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Special Collection:
Equity in Co-Production

A Co-Produced Workflow for Addressing Inequities in Cooling Center Access

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Key Points:

- We co-produced a workflow to improve access to cooling centers for the Phoenix and Tucson areas in Arizona
- The workflow is generalizable to communities with varying levels of resources
- Iterative conversations with our partners enabled us to customize the workflow to better reflect the needs of at-risk communities

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Abstract Increasing extreme heat poses challenges to metropolitan areas, such as those areas already experiencing extreme heat in Arizona. Using the US Centers for Disease Control and Prevention (CDC)'s Building Resilience Against Climate Effects (BRACE) Framework, state and local health departments have looked to expand cooling center networks as one option to build heat resilience. We present a method to pick new locations for cooling centers based on demand and current coverage. Using two locations in Arizona, we highlight differences in workflows and how the resulting information can be incorporated into separate but parallel efforts to reduce heat impacts. We used the Network Analyst Location-Allocation tool in ArcGIS Pro to maximize coverage of cooling centers in each area, so that additional cooling centers are selected to reflect local needs. The input data and parameters of the workflow were co-produced with input from two county health departments and a cooling center working group to better address the unique challenges related to cooling center access. To facilitate the application of this approach to other regions seeking to address heat health inequities, we provide a detailed protocol and a discussion of alternative selections.

Plain Language Summary Cooling centers are a primary response to extreme heat in metropolitan areas. Ideally, they are located in ways to balance community need and broad coverage. We use existing technology and publicly available data to present a method for picking cooling center locations based on demand and current coverage. We use two locations in Arizona to highlight different choices that the users can make. The methodology is described as well as rationale for the choices and discussion of alternative options.

1. Introduction

Extreme heat is the deadliest of all weather-related hazards in the US (Berko et al., 2014). As the climate continues to warm, extreme heat will pose a greater public health threat (Ebi et al., 2006; Meehl & Tebaldi, 2004; Sarofim et al., 2016). The impacts of extreme heat are inequitable as several socioeconomic and health factors influence heat risk. People who are socially and/or physically isolated, older adults, very young, lower income, from racial and ethnic minority groups, less educated, have preexisting conditions, or experiencing homelessness tend to experience higher rates of mortality and hospitalization due to extreme heat (Basu & Samet, 2002; Dialesandro et al., 2021; Gronlund, 2014; Wilhelmi & Hayden, 2010). The impact of extreme heat can also be influenced by the perceived risk of extreme heat, prior experience with extreme heat, individual behavior, and the degree to which governance supports heat adaptation and intervention strategies in a jurisdiction (Keith et al., 2019; Yazar et al., 2022). Addressing extreme heat is a complex problem requiring a collaborative, cross-sectoral effort to bring together stakeholders from governments, communities, universities, and non-profits (Turek-Hankins et al., 2021).

Various heat adaptations and interventions are being explored as options to improve heat resilience. Meerow and Keith (2022) categorized heat resilience strategies as heat mitigation, reducing urban heat in the built environment, and heat management, preparing, and responding to both chronic and acute heat risk. They acknowledge that, to date, most heat adaption strategies focus on adjusting the design of the built environment to reduce urban heat. Examples of these design strategies include increasing tree canopy cover or surface materials reflectivity (Hatvani-Kovacs et al., 2018). Heat management strategies include efforts like improved heat warning systems or

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targeted public health campaigns focused on increasing awareness of the heat risk among communities at increased risk of exposure to extreme heat. Cooling centers are another example of a heat management strategy that offer an indoor location to provide heat reprieve.

A cooling center is generally described as an air-conditioned building designated as a location for the public to get a reprieve from the heat (Widerynski et al., 2017). Cooling centers tend to be locations whose primary function is not related to extreme heat (e.g., church, community center, or school). Generally, an organization volunteers to host a cooling center staffed by those who already work at the location and with little to no financial compensation. The network of cooling centers within a community is not typically managed by any one agency, although they can be supported by health departments, city governments, or other partners (Widerynski et al., 2017). Related, but not as robust, are hydration stations which provide shade and water, but not indoor air-conditioned cooling. Resilience hubs are an evolution of cooling centers in some locations, referring to a community-managed facility that supports residents, coordinates communication, and distributes resources and services to enhance individual and community resilience to climate impacts (Baja, 2018).

