadboard prototype is built using a SeeedStudio XIAO nRF52840 board (changed from Arduino Nano 33 BLE), with breakout boards of the sensors connected via I2C Qwiic connectors. Current conversion of the breadboard into a compact wearable PCB is underway.

The app presents a dynamic page prototype where data is read then updated on the screen. Each component - heart rate, skin resistance, and body temperature - can be measured individually (Figure 29). Notifications will alert the user if the updated data depicts any unhealthy and even harmful result(s) from the measurements and previous messages can be browsed through below the most recent alert. Currently, the application is accessed as a website, but soon will work as an iOS and Android app.

## 2.6 Materials

While natural vegetation—such as trees for shade to promote thermal comfort—is an important contributor to green infrastructure design, the materials incorporated into engineered systems and built environments are also vital. When considering materials and engineered systems, it is paramount that systems be designed to perform their primary function. Minimizing the cost of infrastructure is also often a priority. Recognizing the role of materials in urban environments, HUE researchers set out to design, demonstrate, and deploy engineered materials capable of performing multiple functions: both serving their primary purpose and minimizing cost while simultaneously advancing thermal comfort and/or minimizing air pollution. The HUE projects focused on engineered materials include:

### Key Takeaways

- TiO<sub>2</sub> coated panels proved successful at removing atmospheric NO<sub>x</sub>.
- The magnitude of NO<sub>x</sub> removal depends on ambient NO<sub>x</sub> concentrations, atmospheric transport and irradiation.
- The overall impact on NO<sub>x</sub> concentrations on an airshed scale is small but locally, the impact can be significant and can be increased by extending to surfaces beyond panels.
- Engineered approaches using artificial light and forced mixing showed significant potential in industrial point of use application to reduce NO<sub>x</sub> emissions at the source.

### Photocatalytic Solar Panels to Control NO<sub>x</sub>

This project investigated whether nanoparticle titanium dioxide TiO<sub>2</sub>-coated solar panels are able to remove atmospheric nitrous oxide (NO<sub>x</sub>) compounds, the precursors to photochemical smog. The goal was laboratory proof of concept, followed by an outdoor pilot study on glass-coated panels. The novel concept of photocatalytic abatement on solar panels allowed panels to be bifunctional, generating electricity and providing air-pollutant abatement by using the part of the solar spectrum less efficiently converted to electricity. Coating solar panels also held promise for overcoming a major impediment to surface photocatalytic abatement of air pollutants—surface soiling—as solar panels require regular upkeep and cleaning to maintain electrical output performance.

In a first step, ASU researchers successfully demonstrated in the lab, through batch and continuous flow studies, the removal of NO<sub>x</sub> by converting nitrogen monoxide (NO) and nitrogen dioxide (NO<sub>2</sub>) all the way to nitrate/nitric acid (NO<sub>3</sub><sup>-</sup>/HNO<sub>3</sub>). While most existing studies only monitored the removal of NO, this project monitored both NO and NO<sub>2</sub> concentrations to assure complete transformation into NO<sub>3</sub><sup>-</sup>/HNO<sub>3</sub>. The team tested different commercial catalysts, including a product from an ASU-derived startup, and observed removal efficiencies up to 40%.

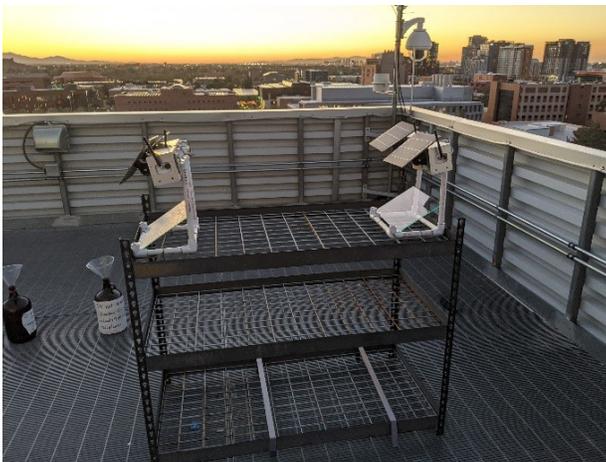
After the successful proof-of-concept demonstration, the team performed a small, pilot-scale experiment in outdoor Tempe air. Initial observations using a battery of NO<sub>2</sub> sensors failed to show clear quantitative results, echoing similar challenges from other studies related to atmospheric variability. A novel approach to measure only the final product, nitrate, on the panels through ion chromatography of DI water washes was successful. While a conservative measurement (some abated NO<sub>x</sub> might be

**Project Team:**

- *Pierre Herckes*  
*Molecular Sciences, ASU*  
*(Lead)*
- *Jesse Molar*  
*Molecular Sciences, ASU*
- *Matthew Fraser*  
*HUE & Sustainable*  
*Engineering and the Built*  
*Environment, ASU*

missed), it clearly showed that NO<sub>x</sub> was converted to NO<sub>3</sub><sup>-</sup>/HNO<sub>3</sub> and removed from the ambient air. The panels successfully removed nitrate continuously over several weeks of use, demonstrating that the coatings were durable enough to withstand extended use in ambient conditions. With periodic washing of the photocatalytic surface, the panels maintained their removal efficiencies without the need to reapply coating through three months of exposure. The NO<sub>x</sub> removal averaged several to tens of milligrams per day and per square meter of surface. While not a huge removal at an airshed scale, this clearly is another tool to passively aid in pollutant removal. Improved performance is likely to be obtained by optimizing light sources and having active transport. Also, adapting surface materials other than glass would be one potential approach to generate an overall larger removal flux than one solely based on glass/photovoltaic surfaces.

The successful proof of concept in the lab and at pilot scale generated additional interest and further research funding. Going beyond solar light and utilizing active airflow, the Semiconductor Research Corporation funded a three-year project to investigate the photocatalytic removal of NO<sub>x</sub> in semiconductor exhaust streams. Current status of the research shows that under engineered conditions, removal efficiencies of up to 80% are possible. This research is ongoing. In terms of ambient abatement of NO<sub>x</sub>, other organizations, such as the City of Phoenix, are interested in further exploring the concept and may include it in shade structures to allow for larger surface areas. The team has discussed potential follow-up studies within the context of the City of Phoenix “Cool Corridors” program.

**FIGURE 30**

Outdoor testing of NO<sub>x</sub> removal by photocatalyst covered panels on the ASU campus.

**Key Takeaways**

- Reflective treatments on parking lots and local streets can decrease the absorption of solar radiation by pavements.
- However, in complex urban environments with active heat transfer, these treatments have minimal impact on ambient air temperatures.

*Project Team:*

- *Matthew Fraser*  
HUE & Sustainable Engineering and the Built Environment, ASU (Lead)
- *Jennifer Vanos*  
Sustainability, ASU
- *Ariane Middel*  
Computing & Augmented Intelligence, ASU
- *David Sailor*  
Geographical Sciences & Urban Planning, ASU

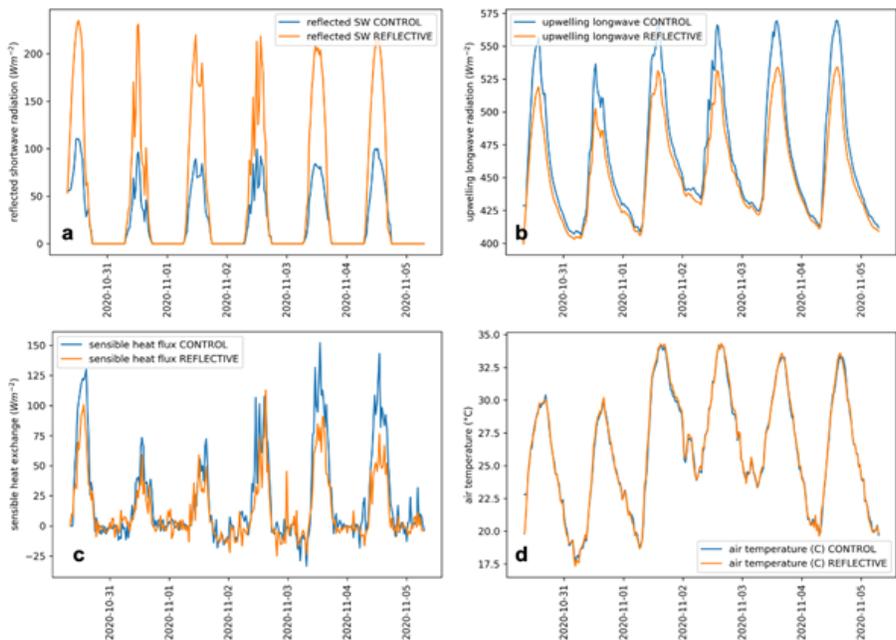
*Partner Organizations:*

- *Global KAITEKI Center*
- *City of Phoenix, Street Transportation Department*
- *Maricopa County Facilities Management Department*