Despite cooling centers increasing role in heat management and that they improve thermal comfort, there is uncertainty regarding their effectiveness to reduce heat-related illness and death (Bedi et al., 2022). The evaluation of heat strategies and interventions, including cooling centers, is an ongoing area of research. Prior research has identified a few reasons why people are hesitant to use cooling centers. Some commonly perceived barriers that prevent someone from using a cooling center include accessibility of other cooled spaces (e.g., malls and grocery stores), concerns about boredom at the center, lack of awareness of cooling center existence or location, failure to acknowledge one's risk associated with extreme heat, restrictions around pets in the cooling center, personal safety, and concerns about leaving homes unattended (Alberini et al., 2011; Berisha et al., 2017; Sampson et al., 2013; Widerynski et al., 2017).

To maximize the potential impact of cooling centers, locations relative to people with the greatest risk of heat-related illness and death should be considered. There is considerable variability in the percentage of the US population living near a cooling center (Adams et al., 2023; Kim et al., 2021). In some US cities, cooling centers are not always within an accessible distance to at-risk populations, which implies that cooling center placement needs to be optimized to reach those with increased risk of exposure to extreme heat (Adams et al., 2023; Black-Ingersoll et al., 2022; Kim et al., 2021). For example, a study in Portland, OR, indicated that census blocks with more African American residents were more likely to live within walking distance of a cooling center (Voelkel et al., 2018). However, the same study found that census block groups with a higher portion of older adults or Asian populations had less likely to live within walking distance to cooling centers. Even though older adults are often identified as at higher risk to extreme heat exposure (Gronlund, 2014). Both Kim et al. (2021) and Adams et al. (2023) found that those 65 years or older were less likely to live within a mile of a cooling center compared to the general population. Additionally, cooling center visitors might come with different needs. Someone experiencing unsheltered homelessness might be better served by a cooling center that allows visitors to sleep, which is not always allowed in every facility that serves as a cooling center.

Research Objective: This manuscript describes the process of co-producing a workflow using commercial software to provide greater cooling center access to those with a high risk of exposure to extreme heat. We identified census tracts with high social vulnerability in two Arizona metropolitan areas (Phoenix and Tucson), which are likely to have populations at greater risk of exposure to extreme heat. The software then identifies potential new locations based on user input to minimize the distances from residences to cooling centers, while accounting for existing locations. We focus on the available options for this approach that can be applied to other areas with varying resources and historical investment in cooling centers. Some of these differences are reflected in the choices of input data and parameters provided by community partners. This document aims to provide guidance on how this optimization can be used among those working to enhance cooling center coverage for people at increased risk of exposure to extreme heat in metropolitan areas globally.

1.1. Research Question

How can community-supported spatial optimization of cooling center locations be incorporated into public health and resilience processes and plans to reduce the impact of extreme heat?

1.2. Study Area

The study area of our work includes the cities of Phoenix and Tucson in US state of Arizona. The impact of extreme heat is an increasing concern for the US Southwest. According to the Arizona Department of Health Services (ADHS, n.d.), in Arizona, there are nearly 3,000 emergency room visits associated with heat-related illness a year. Between 2011 and 2021, over 2,000 people died from excessive heat exposure (ADHS, n.d.). Maricopa County is the most populous county in Arizona, with an estimated population of nearly 4.4 million in 2020 (U.S. Census Bureau, 2020). Most of Maricopa County's population resides in the Phoenix metropolitan area (hereafter Phoenix area). Pima County, which encompasses the Tucson metropolitan area (hereafter Tucson Area), has a population of just over 1 million in 2020, accounting for most of the county's 1.04 million residents (U.S. Census Bureau, 2020).

Phoenix and Tucson experience a hot, semi-arid, climate and experience many days over 100°F (38°C) during the summer. In 2020, Phoenix experienced a heat record-breaking summer with 53 days at or above 110°F (43°C) and 145 days at-or-above 100°F (38°C). In 2021, Tucson broke a 125-year-old record for maximum temperature when the temperature reached 115°F (46°C) in June. From 2017 to 2021, Maricopa County had 1,476 heat-related emergency room visits (33.3 per 100,000 population) and 478 inpatient hospitalizations (10.8 per 100,000). During the same period, there were 287 heat-related emergency room visits (27.6 per 100,000 population) and 78 inpatient hospitalizations (7.5 per 100,000) on average, annually in Pima County. While the impact of extreme heat in this region is pronounced, heat-related deaths and hospitalizations are preventable.