**Benefits and Costs of Cool Pavement for Mitigating Heat**

This project quantified the benefits associated with cool paving technologies. Working with Maricopa County Facilities Management Department (MCFMD) on a downtown Phoenix parking lot and the City of Phoenix on neighborhood “Cool Pavement” program implementation sites, HUE researchers quantified the impact of cool pavement approaches to evaluate the effect of reflective pavements on lowering ambient temperatures and offsetting the urban heat island effect.

The team collected primary data on the effectiveness of a coating designed to reflect some of the incoming solar radiation. These primary data showed that the parking lot treatment reduced absorbed solar radiation by about 50% by increasing the fraction of reflected radiation from 0.15 to 0.30, as shown in Figure 31a. HUE researchers also measured emitted surface radiation, which was reduced approximately 10% (Figure 31b), indicating that peak surface temperature was cooled by 8°C at the daily solar maximum. However, despite an approximate decrease of 25% in heat exchange at the treated site (Figure 31c), they found no differences in air temperature above the treated and untreated portion of the parking lot (Figure 31d).



**FIGURE 31**

Results from primary data collection on the Maricopa County reflective parking lot (western half) versus the untreated control lot (eastern half) in downtown Phoenix: (a) reflected shortwave radiation, (b) upwelling longwave radiation, (c) sensible heat flux, and (d) air temperature.

The data showed that the treated parking lot reflected a larger fraction of solar radiation, which resulted in a lower surface temperature compared to the untreated lot. However, in terms of ambient air temperature (measured ten feet above the surface), there was no difference between the two lots. One possible explanation for this result is that the area treated—a single parking lot in Central Phoenix and streets in a single location in the City of Phoenix—is too small to impact ambient air temperature, as atmospheric mixing and convective heat transfer offset any localized change in the urban heating balance in a single location.

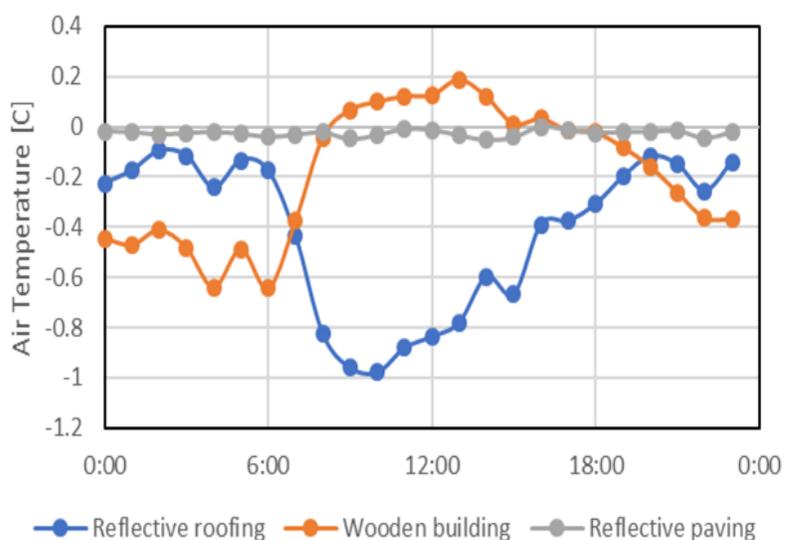
To investigate whether a more widespread deployment of reflective pavements could lower air temperatures in Phoenix based on the primary data, the team turned to urban climate models and collaborated with Prof. David Sailor and a closely related project funded by the Global KAITEKI Center. That project used the Weather Research and Forecasting (WRF) model developed by the National Center for Atmospheric Research in Boulder, Colorado to evaluate the impact of different heat mitigation approaches on our local air temperature. WRF uses fundamental data to simulate air temperatures under different scenarios and can be used to estimate the impact of more widespread use of reflective pavements on local air temperatures. For comparison, the team also simulated the impact of other heat mitigation approaches, such as widespread use of highly reflective rooftops and alternatives that use timber in building roofs and walls. They considered three scenarios to estimate the possible regional impact on Phoenix air temperature: increasing building rooftop reflectivity from 0.20 to 0.96, replacing traditional construction materials with wood in building walls and roofs, and increasing reflectivity of paved surfaces from 0.10 to 0.35. For each of these three scenarios, the team ran WRF for downtown Phoenix for a base case and three heat mitigation cases. For each heat mitigation approach, half of the built infrastructure (rooftop reflectance, timber construction practices, and reflective pavements) was modified in the model relative to the base case. The team based the level of change in the thermal properties under the heat mitigation cases on their review of a range of primary data sources, such as HUE’s MCFMD parking lot project and the City of Phoenix “Cool Pavement” program (<https://www.phoenix.gov/streets/coolpavement>). Table 1 summarizes the specifics of the physical properties modeled for downtown Phoenix using WRF.

**TABLE 1**

Average properties across downtown Phoenix for cases involving modifications of half of all surfaces (e.g., 50% of rooftops or paved surfaces).

	Base	Reflective Rooftops	Wood Building	Reflective Pavement
<i>Roof reflectivity (%)</i>	20	58	20	20
<i>Wall Conductivity (W/m-K)</i>	0.67	0.67	0.39	0.67
<i>Roof Conductivity (W/m-K)</i>	0.67	0.67	0.39	0.67
<i>Wall Thermal Storage (MJ/m<sup>3</sup>K)</i>	1	1	0.85	1
<i>Roof Thermal Storage (MJ/m<sup>3</sup>K)</i>	1	1	0.85	1
<i>Pavement Reflectivity (%)</i>	10	10	10	22.5

Figure 32 shows the change in air temperature compared to the base case predicted using the WRF model for the implementation of different strategies. The reflective rooftop mitigation strategy showed significant cooling during the daytime and moderate cooling during the night. However, simulations showed that adding cool pavements would not result in significant cooling for downtown Phoenix. While this is consistent with the observations at the MCFMD parking lot, it may be a function of the region selected for modeling: the building heights modeled in downtown Phoenix result in significant shading of paved surfaces throughout the day, which then limits the potential benefit of reflective pavements as opposed to reflective roofing.



**FIGURE 32**

Modeled change in air temperature while implementing different cooling strategies in downtown Phoenix predicted by the WRF Model. Negative values indicate urban cooling and positive indicates warming.

### Key Takeaways

- Through their dark surfaces and limited shade, parking lots can expose pedestrians to dangerous levels of heat.
- Added shading through plants and structures along pedestrian routes helps to protect visitors to the zoo.
- Swales, pervious pavers, and curb cuts can be used to reduce stormwater runoff from parking areas.