Addressing the health impacts of extreme heat continues to be a priority for the Maricopa County Department of Public Health (MCDPH) and the Pima County Health Department (PCHD). MCDPH's and PCHD's approaches to addressing extreme heat are based on the US Centers for Disease Control and Prevention (CDC)'s Building Resilience Against Climate Effects (BRACE) Framework, a process which assists in the development of strategies to mitigate the potential risks of climate impacts (Marinucci et al., 2014). Operating cooling centers is one approach to reduce these impacts, especially among those with an increased risk of exposure to extreme heat. Both regions have an existing volunteer network of cooling centers, although the resources and coverage of cooling centers vary.

2. Methods

As a component of BRACE, both MCDPH and PCHD evaluate their cooling center network and resources to support the cooling centers annually. MCDPH and PCHD requested support in identifying existing locations that could be used as a cooling center in the future. The approach to identifying new cooling center locations we present here is in direct response to the request by MCDPH and PCHD to help enhance cooling center coverage for people at increased risk of exposure to extreme heat. We used the *Location-Allocation Analysis Layer* within the *Network Analyst* extension of ArcGIS Pro version 2.9.1 (Environmental Systems Research Institute, 2023) to identify locations for additional cooling centers. Our main objective is to demonstrate how this approach was used to identify new cooling center locations using open public data and taking into account MCDPH and PCHD input throughout the process.

2.1. Social Vulnerability Index

In the context of extreme heat, a social vulnerability index is often used to describe the sociodemographic variables that can influence the risk of heat-related health outcomes. We used CDC's 2018 Social Vulnerability Index (SVI), which is publicly accessible from the CDC's Agency for Toxic Substances and Disease Registry, to identify census tracts that might be home to populations at increased risk of exposure to extreme heat. The CDC's SVI was designed to reflect social vulnerability, which can influence a community's ability to respond to various hazards, including heat. While the CDC SVI is not specifically tailored to extreme heat, it is built upon many of the socioeconomic variables that are associated with heat-related risk. Most of the variables in the CDC's SVI have also been included in heat specific vulnerability indices (Bao et al., 2015; Ellena et al., 2020; Gronlund, 2014; Niu et al., 2021). The CDC's SVI does not include information related to adaptive capacity. However, in many heat-specific vulnerability indices information on adaptive capacity is often limited to central air conditioning prevalence (Belanger et al., 2015; Conlon et al., 2020). We subset the Arizona SVI data set to identify the 25% most vulnerable census tracts in Phoenix and Tucson. We selected a 25% threshold to prioritize areas with the highest social vulnerability.

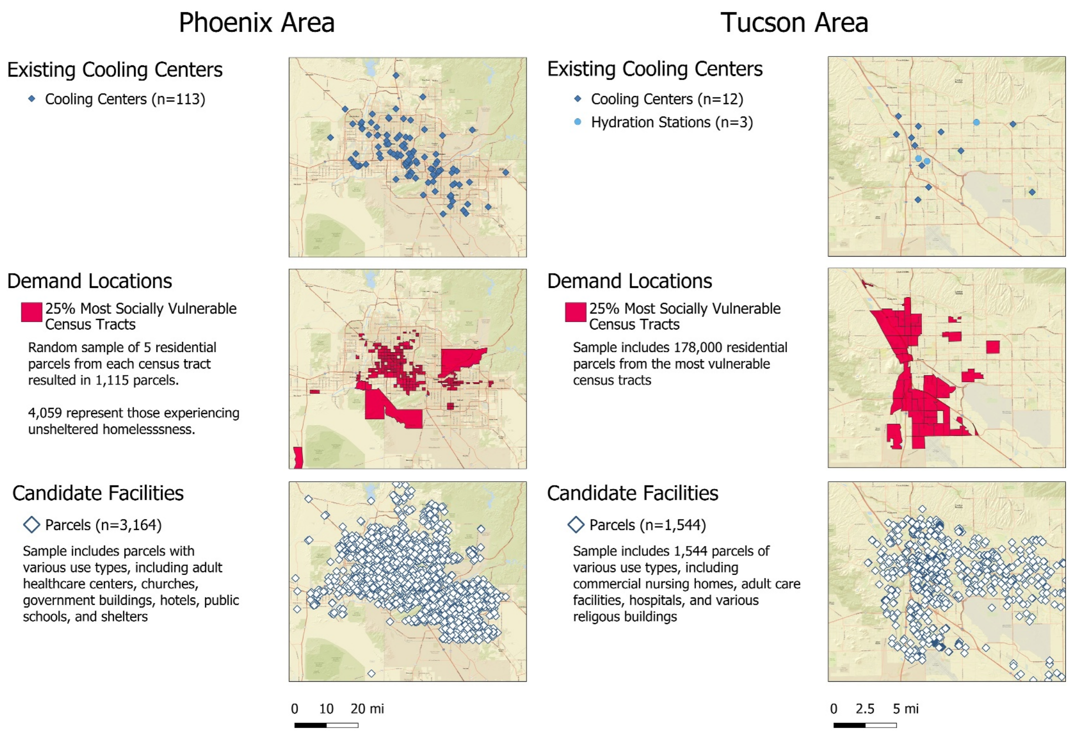

Figure 1. ArcGIS Location-Allocation tool uses existing center locations (2022), demand locations, and candidate locations to optimize the network of cooling centers for maximum coverage. This figure outlines the differences in these parameters between the two areas.

2.2. Existing Facilities

Existing facilities represent the point locations of all active cooling center locations. For the Phoenix area, this was restricted to the 113 cooling centers active during the study period. Because there were fewer cooling centers ($N = 12$) active in the Tucson area at this time, the three hydration stations (i.e., areas that provide water but not air conditioning) were also included in the analysis. See Figure 1 for a comparison of the input for both metropolitan areas. In ArcGIS, these data are identified as "required" for the analysis to ensure existing locations are included in the output of the location-allocation analysis layer. The data on cooling center locations in the Phoenix area came from the Maricopa Association of Governments (MAG), which hosts and maintains a public Heat Relief Network web map of publicly accessible cooling centers in Maricopa County (Heat Relief Network, 2022). In the Tucson area, the data on cooling centers and hydration stations came from the University of Arizona's previously developed map of Pima County cooling centers. A publicly available map of the current cooling center locations is maintained by the Pima County Health Department (Pima County Cooling Centers, 2022).

2.3. Candidate Facilities

Candidate facilities represent the potential locations of additional cooling centers. In ArcGIS, candidate facilities are represented with parcel data. These data are identified as "candidate" for the analysis to identify that the facility may be selected but is not required. The parcel data was acquired from the online databases of the Arizona Tax Assessor and Pima County Tax Assessor and converted from polygon to points defined by the centroid of each polygon.

In the Phoenix area, a broad range of parcels were included that could serve as potential locations for cooling centers, including parcels designated for use as churches, adult healthcare centers, government facilities, hotels (especially for emergency responses), schools, and shelters. Computational constraints in running the optimization precluded the inclusion of commercial locations from the optimization in Phoenix. We started with a broader set of candidate parcels in Phoenix based on initial conversations with partners at the Arizona Department of Health Services, Maricopa County Department of Public Health, and Maricopa Association of Governments and current efforts to support the Heat Relief Network (HRN). In Phoenix, the spatial optimization of cooling centers is one tool meant to help support the broader efforts to identify locations near populations at increased risk of exposure to extreme heat that could be recruited into the HRN. Additionally, even if a parcel is optimally located near at-risk populations, there are other factors to consider when determining if the parcel would work as a cooling center. In Phoenix, if a candidate parcel is selected by the optimization to serve as a cooling center, then local partners can reach out to that location to see if they would like to volunteer as a cooling center. If they are interested in volunteering, they must complete the HRN's Sites Standards & Expectations and application forms. If managers at a chosen candidate parcel decided not to participate in the HRN, we would look at parcels within a mile of the chosen candidate parcel as potential alternatives.

In the Tucson area, a more restrictive definition of the type of parcels that could be used as cooling centers was used. This choice was determined by PCHD partners in the project. For example, schools were not included to serve as candidate locations. After discussion with partners, potential parcels that could serve as cooling centers included commercial nursing homes, adult care facilities (senior living facilities), hospitals, and places of worship.

2.4. Demand Locations

Demand locations represent where the populations that will be serviced by cooling centers reside (Figure 1). In ArcGIS, locations are represented as points.