### Project Team:

- **Ray Quay**  
*DCDC, ASU (Lead)*
- **Steve Betts**  
*Managing Director of Development, Holualoa Companies; Board of Directors, ASU Foundation; Capital Campaign Cabinet, Phoenix Zoo*
- **Ashley Broadbent**  
*Geographical Sciences and Urban Planning, ASU*
- **Norberto Castro**  
*President/CEO, Phoenix Zoo*
- **Paul Coseo**  
*Design, ASU*
- **Nancy Grimm**  
*Life Sciences, ASU*
- **Allyce Hargrove**  
*Design, ASU*
- **David Hondula**  
*Heat Response and Mitigation, City of Phoenix; Geographical Sciences and Urban Planning, ASU*

### Phoenix Zoo Parking Lots

Parking lots in Arizona are a significant source of heat exposure between late spring and early fall and are an important target for urban heat island mitigation measures. As an example, the Phoenix Zoo parking lot consists of asphalt that can reach a surface temperature of up to 160°F. Every year, 1.5 million people—including adults and vulnerable youth, who are closer to the hot pavement—cross this surface. In 2019, the City of Phoenix approved funds for the improvement and expansion of the parking lot on the condition that the project be designed to be sustainable. The City asked HUE to participate in an advisory capacity to suggest sustainability strategies, specifically regarding stormwater runoff and heat.

This project divided the parking lot project into two sections. The first involved creating a new parking area in the open desert south of the path connecting the zoo and nearby Papago Park. Its sustainable features included:

- a modified wash/swale to direct stormwater through retention areas to reduce runoff, allow infiltration to recharge aquifers, and provide a water source for vegetation along the swale
- curb cuts, allowing stormwater to flow into planter areas
- a stormwater catchment basin
- native and drought-resistant plantings throughout the site

The second section focused on rehabilitating the existing lot to the west of the zoo and included:

- tree planting along two pedestrian routes to the zoo entrance to provide shading upon maturation
- replacing existing pavement around new trees with porous pavers, increasing the potential amount of water to each tree and thereby improving their chances for survival and reducing stormwater runoff
- the Salt River Project's placing an array of solar collectors in the parking lot to provide a power source for 20 EV charging stations, which also provided shade to a large area of the lot

The existing lot had few trees or structured shade, rendering it an extremely hot place for the zoo's visitors, which include thousands of young students on field trips. HUE helped with funding and expertise to design and implement structured shade strategies for key pedestrian areas near the entrance most frequented by children during these trips. A collaborative design process between the zoo, the City of Phoenix, and HUE researchers resulted in shade structures being built over areas where students typically walk or wait for buses, along with multiple strategic spots adjacent to the zoo entrance—most notably, a large shade structure near the new parking lot, where students can cool off after crossing from the zoo exit before boarding their school buses.

- *Kamil Kaloush*  
Sustainable Engineering and the Built Environment, ASU
- *Kristian Kelley*  
Landscape Architecture, Design, ASU
- *Mandy Kuhn*  
Life Sciences, ASU
- *Ariane Middel*  
Arts, Media and Engineering, ASU
- *Alexandro Medina*  
Landscape Architecture, Design, ASU
- *Michael Mohr*  
Landscape Architecture, Design, ASU
- *Florian Schneider*  
Sustainability, ASU
- *Jennifer Vanos*  
Sustainability, ASU
- *Joe Wilkes*  
Senior Vice President, Facilities, Construction & Operations, Phoenix Zoo

**Partner Organizations:**

- City of Phoenix
- Arizona Center for Nature Conservation
- Phoenix Zoo
- Salt River Project
- Shade Industries
- Gavan & Barker

Pre-study (June 2020) and post-study (June 2022) assessments of these heat mitigation strategies were conducted utilizing ASU’s human-biometeorological “MaRTy” (short for “Mean Radiant Temperature”) cart to quantify the heatscape that students experience along this route.

HUE also worked with zoo staff to assess heat landscapes within the Children’s Zoo itself. The team coordinated two ASU landscape architecture classes to assess existing conditions among the Children’s Zoo exhibits and pathways, developing projects the zoo could implement to reduce young visitors’ exposure to heat. These projects ranged from simple shade structures utilizing traditional materials to those using organic, growing structures, from active cooling places using living materials all the way to complex, mechanized structures that slowly move during the day to intercept sunrays.

A four-panel infographic (Figure 33) presents the results of the three project phases to the public and will be used by the Zoo for an onsite exhibit.



**FIGURE 33**

Four-panel infographic featuring results of the three project phases.



### Key Takeaways

- The aMBx modified asphalt roofing shingles provide an insulating effect. Lower temperatures are expected in attics' homes leading to decreased energy consumption.
- For a 1000 ft<sup>2</sup> house, the energy savings are estimated to be \$825 per year.
- Economic benefits: the market size for roofing material is projected to be \$152 billion by 2027.

#### Project Team:

- Kamil Kaloush (Co-Lead)
  - Jose Medina (Co-Lead)
  - Carlos Obando
  - Jolina Karam
- Sustainable Engineering and the Built Environment, ASU

#### Partner Organizations:

- GAF Materials Corporation
- Crafcro Inc.

### Sustainable Asphalt Roofing Technology Solution for Heat

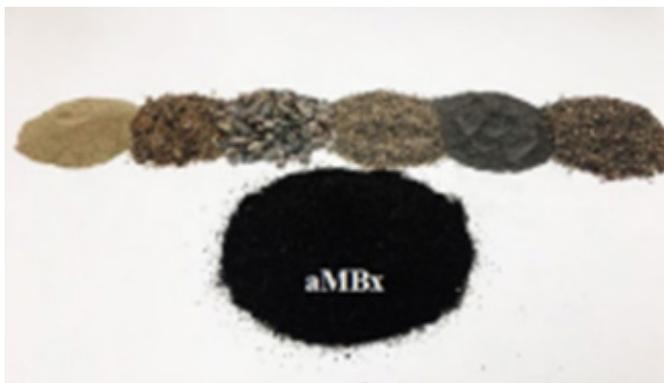
Over 75% of North America's housing has roof shingles, and 90% of those roofs are made with asphalt fiberglass material. Asphalt is one of the least energy-efficient roofing materials because it absorbs and conducts heat from the sun to attics. As a result, consumer demand for energy-efficient roofs is greatly rising (Figure 34). Furthermore, asphalt shingles' durability is affected by weathering and moisture. They typically age/dry out from the heat, which makes them brittle. With a lifespan of just 15 to 20 years, asphalt shingles annually produce an estimated 11 million tons of waste in the US.



**FIGURE 34**

Attic heat underneath asphalt shingles.  
(Credit: [Green Building Advisor](#))

There is a need to better tackle energy storage and extend the durability of asphalt roofing shingles. This project developed a modification of asphalt shingles with an encapsulated aerogel product, called Aerogel Modified Bituminous material (aMBx), recently developed at Arizona State University (Figure 35). HUE expected that (1) aMBx would act as



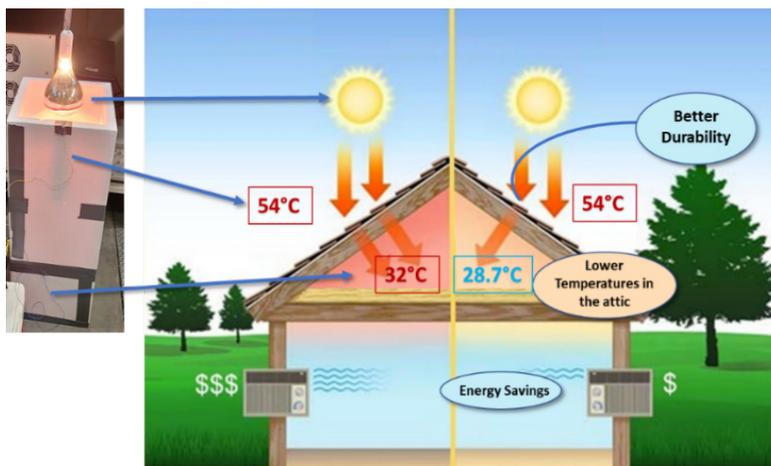
**FIGURE 35**

Appearance of aMBx.

an insulator and make roofing shingles less temperature susceptible and that (2) the modified shingles would in turn offer an improved thermal resistance by reducing cooling and heating loads in homes and buildings—thus potentially reducing the urban heat island effect.

As part of this project, HUE researchers explored two methods for incorporating aMBx in roofing shingles after consultation with GAF, one of the leading companies in roofing shingles manufacturing. The team also conducted thermal properties testing; thermal properties of aMBx have shown excellent thermal resistance in asphalt materials. Some data of interest include those particles ranged from 0.1 to 3mm, density ranged from 0.32 to 0.38 g/cm<sup>3</sup>, and thermal conductivity ranged from 0.15 to 0.20 W/ moK. The modified shingles proved effective in providing thermal insulation and increased durability for asphalt binders and mixtures.

HUE conducted modeling simulations using EnergyPLUS to evaluate the benefits of the roofing shingles modified with aMBx. These modified roofing shingles would offer unique thermal resistance properties, and potentially providing added value to the end user and society by saving energy, reducing cooling and heating loads during summer and winters, and reducing CO<sub>2</sub> emissions. These benefits align well with EPA's initiatives on the use of sustainable practices for mitigating the urban heat island effect with cool roofs and pavements.



**FIGURE 36**

Modeling attic heat underneath asphalt shingles based on laboratory.

### Key Takeaways

- Ramada construction materials can increase surface temperature on top of the roof and transfer heat to the roof's underside, which makes people in the shelter warmer, as well.
- Special reflective films applied to ramada roofs can potentially produce cooler temperatures by helping to reflect the sun's energy back into the sky.
- Initial results from several months of data from a scaled down test site, located at ASU's West Campus reveal that a ramada roof coated in one of these reflective films can actually remove from the urban environment – through a combination of solar reflectance and thermal emittance – 108% of the radiant energy that is incident on the surface, while a conventional ramada roof redirects only 85% of the incident radiation back into space. As a result, these cool film surfaces contribute both to local and global cooling.

#### Project Lead:

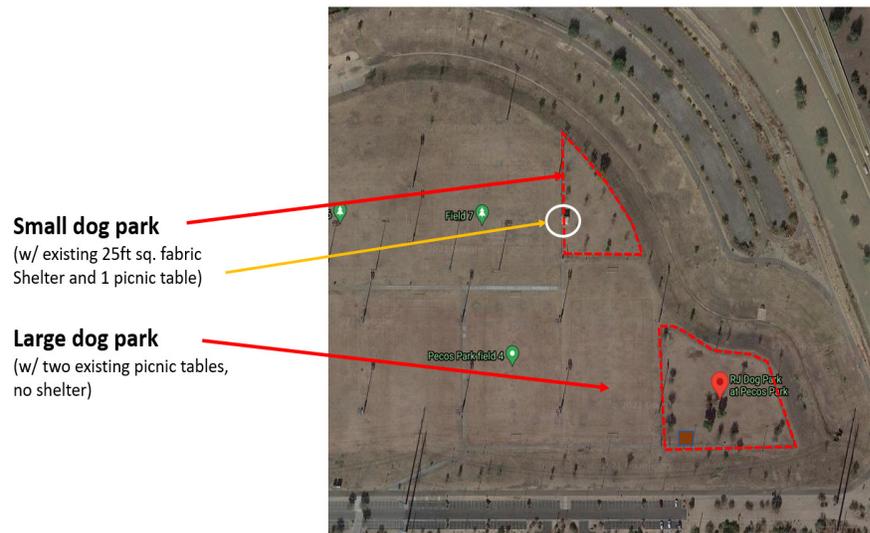
- *David Sailor*  
Geographical Sciences  
and Urban Planning, ASU

#### Partner Organizations:

- *City of Phoenix, Parks Department*
- *3M Corporation*

### Cool Ramadas

In collaboration with the Phoenix Parks Department, HUE researchers designed and installed a cool ramada shade structure in a local dog park (in Pecos Park in south Phoenix; Figure 37). The cool ramada is unique in that it uses radiative cooling films on the top surface and selective coatings on the bottom surface of the ramada roof. This creates a surface that is cooler than a conventional ramada roof structure and that, most of the time, is even cooler than the surrounding ambient air. As a result, this structure provides enhanced cooling performance in two ways: it radiates less heat (longwave/thermal radiation) to the users beneath it, directly improving pedestrian thermal comfort, and it convects less heat into the air that passes overhead, resulting in a broader urban air temperature benefit.



**FIGURE 37**

General layout of RJ dog park within Pecos Park.

HUE researchers developed a monitoring protocol, ordered/acquired sensors, designed and initiated procurement of the ramada shade structure itself, and started developing a surface energy balance model to assess thermal performance of multiple design alternatives. This model took and input the hourly environmental conditions (temperature, humidity, wind speeds, and solar radiation) as well as the upper and lower ramada roof surface radiative properties (emissivity and solar reflectance). It then estimated the diurnal course of ramada roof surface temperatures and convective heat fluxes (validated against measurements using surface temperature and heat flux sensors).

Supply chain issues delayed the delivery of the ramada structure itself, so the team could not complete their assessment of the ramada's impact during a summer period. However, installation at the end of the HUE project funding will serve as a lasting demonstration of this approach to provide cool places in community settings. Follow-up funding to complete the assessment during summer 2023 has been provided by the film manufacturer—3M—who is very interested in demonstrating this novel material in the Phoenix market.



**FIGURE 38**  
Monitoring Station.



**FIGURE 39**  
Finished Ramada Structure (no film).

### Key Takeaways

- Greywater irrigation will have positive impacts on soil health.
- Perceptions of the use of greywater and organic mulch are strongly positive and may impact decisions of where to live and shop.
- Implementation of greywater irrigation in this project provides ecological benefit and therefore is a basis for the continued use of these approaches in future urban developments. Under water scarcity demands, the potential benefits far exceed the limitations.

#### Project Team:

- *Anne Reichman*  
Director of SCN & Project Cities, ASU (Lead)
- *Jesse Westad*  
Principal/Founder, WERK | urban design
- *Brian Sager*  
Principal/Landscape Architect, WERK | urban design
- *Die "Kristen" Hu*  
Design, ASU
- *Jillian Edmonson*  
Design, ASU

### ECO PHX Project

ECO PHX, located at 301 W. Roosevelt Street, is a mixed-use urban infill development of 70 apartment homes and six commercial spaces in downtown Phoenix (Figure 40). This new development uses alternative materials and innovative landscape design solutions. Among those design solutions are two innovations not commonly seen in high-density development projects. The first of these is the use of greywater, generated from residential shower use, as a supplemental irrigation water source. The second is the use of organic mulch, such as shredded wood, in lieu of the commonly used decomposed granite, as ground covering. For this project, the team demonstrated that these two innovations/materials had a measurable qualitative impact on prospective ECO PHX residents' decision to move to the development and/or to continue living there.

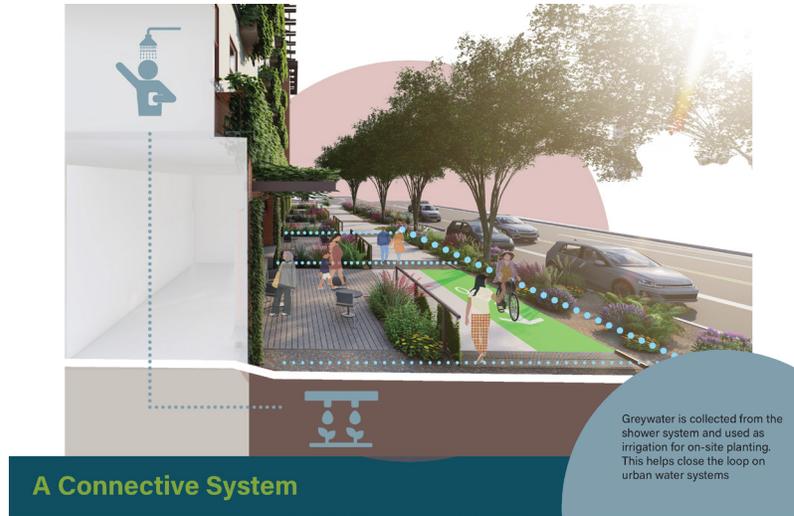


**FIGURE 40**

ECO PHX under construction. (Credit: AboveAZ)

The use of greywater as a supplemental irrigation source in built landscapes is uncommon. To facilitate its use in a public, commercial development such as ECO PHX, the design team invested significant time coordinating with the City of Phoenix development review staff to gain their support for this application. Organic mulch is used as a ground cover at ECO PHX. The material is hypothesized to provide many co-benefits related to air quality and heat, particularly in a desert environment, such as reducing the use of leaf blowers, capturing and sequestering settled dust (and reducing imported fines), and attenuating surface and ambient temperatures.