For the Phoenix area, demand locations included a sample of fixed-foundation residential parcels in the 25% most vulnerable census tracts via the SVI and the locations of individuals experiencing unsheltered homelessness. Residential parcel data from the Arizona Tax Assessor was used to identify residential demand locations. Due to computational constraints, every residential parcel in the 25% most vulnerable census tracts could not be included in Phoenix. Therefore, five residential parcels from each of the most vulnerable census tracts were randomly selected, which represents 0.5% of the residential parcels in the most vulnerable census tracts. The choice of five parcels was selected to balance computing capacity and coverage. The subset of residential parcels was weighted based on the population of their census tract. For each parcel, the weight was equal to the population of the census tract they reside in divided by five. The data on those experiencing unsheltered homelessness came from the 2022 Maricopa County Point-in-Time survey of those experiencing homelessness. We removed any personally identifying information from the point-in-time survey. Each data point in the point-in-time survey represented one individual. Every demand location representing those experiencing unsheltered homelessness was used, obviating the need to apply a population weight. Mobile homes were not included because they are not represented in the tax assessor's data set and the alternative source available to us was incomplete.

In Tucson, the demand locations represent the location of residential mobile homes and fixed foundation residential parcels in the 25% most vulnerable census tracts. As with Phoenix, demand locations for Tucson came from the same parcel data from the Pima County Tax Assessor as the candidate locations but restricted to residential parcels. Point-in-Time survey data for those experiencing unsheltered homelessness was not available. Because of its smaller size, and therefore lower computational load, the optimization in Tucson was performed using every residential parcel in the 25% most vulnerable census tracts. Additionally, since every residential parcel was used and the demand locations in Tucson only reflect parcels and not a combination of individuals and parcels, we did not have to apply a population weight to the demand locations.

2.5. Engaging Community Partners With Results

In this project, we engaged with community partners and cooling center leaders through the Arizona Cooling Center Working Group and state and county health departments to identify the key factors that should be included in the workflow to identify new cooling center locations. Engaging public health stakeholders in this type of research helps sustain partnerships and positively impacts outcomes (Austhof et al., 2020). Additional stakeholder meetings took place virtually, including discussions between the research team and other partners on the process, results, and future applications (Meadow et al., 2015), which are synthesized in the Discussion section. Briefly, this project began in January 2022 when MCDPH and PCHD identified a need to expand cooling center locations and requested support from BRACE academic partners. Over a series of monthly and quarterly virtual calls through Spring and Summer 2022, we discussed the project, decision points, and shared preliminary results with partners for feedback. Partners provided their opinions. We integrated them into the workflow. Once the spatial optimization of cooling centers for the two areas was completed, we presented the results and a report documenting the process to MCDPH, PCHD and ADHS. We provided the names of candidate locations with contact information so that MCDPH and PCHD could contact facilities to invite them to the HRN.

2.6. Spatial Optimization Parameters

In addition to preparing the demand point and facilities data sets, other parameters in the analysis were set including direction, cut-off thresholds, units, number of new facilities, and type of analysis (Table 1). The road network for the Phoenix area was obtained from the Arizona State University Geospatial Data Hub and the Tucson area street network data set was acquired from the Pima County GIS Library. *Direction* was defined as "to facilities" to reflect the assumption that people in need of a cooling center will likely be traveling to a cooling center or hydration station. The "Cut-Off" parameter represents a threshold that guides the selection of candidate locations by travel distance to a cooling center. These values can be defined for different types of demand locations and/or applied to every demand location equally. This parameter reflects the potential for different groups to travel different distances. In the Phoenix area, we assumed those experiencing unsheltered homelessness would be more restricted in their ability to travel compared to fixed foundation residences. Thus, the value for the unsheltered was set to 1.6 km (~1 mile) and 8 km (~5 miles) for fixed foundation residences. In the Tucson area, an 8-km (~5 miles) cut-off was applied to fixed foundation residences, and a 5 km (~3 miles) cut-off was applied to mobile homes. Residences beyond the cut-off distance would not be allocated as demand to that facility. We defined the number of new candidate facilities for the analysis to end with, which includes the number of existing locations plus 10 new for Phoenix, and 20 new locations for Tucson. The number of new cooling centers to locate was selected based on the need and resources available to establish additional cooling centers in each jurisdiction. Finally, "maximize" coverage, was selected for the "Type" parameter so the analysis would maximize the spatial coverage of added cooling centers while also trying to allocate as much demand as possible to cooling centers.