**FIGURE 41**  
ECO PHX rendering of a connective system (Credit: Jillian Edmonson)



HUE was tasked with researching two primary questions and hypotheses related to the ECO PHX project: Would the abundant use of greywater as irrigation have a measurable impact on the soil? Would the landscape that results from the use of these systems and materials be healthier, and might that have a measurable qualitative impact on prospective residents' decision to move here?

Over the course of the project, HUE researchers collaborated with WERK | urban design to collect, test, and analyze ten soil samples for quality and promotion of soil health to mitigate heat and improve air quality. In addition, the team distributed an opinion survey to assemble data on whether such features influenced prospective residents' perceptions and desire to live in developments with greywater systems. Final data and findings will guide future investments in dense housing solutions from different sectors (academic, public, private) to further support the use of innovative options to improve local livability in urban developments.

**FIGURE 42**  
ECO PHX streetscape rendering. (Credit: Jillian Edmonson)



### Key Takeaways

- Field testing shows that biologically inspired approaches to stabilize desert soils with a crust produced by an enzyme spray can effectively lower dust entrainment rates.
- Following the proof-of-concept experiments funded by HUE, large scale applications are currently being tested on fallow agricultural land in Pinal County.

#### Project Lead:

- *Matthew Fraser*  
*HUE & Sustainable Engineering and the Built Environment, ASU*

#### Partner Organizations:

- *Republic Services*
- *Salt River Landfill*
- *Freeport McMoRan*

### Novel Approaches for Dust Control

Dust entrainment from uncovered soil results in poor air quality in hot, arid locations such as Maricopa County. The standard approach to control such dust is water spraying, which in summer conditions is a very temporary solution. Alternative approaches include enzyme-induced calcium precipitation (EICP), where a biologically derived enzyme is sprayed on soil to cause calcium carbonate precipitation, which binds soil grains together to reduce dust entrainment.

HUE conducted two demonstrations in collaboration with local industry and ASU's Engineering Research Center for Bio-Mediated and Bio-Inspired Geotechnics. The first demonstration was at the Apache Junction landfill, operated by Republic Services; the second demonstration was at the Salt River landfill, operated by the Salt River Pima-Maricopa Indian Community. In both applications, bare soil was treated with EICP solutions and monitored for the rate of dust entrainment.

The effectiveness of the treatment on dust suppression was quantified on a range of possible dust suppression approaches. Treatments tested in the field included EICP, EICP with xanthan gum additive (xEICP), magnesium chloride ( $MgCl_2$ ), and microbially induced calcium precipitation (MICP). The impact of each dust control approach was tested relative to a control plot, using two experimental methods to quantify each approach's effectiveness at reducing dust entrainment. First, air quality sensors were installed surrounding the treated plots to determine if periodic wind gusts resulted in decreased dust entrainment in the treated plots compared to control/untreated plots. This approach depended on wind gusts sufficient to result in soil entrainment and resulted in a sparse data collection with only limited conditions of dust entrainment.



**FIGURE 43**

Aerial view of EICP treatment at the Salt River Landfill.

**FIGURE 44**

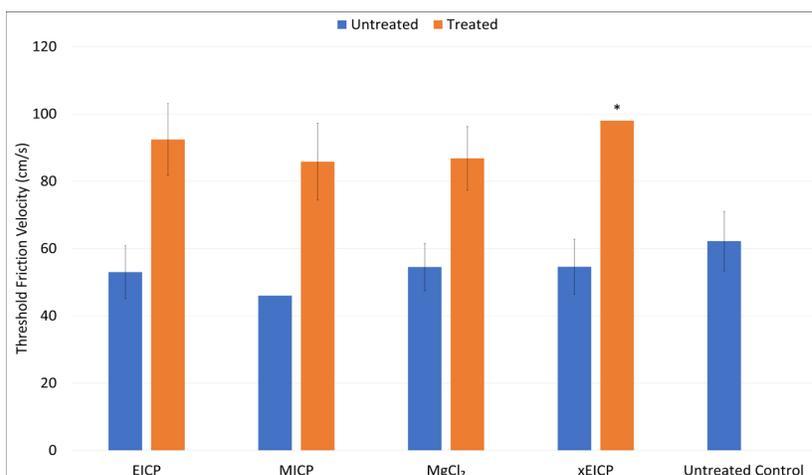
EICP treatment at the Apache Junction Landfill.



The second approach used a portable device to test at which wind velocity the soil structure breaks down, resulting in a dust cloud. This wind speed—called the “threshold friction velocity”—quantifies how strong wind conditions need to be to cause widespread dust entrainment from different plots and allows comparison of treated versus control plots. As shown in Table 2, the threshold friction velocity for treated plots was higher for all four treatment approaches relative to control conditions. Note for the xEICP treatment, the threshold friction velocity exceeded the range of the testing equipment (noted by the asterisk). These higher-threshold friction velocities as a result of treating indicate that the soil is more stable, less prone to dust release, and can be expected to lower airborne particle concentrations under windy conditions.

**TABLE 2**

Threshold Friction Velocity – the wind speed at which soil structure is broken and a dust storm develops – for different treatment approaches. Higher velocity reflects greater soil stability and lower dust entrainment.



### 3.0 HUE Impact

Thanks to Maricopa County Industrial Development Authority's (MCIDA) generous support and to our partner organizations and collaborators, HUE met its primary objectives. From empowering communities to developing new technological solutions to heat and air quality to demonstrating these approaches and educating community stakeholders, HUE's projects show how Arizona can be a model for other regions responding to and preparing for impact of a changing climate.

HUE also made progress in two difficult areas not explicitly captured in our initial objectives: institutional responses to heat and changing the narrative for local and national portrayals and popular perceptions of Maricopa County. We are proud of what the HUE team of diverse collaborators has accomplished and look forward to continuing returns on their hard work based on the productive partnership between MCIDA and ASU.

#### 3.1 Community Impact

The grand challenge of transforming urban centers to be more resilient to changing environmental conditions – to promote thermal comfort and mitigate air pollution – starts with engaging communities. When externally developed strategies are imposed on local communities without considering locally-derived priorities, the neighborhoods impacted are often not committed to achieving the goal of resilient infrastructure. For this reason, HUE projects were typically launched by partnering knowledge development with trusted community partners.

While communities across Maricopa County are exposed to urban heat and poor air quality, many HUE projects focused on developing, demonstrating and deploying solutions to urban heat and poor air quality in those communities most vulnerable to impact such as South Phoenix, Edison-Eastlake, West Mesa and mobile home communities across Maricopa County. From considering urban form and function to promote thermal comfort, to developing Resilience Hubs for community engagement, to focusing on the cooling impact of green infrastructure, to mobile cooling centers to provide services where needed, HUE collaboratively developed solutions to improve air quality and thermal comfort across the Valley. Beyond these tangible outcomes, HUE built relationships with and among community members which broke down barriers between community stakeholders, promoted knowledge sharing and enabled a new strategy of collaboratively solving our common challenges.

Beyond defining community based on physical neighborhoods, HUE convened stakeholders from a diverse range of organizational structures including government partners, the private sector and non-profit organizations to build collective action on solutions to rising urban heat and degraded air quality. HUE projects engaged with

government partners from the cities of Phoenix, Tempe, Scottsdale, Chandler and Mesa), Arizona Departments of Environmental Quality and Health Services, Maricopa County Facilities Management and Public Health Departments and the Federal National Oceanic and Atmospheric Administration; local schools including Paideia Academies, BASIS and Arizona College Prep; the corporate sector including 3M, Republic Services, GAF Industries and Salt River Project; and non-profits including the Foundation for Senior Living, Unlimited Potential and The Sagrado. By serving as a nexus of interested parties, each with an important role to play in solving pressing urban challenges, HUE has catalyzed ideas into action towards a more sustainable Maricopa County.

### 3.2 Institutional Response

Ongoing issues with extreme heat in the Valley and research as part of the HUE project have spurred conversations regarding the institutional response to heat in the region. While government agencies and frameworks dedicated to addressing air quality and flood control exist, historically there have not been official positions or departments with a specific mission of addressing extreme heat in the Valley. As a first step local cities established offices of Sustainability and/or Resilience: Phoenix in 2014, Tempe in 2016, and most recently, Scottsdale in 2022. With these officers as champions, major developments have occurred since HUE's inception that point to increasing recognition that more must be done at an institutional level to address extreme heat. In 2021, the City of Phoenix became the first municipality in the US to create a publicly funded office specifically dedicated to addressing heat. Chosen to lead this newly formed Office of Heat Response and Mitigation was Dr. David Hondula, an ASU associate professor and frequent HUE collaborator who has led numerous HUE research projects. In addition, the HUE model of encouraging collaboration between ASU researchers and external partners generated projects working directly with local municipalities. For example, results of a partnership between ASU researchers and the City of Tempe as part of the HUE project "Heat and Health Maps for Decision-Making in Tempe" led to including the project's results in the [City of Tempe's 2022 Climate Action Plan Update](#). Although work is ongoing to continue improving institutional responses to extreme heat in the region, HUE has yielded new knowledge, partnerships, and conversations that have helped to drive urban sustainability forward. Finally, HUE is working to provide resources and training related to important workforce related topics relevant to improving air quality and mitigating urban heat. We are collaborating with ASU's Office of University Sustainability Practices to roll out a workforce training program to promote trip reduction that will be broadly available to employers in Maricopa County.

### 3.3 HeatReady Cities, Schools, and Neighborhoods

Tackling extreme heat can be a daunting task for municipalities, schools, and residents. The promise of the HeatReady suite of solutions is to demystify creating and implementing evidence-based solutions appropriate for the hyperlocal climate. The frameworks for approaching heat emergency solutions and longer-term heat mitigation and adaptation strategies define responsible parties, appropriate first steps, and evaluative criteria. HeatReady encourages collaboration, coordination of resources, and a multitude of approaches to increase thermal comfort, especially for the most heat-exposed populations. Pilot project results are promising, and interest in scaling up with the support of federal agencies is being discussed. A HeatReady City, School, or Neighborhood would be able to manage heat, even under an increasing heat scenario, to protect people from heat illness, avoid deaths, and increase thermal comfort for all.

### 3.4 Decision Theater

Stakeholders working on extreme heat issues across Maricopa County, including municipalities, nonprofits, researchers, and concerned community members, need to evaluate numerous locations and solution types in order to make the best decisions for actions related to addressing extreme heat. As described in Section 2.4 (Decision Tools), HUE partnered with the Decision Theater at ASU to develop a webtool that synthesizes various datasets related to heat vulnerabilities and solutions across urban Maricopa County. One aspect of this partnership involved hosting workshops that brought together representatives from various groups, including city staff and community organizations, to provide feedback on creating a helpful resource that can guide conversations related to extreme heat and provide insights on implementing solutions. In a series of three workshops, stakeholders were able to discuss how the webtool may impact their work and suggest improvements in the design and contents of the webtool. Suggestions from these workshops were used to make changes in the webtool to improve the functionality and usefulness for stakeholders. The regional [Heat Vulnerability Map and Cool Solutions Webtool](#) is publicly available and provides a means for exploring temperature, vulnerabilities to heat, and solutions to extreme heat developed by HUE researchers and other organizations in the region.

### 3.5 Infrastructure and Technology

HUE's long-term impact is also demonstrated in the translation of materials and technology from the laboratory into practice. As HUE focused on developing new technologies, demonstrating existing technologies, and deploying proven approaches, different engineered infrastructure solutions have been developed to unique technology readiness levels: some are still undergoing development, some are being translated into production, and others have been deployed and are a permanent illustration of the ability to improve thermal comfort and improve air quality.

For the technologies still being developed, HUE work on demonstrating air pollution-removing solar panels has continued, with additional industrial funding, to engineer a solution to air pollution emission sources—rather than targeting control of ambient air pollution. HUE researchers Prof. Pierre Herckes and Prof. Matthew Fraser received \$249,000 in funding from the Semiconductor Research Corporation to collaborate with Intel, Texas Instruments, IBM, and Global Foundries on implementing the HUE-sponsored photocatalytic NOx system in an industrial setting. HUE research on quantifying the benefit of a novel dust suppression approach to mitigate air pollution received \$956,000 in funding from the Arizona Board of Regents (ABOR) to implement enzyme-induced calcium precipitation for dust control on fallow agricultural land in Pinal County.

For more mature technologies in the HUE portfolio, industrial collaboration is seeking to translate knowledge into industry. HUE researcher Prof. Kamil Kaloush is working with GAF Materials in Phoenix to incorporate knowledge from HUE research on modified asphalt shingles into commercial products. In summer 2023, HUE researcher David Sailor will evaluate and monitor the durability of 3M's highly reflective material used in the cooling ramada, with financial support from 3M.

### 3.6 Extreme Heat Toolkits

HUE offers resources for practitioners in the fields of education, industry, community and government. The following thirty-six documents contain well over one hundred best practices, recommendations, scorecards, and tools for decision-making with resilience to extreme heat in mind. Each of these documents can be reached via the live link in this report or via the HUE website. They contain background information, rationale for the suggestions, and examples where they have been employed.

#### Education

##### [HeatReady Schools](#)

- [Scorecard](#): Assessment of a school's heat preparedness, providing data-driven recommendations for interventions in the areas of school policy, environment, training, prevention, and community.
- [Decision-making Tree and Basket](#): A companion to the HeatReady Schools Scorecard, this tool is aimed to facilitate the planning process by providing prompts that will help prioritize actions on the path to heat resilience. This can be done collaboratively between school staff and administrators, staff and students, and even incorporating input from parents and community members.
- [Summer Emergency Preparedness course](#): Interactive K-12 extreme heat risk course with supplemental activities for enhanced learning.
- [HeatReady Teacher Training](#): Especially designed for pre-service teachers to implement heat safety measures into their learning environments.
- [Intro to Extreme Heat](#): Heat safety training for caregivers and community members.

[Coordinated Approach to Child Health \(CATCH\) Sunbeatable program](#)  
(Self-paced for teachers - lessons can be bundled together or split by unit): Available for Pre-K – 5th grade students, it includes instructions and a training webinar, as well as action steps for teachers to effectively implement the program and engage parents in the curricula, too. This is an interactive program especially aimed at sun safety to prevent skin cancer. Even though it is not directly addressing HRIs, the behaviors addressed in this course are tied to actions that are preventative for HRIs, too.

[Recognizing, Preventing and Treating Heat-Related Illness: a CDC training course](#)

Especially recommended for educators and PE/sports coaches, this course provides information on risk conditions, warning signs, and treatment of heat-related illnesses.

[Natural Environmental Education Foundation \(NEEF\) Sunwise program](#)

Available in English and Spanish, this program provides K-8 lesson plans and activities for formal and informal educators focused on sun safety and health.

[ADHS Heat Illness Prevention School Project \(HIPSP\) Toolkit](#)

The goal of the toolkit is to educate students, school staff, athletic coaches, and parents regarding heat-related illness and prevention. The Heat Illness Prevention School Project aims to reduce the number of heat-related illnesses in schools (ADHS, 2023).

[Managing Extreme Heat Recommendations for Schools \(Pilot Version\)](#)

This document provides recommendations for schools serving grades K-12 on actions to mitigate the effect of extreme heat on students and reduce the frequency of heat-related illness among students. To aid in the formulation of district-level heat policies, this document also provides a summary of practices that schools can consider and adopt based on each district's environment and resources (ADHS, 2021).

[CDC Body and Mind \(BAM\) Sun Safety Tips for Schools](#)

Tips and strategies for schools to improve sun safety measures with an emphasis on skin safety and prevention to overexposure to heat and sun radiation.