3. Results

We show that through a co-production approach, the spatial optimization tool can identify candidate locations for cooling centers to address heat health inequities. We use two different metropolitan areas to demonstrate the flexibility of the tool to meet local demand and data availability (Figure 2). For the candidate locations in the Phoenix area, the average demand was 3231.5 residential parcels per location and 92.2 unsheltered individuals per location. The average distance from the location of an unsheltered resident or a residential parcel to one of the 10 new cooling centers was 1.08 km (0.67 mi [standard deviation = 0.373 km (0.232 mi)]). Because of the parameters selected, there was a difference in average distance traveled based on the type of demand (e.g., residential parcels or unsheltered individuals). Those experiencing unsheltered homelessness within a mile of one of the new cooling centers would travel an average of 0.89 km (0.55 mi [standard deviation = 0.407 km (0.253 mi)]) to the nearest cooling center. This is slightly shorter than the average distance, 1.09 km (0.68 mi [standard deviation = 0.371 km (0.231 mi)), which sheltered residents living within a mile of one of the new cooling centers would have to travel. Additionally, there were several locations throughout the Phoenix area where individuals live within a mile of several cooling centers.

For the candidate locations in the Tucson area, the average demand was 1,374 residential parcels per location, where demand is defined as the count of residential parcels that fall within the maximum cut-off distance set by the user. The average travel distance for these locations was about 1 km (0.62 mi. [standard deviation = ~ 0.400 km (0.2 mi)) from residence to location. In this example, the partners opted to generate a list that would be refined and selected from based on local knowledge of the communities and organizations identified. Visually inspecting the map, these candidate locations are non-overlapping with existing locations and located in parts of Tucson with higher SVI. Community partners utilized the lists of candidate locations as part of their cooling center recruitment to on-board new facilities for 2023. In Tucson, one location joined the cooling center network for the next year, and many more in 2024.

4. Discussion

This study demonstrates how to identify new cooling center locations in two different metropolitan areas, highlighting the use of nuanced data (e.g., inclusion of data on those experiencing unsheltered homelessness and

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Table 1
Comparison of ArcGIS Location-Allocation Tool Parameters

Parameter	Options/Definition	Phoenix Area	Tucson area
Direction	The direction of travel. "To facilities" indicates the direction of travel from demand locations to facilities. "Away from facilities" indicates the opposite direction of travel	"To facilities"	"To facilities"
Cut-Off	This is an impedance factor that constrains the optimization to reasonable distances	Residential: 8 km (i.e., 5 miles)	Fixed foundation Residential—8 km (i.e., 5 miles)
		Point in time: 1.6 km (i.e., 1 mile)	Residential mobile homes—5 km (i.e., 3.1 miles)
Units	Are dependent, defined by the imported network data set	Meters	Meters
Facilities	The number of facilities to end with: existing plus the desired number of new locations	123 total facilities:	35 total facilities:
		113 existing	15 existing
		10 new	20 new
Type	Type of problem being solved (e.g., minimize impedance, maximize coverage)	Maximize coverage	Maximize coverage

Note. The tool uses existing layers, demand locations, and candidate locations to optimize the network of cooling centers for maximum coverage. This figure outlines the differences in these parameters between the two metros, and parameters are easily modified based on available data and local needs.

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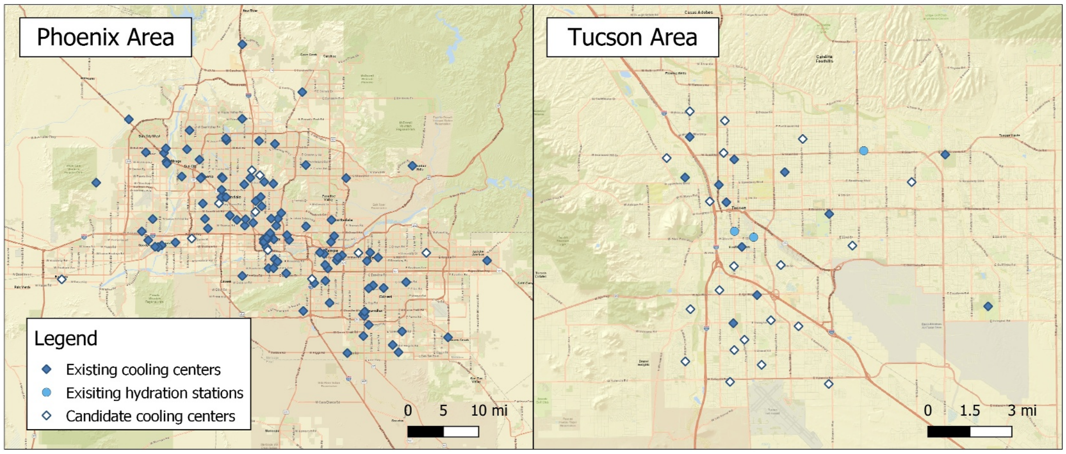