[CDC Shade Planning for America's Schools](#)

Resource for school officials and administrators to inform the planning process of shade additions to school facilities.

[National Health Education Standards and Heat Related Illness Prevention](#)

Educational Standards that outline performance indicators related to lessons on heat related illness prevention.

**Industry**[Cool Region Toolkit](#)

This webtool maps land surface temperature comparisons and infrastructure locations to allow stakeholders to compare and contrast needs and existing infrastructure in different locations, and presents relevant, contextually-appropriate solutions to extreme heat.

[MCDPH Heat Toolkit](#)

Outlines information and services provided by the Maricopa Department of Public Health, as well as other trusted sources like the Maricopa Association of Governments and the Centers for Disease Control.

[Outdoor Worker Heat Safety/Spanish Version](#)

Provides concise guidance and recommendations for workers to stay safe during outdoor activities in high heat environments.

[NIOSH Criteria for Recommended Standard:  
Occupational Exposure to Heat and Hot Environments](#)

The 2016 revision of the document includes updated information on heat-related illnesses, risk factors affecting heat-related illness, physiological responses to heat, effects of clothing on heat exchange, and recommendations for control and prevention.

[NIOSH Heat Stress Recommendations](#)

Basic recommendations for control of heat stress, training, acclimatization, hydration, and rest breaks.

[ADHS Outdoor Worker Heat Safety Toolkit](#)

The toolkit provides outdoor workers and employers with resources to prevent, recognize, and treat heat illness utilizing information developed by the Occupational Safety and Health Association (OSHA). (ADHS, 2023).

[White House Planning Tools for Combating Extreme Heat](#)

Multiple Federal and private resources are available to help identify how investments in urban green infrastructure will help combat extreme heat, and to better understand the risks posed by extreme heat and poor air quality. (WH, 2023).

[Design Performance Scale-Up Evaluation Tool for Sustainable Business](#)

This design performance evaluation tool aims at providing local businesses with a platform to evaluate the sustainability practices of their business. Overview of research and instructions for tool provided.

[Reducing Ozone Using Teleworking as Strategy](#)

This report presents a series of recommendations for managers and employees to create stronger teleworking programs.

## Community

### [HeatReady Neighborhoods Community Action Plan](#)

The HeatReady Neighborhoods rubric is a comprehensive list of possible interventions where communities can select priorities under the themes of Equity/Inclusion, Neighborhood Cohesion, Education/Advocacy, Emergency Preparedness, Landscape Level Changes, and Funding, for heat mitigation and adaptation purposes at the neighborhood level.

### [CDC Heat and Health Tracker](#)

This tracker provides information about extreme temperature trends and health vulnerabilities both on the local and national level, to inform preventative actions. This website links to other CDC extreme heat adaptation resources that can be helpful in adopting heat-related illness tracking and monitoring measures.

### [American Red Cross - Heat Wave Safety](#)

This resource outlines “before, during, and after” actions to take during an extreme heat event for those vulnerable to extreme heat, including people with disabilities, children, older adults, and pets. This site is especially helpful to share with community members, as the recommendations given can easily be applied to workplaces, homes, and other spaces.

### [ADHS Heat Alerts](#)

Individuals and institutions can sign up for extreme heat alerts from ADHS, receiving information on air quality index and other health indicators during heatwaves.

### [ADHS/CDC Caregiver fact sheet for heat-related illnesses](#)

This document is designed to help caregivers recognize the symptoms of heat-related illness (HRI) and learn about how to prevent and treat its occurrence.

### [Heat Relief Network](#)

The Heat Relief Network is a regional partnership of the Maricopa Association of Governments (MAG), municipalities, nonprofit organizations, the faith-based community, and businesses. Each year, MAG coordinates the mapping of the Heat Relief Network, a network of partners providing hydration stations, refuge locations, and water donation sites throughout the Valley with the goal of preventing heat-related illnesses and deaths among vulnerable populations. The map and directories are updated as new partners sign up throughout the summer season, which runs May 1 to September 30. (HRN, 2023)

### [211 AZ Heat Relief Transportation](#)

2-1-1 Arizona and Arizona Public Service (APS) have partnered to offer rides to cooling centers and emergency heat relief stations during Arizona’s hot summer months.

#### [National Integrated Heat Health Information System](#)

A collection of heat health tools and products from across public agencies. Tools in this section can help community members prepare for heat events and learn more about their risk to extreme heat (NIHHIS, 2023).

#### [FEMA Preparedness Community - Extreme Heat](#)

Information about heat emergencies and recommendations of research-backed protective measures before, during, and after heat events.

#### [Ready.gov Disasters and Emergencies - Extreme Heat](#)

Information on heat-related illnesses and heat safety tips and resources.

### **Government**

#### [HeatReady City Standards](#)

City-level actions, in research, policy, and governance, to optimize responses and mitigation efforts to extreme heat. Now being implemented as part of the City of Phoenix's [Office of Heat Response and Mitigation](#) or HeatReady PHX.

#### [Planning for Urban Heat Resilience](#)

The report lays out the complexity of heat, outlines the role of planners in equitably addressing heat, and presents a framework for how planners can mitigate and manage heat across a variety of plans, policies, and actions. (Keith & Meerow, 2022)

#### [EPA Excessive Heat Events Guidebook](#)

This guidebook provides public health officials with background information on extreme heat event risks and impacts to roughly assess potential local health risks from these events. In addition, it provides a menu of notification and response actions to consider when developing or enhancing a local heat action program (EPA, 2016).

### **3.7 Media Coverage**

As one component of the HUE mission is to serve as a nexus for solutions to mitigate urban heat and air quality, sharing knowledge and solutions with broadly defined stakeholders is key to the impact of our program. For this reason, HUE has worked diligently to share our stories and successes with as broad an audience as possible. Below is a list of these media mentions; full details are available on the HUE website at <https://sustainability-innovation.asu.edu/hue/news/>.

Date	Topic	Outlet
7/19/2019	<a href="#">HUE Researcher Highlights the Impacts of Extreme Heat on Outdoor Playgrounds</a>	Boston Globe
11/7/2019	<a href="#">HUE Researcher Receives Maricopa County's 2019 Climate and Health Champion Award</a>	MaricopaCounty.gov
5/5/2020	<a href="#">HUE's "Cool Pavement" Project Featured in AZ Central</a>	AZ Central
6/30/2020	<a href="#">HUE Researchers Address Heat, Health, and COVID-19 on the "Vitalyst Spark" Podcast</a>	Vitalyst Health Foundation
7/8/2020	<a href="#">HUE's HeatReady Initiative Highlighted in the Washington Post</a>	Washington Post
7/29/2020	<a href="#">HUE Researchers Highlight "Cool Pavement" Project</a>	AZ Big Media
8/26/2020	<a href="#">HUE Researcher Discusses Dangers of Extreme Heat and the Most Vulnerable</a>	Arizona Republic
8/31/2020	<a href="#">HUE Researchers Highlight Importance of Neighborhood Engagement when Addressing Extreme Heat</a>	Arizona Republic
10/8/2020	<a href="#">HUE's Efforts to Combat Phoenix Heat in State News</a>	The State Press
10/19/2020	<a href="#">HUE Researcher Discusses the Benefits of Reducing Surface Temperature</a>	AP News
1/31/2021	<a href="#">HUE Researcher Talks Extreme Heat Solutions for Low-Income Households</a>	Arizona Republic
6/6/2021	<a href="#">HUE Researcher Brings Awareness to Disparities of Extreme Heat and Low-Income Housing</a>	Arizona Republic
6/2/2021	<a href="#">HUE Researcher Discusses Shade Alternatives Based on Local Research</a>	ASU News
6/7/2021	<a href="#">HUE Researchers Speak to PBS' 'Weathered' about Common Disasters and How to Prepare</a>	PBS 'Weathered' News
6/10/2021	<a href="#">HUE Researchers Provides Insights on CoolSeal</a>	ABC15 News
6/17/2021	<a href="#">HUE Researcher Shares Shade and Thermal Comfort Insights</a>	NatGeo Magazine
6/20/2021	<a href="#">HUE Researcher Discusses Phoenix's Extreme Heat and Housing Shortage with The New York Times</a>	The New York Times
7/21/2021	<a href="#">HUE Researcher Testifies to U.S. House of Representatives Committee on Extreme Heat</a>	Congress.gov/ House.gov
8/4/2021	<a href="#">HUE Researcher Talks Partnership with 3M to Reduce Temperatures around the Valley</a>	ABC15 News
8/23/2021	<a href="#">HUE Researchers Discuss Impacts of Extreme Heat on the "Come Rain or Shine" Podcast</a>	SW CASC/USDA SW Climate Hub
9/20/2021	<a href="#">HUE Researcher Discusses Cool Pavement Program's First Year Results</a>	KTAR News
9/23/2021	<a href="#">HUE Researchers Provide Update on Cool Pavement Pilot Program and New Cool Corridors Program</a>	AZ Big Media