Figure 2. Maps of the existing cooling centers, hydration stations, and optional locations for new cooling centers for Phoenix (left) and Tucson areas (right).

mobile homes), and reflecting the unique priorities and available resources to support cooling centers in each jurisdiction. For example, in Tucson, prior experience with onboarding a cooling center helped to identify additional facilities that wanted to provide heat respite but could not provide indoor accommodation. These facilities were provided with water bottles that they could distribute and serve as hydration stations. Unlike the Phoenix area, hydration stations were incorporated into the optimization to complement the current number of cooling centers in the Tucson area. Importantly, these results have been helpful in discussions with external stakeholders via virtual meetings related to heat relief efforts in subsequent summers as we seek to identify gaps in the coverage of cooling centers and improve heat relief resources in each jurisdiction.

In addition to the choices detailed here, the parameters in the location-allocation analysis layer can be adjusted to reflect limitations in mobility among some populations. For example, the optimization for the Phoenix area used a 1.6 km (1 mi) threshold to cooling centers for those experiencing homelessness and an 8 km (5 mi) threshold for those with fixed foundation residences. While these specific distances may not reflect travel limitations, they highlight the ability to make these adjustments, which can be updated in future iterations of spatial optimization to reflect walkability. Related would be to emphasize the locations identified in census tracts that have a higher concentration of houses lacking vehicles—these locations would have populations walk to cooling centers and would need a reduction in distance to limit heat exposure in the trip to the cooling center. Future efforts to optimize cooling centers could consider modeling additional modes of travel beyond walking (e.g., public transit, bicycle, and/or personal vehicle) to cooling centers. Accounting for additional modes of travel will impact the resulting optimization as some individuals would be able to travel larger distances. Additionally, travel mode will influence the degree to which individuals are exposed to heat. Fraser and Chester (2017), demonstrated how walking and wait times to and at transit stops contribute to the overall heat exposure experienced by riders. In a separate study, researchers surveyed public transit riders in Phoenix, AZ and found that nearly half felt "hot or very hot" and more than half felt "thermally uncomfortable" (Dzyuban et al., 2022). Access by public transport is important, but the additional heat exposure an individual might experience as they walk to the transportation station and waiting for transit should be factored into the exposure. These additional factors to consider speak to how generalizable this optimization workflow is.

Through ongoing discussions with partners, MCDPH and PCHD, we considered how this approach could fit into broader efforts to address heat risk. In Maricopa County, the network of publicly accessible cooling centers is primarily maintained and supported by the faith-based community, nonprofits, and local municipalities. While most publicly accessible cooling centers in Maricopa County operate continuously throughout the summer, a portion of them do not. This approach can be applied throughout the summer as different cooling centers close and open during the day. Functionality in ArcGIS also allows users to identify cooling center locations while considering the capacity of cooling centers. The resulting optimization can be examined to identify the portion of demand that might come from a different subset of the population. As one of the Cooling Center Workgroup members pointed out, it can be important to stratify the needs—persons experiencing homelessness may have different cooling center needs compared with persons in temporarily overheated homes. Being able to identify the portion of potential demand that is coming from those experiencing homelessness could impact the type of services offered at a cooling center.

There are several ways in which future work can enhance our approach to optimizing cooling center locations. We used the tax assessor database to identify candidate and demand locations, which may not represent mobile home parks and would not represent those experiencing homelessness. In the Phoenix area, we were able to supplement the tax assessor data with a recent point-in-time survey that represented those experiencing unsheltered homelessness. However, a recent point-in-time survey was not available for the Tucson area. Other parcel data sets exist that include information from the North American Industry Classification System (U.S. Census Bureau, 2023), which might have more specific information from which to select locations. Further, with the exception of accounting for census tract population counts in the Phoenix area, we did not introduce any weighting of demand locations or facilities. Additional weighting schemes could be used to differentiate the relative importance of certain demand locations over others. For example, Fraser et al. (2018) weighted the demand locations based on vulnerability index score, population, and proximity to publicly accessible air-conditioned space like a mall or movie theater. Demand locations could be weighted based on the relative risk of heat-related illness associated with different populations. In that situation, people at increased risk of heat-related illness could be given higher priority in the optimization approach. Similarly, facilities can also be weighted if there is reason to believe some set of facilities would be more or less ideal for serving as cooling centers. Ongoing efforts to survey visitors and cooling center managers could provide additional information that can be used to refine the cut-off threshold distances. While those experiencing unsheltered homelessness were included in the Phoenix area optimization, they were not available for the optimization in the Tucson area, even though they have some of the highest risk of exposure to extreme heat in both cities. The COVID-19 pandemic delayed the Pima County point-in-time survey (Bentele, 2022) and suggested alternatives were not of sufficient resolution for this application. We recommend including this information in future iterations as it becomes available. The utility of this tool is that, once the data are collected, it can be rerun as necessary with alternative parameters based on the needs of the user.