9/28/2021	<a href="#">Focus on HUE “Cool Ramadas” Partnership with 3M</a>	The State Press
9/29/2021	<a href="#">HUE-City of Tempe Collaboration on Jenny’s Trailer (a mobile cooling trailer)</a>	KJZZ
10/3/2021	<a href="#">HUE Researcher Provides Update on Cool Pavement Program</a>	12News
10/12/2021	<a href="#">HUE Researcher Appointed First Phoenix Heat Officer</a>	Arizona Republic
10/21/2021	<a href="#">Focus on Cool Pavement Results Measured by HUE Researchers</a>	Business Wire
10/27/2021	<a href="#">HUE Researcher Discusses “Cool Corridors” project and the NCS Heat Action Guide</a>	Arizona Republic
12/6/2021	<a href="#">HUE’s Cool Pavement Program Receives Spotlight in Economic Assessment of Heat Report</a>	The Nature Conservancy
1/26/2022	<a href="#">HUE Researchers Discuss New Resilience Hub in Tempe</a>	KJZZ Radio
4/1/2022	<a href="#">HUE Researcher Selected to Participate in the American Council on Education (ACE) Fellows Program</a>	ASU News
5/3/2022	<a href="#">HUE Researchers Describe Tempe’s Resilience Hubs</a>	NPR News
6/1/2022	<a href="#">HUE Researchers Continue to Bring Awareness to New Resilience Hubs in Tempe</a>	ABC15 News
6/1/2022	<a href="#">HUE’s “HeatReady Schools” Program Featured on Local News Station</a>	ABC15 News
6/8/2022	<a href="#">HUE Researcher Wins TIME’s 2022 Innovative Teachers Award</a>	TIME Magazine
6/14/2022	<a href="#">HUE Researcher Featured in Local News for Winning TIME Award</a>	Chandler News
6/15/2022	<a href="#">HUE Researchers Talk Awareness of / Efforts to Mitigate Extreme Heat</a>	Grist Magazine
6/16/2022	<a href="#">HUE Researcher Addresses Extreme Heat Impacts on Mobile Home Communities</a>	The Washington Post
6/30/2022	<a href="#">HUE’s Mobile Cooling Trailer “Jenny’s Trailer” Covered in University News</a>	ASU News
7/27/2022	<a href="#">HUE’s “HeatReady Schools” Featured on an International Weather Station</a>	The Weather Channel (Spanish)
7/29/2022	<a href="#">HUE Researchers Receive Additional Funding to Address Local Air-Quality Concerns</a>	ASU News
8/2/2022	<a href="#">HUE Researcher Highlights Efforts Being Done to Address Extreme Heat</a>	Cronkite News, Arizona PBS
8/2/2022	<a href="#">HUE Researcher Discusses Impact of Extreme Heat in Phoenix</a>	The Guardian
8/24/2022	<a href="#">HUE Researcher Talks about Homelessness and Heat</a>	NPR News

8/29/2022	<a href="#">HUE Researcher Recognized for Urban Heat Resiliency Research</a>	ASU News
9/8/2022	<a href="#">HUE's "Waking up Wall Street" Project Featured in Local News</a>	Chandler News
10/5/2022	<a href="#">HUE Researchers Shed Light on Methods Implemented to Provide Shade to Pedestrians across ASU Campus</a>	The State Press
10/19/2022	<a href="#">HUE Researchers Discuss Ways to Cope with Extreme Heat Exposure</a>	ASU News
11/2/2022	<a href="#">HUE Researcher Talks Extreme Heat and the Risk to Mobile Home Communities</a>	Slate Magazine
11/7/2022	<a href="#">HUE Researcher Receives Additional Funding to Combat Extreme Heat</a>	ASU News
11/9/2022	<a href="#">HUE Researchers Awarded Funding to Continue Tackling Extreme Heat</a>	UofA News
1/20/2023	<a href="#">HUE's "HeatReady Schools" Featured in University News</a>	Yale Climate Connections
1/30/2023	<a href="#">HUE's "Cool Pavement" Project Spotlited in Government Magazine</a>	American City & County Magazine
3/17/2023	<a href="#">HUE's Air Quality Sculpture Featured in Local News</a>	AZ Republic
3/17/2023	<a href="#">HUE's "Heat Vulnerability Map &amp; Cool Solutions Webtool" Featured in University News</a>	ASU News
4/12/2023	<a href="#">HUE Researcher Participated in Video Segment about Fighting Extreme Weather</a>	NOVA
4/14/2023	<a href="#">HUE's Cool Pavement Project is Highlighted in Local News</a>	Arizona Republic
4/14/2023	<a href="#">HUE Researchers Highlight UHI Mitigation Strategies, including "Cool Corridors" Project</a>	NOVA
4/21/2023	<a href="#">HUE's "Heat Vulnerability Map &amp; Cool Solutions Webtool" Spotlited in State News</a>	AZ Capitol Times
4/26/2023	<a href="#">Mayor Gallego Speaks about HUE-funded Projects</a>	SDG Knowledge Hub

## 4.0 Changing the Narrative to a New Perspective

For most of the twentieth century, people across the US looked to Arizona as a place of respite, recreation, and refuge. Individuals suffering from health ailments such as asthma and tuberculosis migrated to the desert for the dry air and warm climate. As farmland and resorts evolved into city centers and suburbs, the picture dramatically changed. The influx of those seeking a better life has led to an increasingly diverse and successful economic landscape but has also led to the region becoming emblematic of a city that sits precariously between scarcity and abundance. Climate, once touted as one of Arizona's chief assets, has in recent years become seen as a liability due to the extreme heat of the summer months. This narrative of Maricopa County as exemplifying uncontrolled, sprawling urbanism—where it is so hot one can fry an egg on the pavement—has become a cliché, largely due to writers from the East coast (front page article in New York Times Dec. 29, 1996 and widely publicized book, *Bird on Fire*, by Andrew Ross, 2011).

It is into this dire scenario, which threatens our future economic vitality, that Maricopa County's Industrial Development Authority and Arizona State University have jointly stepped to form the Healthy Urban Environments Initiative (HUE). HUE, together with its partners, has taken giant strides to change this perception by establishing a solutions-focused research, policy, and technology incubator designed to rapidly test, develop, and deploy heat mitigation and air quality improvement strategies and technologies. Despite the increasing heat of the past several years, the impact of the 33 HUE pilot projects has begun to transform the negative narrative into one of a county and its cities meeting these challenges with innovative, practical solutions and a can-do spirit. Ultimately, these efforts will improve the health of our communities, save lives, and allow continued and sustainable regional economic expansion. By one important measure, media coverage, both local and national, has changed its tune and is rightly heralding Maricopa County's leadership in meeting these challenges (see 3.7 for a list of HUE-related media coverage).

To ensure the region continues to prosper and provide an attractive quality of life, it is imperative that we build partnerships and share up-to-the-minute information so that every community across Central Arizona can improve thermal comfort and local air quality.

# HUE

## HEALTHY URBAN ENVIRONMENTS INITIATIVE

A digital version of this report, as well as resources for the HUE-funded projects, can be found by scanning the below QR code or clicking the following link to the HUE website: <https://sustainability-innovation.asu.edu/hue/>.