The tool presented requires local knowledge and future work must consider the use and perceptions around cooling centers to select viable locations within the algorithm defined candidate locations. The current understanding of the public's use and perception of cooling centers is somewhat limited, which has implications for our approach. Literature on cooling center use indicates that some cities cooling center attendance can be generally low (Widerynski et al., 2017). When surveyed regarding cooling center use, some common reasons for limited use included the belief among some individuals that extreme heat does not pose an elevated risk for them, lack of knowledge about services and activities offered (Sampson et al., 2013), accessibility of other cooled spaces (e.g., shopping mall or grocery stores), and lack of awareness about cooling centers (Alberini et al., 2011; Widerynski et al., 2017). Some of those themes emerged in Berisha et al. (2017)'s evaluation of cooling centers in Maricopa County. Importantly, they identified that many visitors in Maricopa County were unemployed, lacked permanent residence, had a chronic medical condition, and/or had limited to no access to air conditioning. For the public, a cooling center might not be the first place they think of for reprieve from the heat. However, cooling centers provide a vital resource for those experiencing unsheltered homelessness and other people with a risk of exposure to extreme heat. Future efforts to optimize cooling center locations and improve the use and services at cooling centers should consider the unique needs of those experiencing unsheltered homelessness, such as expanding capacity for overnight stays; they should also consider the needs of the facilities themselves, given that cooling centers are organizations that volunteer to serve the community. Facilities identified as being near ideal locations may require additional funding or other support to take on this role.

Finally, there are many opportunities to work alongside health departments and local cooling center networks to further enhance the optimization to better reflect the specific needs of each region. The process of collecting the data needed can expand the networks and encourage communication between sectors. For example, in the Tucson area the Sherriff's Office collects data on heat incidents, while SunTran, the City's public transit system, might have important views about public transportation. Many of the parameters and options within the optimization approach can be further specified by continuing to incorporate the experience and perspective of those who manage the cooling centers. Some of these parameters and options include the cut-off distance, capacity of the cooling center, time of operation, multimodal travel, and identifying people at increased risk of exposure to extreme heat.

5. Conclusion

Cooling centers can be an important resource for those experiencing excessive heat exposure, especially for those who lack other means to find relief from the heat. Cooling centers should be located in communities with the greatest need. We built on previous work-related cooling center optimization to co-produce an optimization that addresses the specific needs to reduce the effects of extreme heat in the Phoenix and Tucson areas in Arizona. This work is presented as an example of how local governments with varying resources can identify optimal cooling center locations. Engaging with our community partners allowed us to customize the workflow to account for regional differences in data and demand. The co-produced spatial optimization approach piloted here can be used in other communities seeking to expand cooling center coverage to help improve heat resilience for the populations at increased risk of exposure to extreme heat.

6. Significance

This co-produced project provides a replicable, data-based means for identifying candidate locations to strategically grow heat relief networks in Arizona and beyond. Because ArcGIS's Network Analyst was used, this is a reproducible project that can be re-run with alternative parameters or as additional locations are added to iteratively respond to need.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

All of the data used for this project are from public databases including CDC/ATSDR for the SVI (CDC, 2018) and then county specific websites for Cooling Centers locations as web maps (Heat Relief Network, 2022; Pima County Cooling Centers, 2022), Tax Assessor websites for parcel data (Maricopa County Parcels, 2024; Pima County Parcels, 2024) and street networks (Maricopa County Streets, 2024; Pima County Street Network, 2024). We developed a GitHub webpage (Austhofe, 2022) to facilitate the adoption of this workflow by other practitioners interested in optimizing cooling center locations. It details each step of the optimization workflow and has been tested by other members of the team as well as by students in a spatial analysis course at the University of Arizona.

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