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Examining the Optimal Placement of Cooling Centers to Serve Populations at High Risk of Extreme Heat Exposure in 81 US Cities

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Abstract

Objective: Although extreme heat can impact the health of anyone, certain groups are disproportionately affected. In urban settings, cooling centers are intended to reduce heat exposure by providing air-conditioned spaces to the public. We examined the characteristics of populations living near cooling centers and how well they serve areas with high social vulnerability.

Methods: We identified 1402 cooling centers in 81 US cities from publicly available sources and analyzed markers of urban heat and social vulnerability in relation to their locations. Within each city, we developed cooling center access areas, defined as the geographic area within a 0.5-mile walk from a center, and compared sociodemographic characteristics of populations living within versus outside the access areas. We analyzed results by city and geographic region to evaluate climate-relevant regional differences.

Results: Access to cooling centers differed among cities, ranging from 0.01% (Atlanta, Georgia) to 63.2% (Washington, DC) of the population living within an access area. On average, cooling centers were in areas that had higher levels of social vulnerability, as measured by the number of people living in urban heat islands, annual household income below poverty, racial and ethnic minority status, low educational attainment, and high unemployment rate. However, access areas were less inclusive of adult populations aged ≥65 years than among populations aged <65 years.

Conclusion: Given the large percentage of individuals without access to cooling centers and the anticipated increase in frequency and severity of extreme heat events, the current distribution of centers in the urban areas that we examined may be insufficient to protect individuals from the adverse health effects of extreme heat, particularly in the absence of additional measures to reduce risk.

Keywords

extreme heat, cooling centers, social vulnerability, spatial analysis

Extreme heat events are projected to increase in frequency and intensity with continued climate change, but populations are already experiencing adverse health effects from extreme heat.[1-4] The effects of extreme heat are unequally distributed because of differences in exposure, adaptive capacity, and susceptibility. For a given day of extreme heat, some people are more exposed than others (eg, people experiencing homelessness, outdoor workers, those living in urban heat islands, those with limited greenspace), have reduced adaptive capacity (eg, households without access to air conditioning or the ability to pay utility bills), and/or have greater susceptibility to the negative health effects of heat exposure

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(eg, older adults, those with preexisting chronic conditions or other comorbidities).[5]

Heat action plans are critical to public health infrastructure; successful heat action plans include warnings that convey information to the public and local officials about upcoming heat events, which are sometimes used to trigger interventions. One intervention that has been highlighted in successful heat action plans in the United States is the opening of cooling centers on days of extreme heat.[6] Cooling centers, designated by city, town, or county officials, are a low-cost intervention that involves the use of publicly accessible locations with air conditioning (eg, community centers, libraries, senior centers, churches, synagogues, mosques, police stations, schools).[6,7] Cooling centers may also offer medical services or distribute fans and drinking water during periods of extreme heat.[8]

Given that the use of air conditioning is one of the most effective means of preventing heat-related illness and mortality,[9,10] cooling centers offer a potentially important intervention for those without regular access to a cool environment. Access and the ability to use home air conditioning are not equally distributed across the United States. The prevalence of air conditioning is higher in warmer climate regions than in typically cooler climates, which can increase risks of heat-related morbidity and mortality during heat events in cooler regions.[11] However, cooling centers are often underutilized.[12]

Previous studies have investigated common barriers to accessing cooling centers to better understand how to reach people who are likely to need them.[5,13] Sociodemographic factors influence an individual's level of risk of extreme heat exposure and susceptibility to the negative health effects of heat exposure.[14] For example, people who have low incomes or are unemployed often have limited access to air conditioning.[11] Adults aged ≥65 years have limited ability to thermoregulate and are more likely than younger people to have preexisting chronic conditions, which can increase their likelihood of heat-related illness following extreme heat exposure.[15] Level of education has been identified to be inversely related to risk of heat-related health effects (ie, greater risk among individuals with lower levels of education), and the lack of a high school degree may be indicative of socioeconomic and occupational conditions that could influence a person's ability to take health-protective action during extreme heat events.[16] In many cities, racial and ethnic minority groups are more likely than non–racial and ethnic minority groups to experience not only higher temperatures in their neighborhoods but also systemic racism, which exacerbates the effects of extreme heat exposure.[17]

Equitable placement of cooling centers in the United States has been assessed in places where extreme heat during summertime is common, such as Maricopa County (encompassing Phoenix, Arizona) and Los Angeles, California.[8,18] Cooling center placement has been assessed in some of the most populous US cities, including Portland, Oregon; Philadelphia, Pennsylvania; and New York City.[7,19,20] In an evaluation of cooling center preparedness (which the authors defined as cooling center population coverage) in 25 US cities with populations >300 000, cities at higher latitudes tended to be better prepared than cities at lower latitudes.[21] The authors also showed that subpopulation coverage differed substantially among cities.

Our objective was to build on this past work with an expanded spatial scale to determine whether the areas surrounding cooling centers corresponded with areas of putative high risk for the negative health effects of extreme heat based on markers of urban heat islands and social vulnerability. This expanded analysis provides additional focus on smaller communities that are vulnerable to extreme heat and for which cooling center locations were publicly available. A diversified understanding of the characteristics of cities with cooling centers may provide a useful framework for additional cities to leverage and improve in the process of developing heat action plans. We assessed population-level access to cooling centers to estimate which populations are currently being served and to identify those that may benefit from additional or alternative heat interventions. We analyzed sociodemographic and environmental data to identify whether cooling centers are adequately serving those with greatest need.

Methods

Cooling Center Locations

Among the top 100 most populated US cities, we identified 81 cities that had publicly available information on cooling center locations for at least 1 year from 2017 through 2020. For each city, we gathered information on cooling center locations during the most recent year from 2017 through 2020 from multiple public sources, including city government websites, government-run geographic information system sites, and local news articles highlighting the opening of cooling centers during periods of extreme heat (eTable 1 in Supplemental Material). Periods of extreme heat may be defined differently among cities because heat warning systems rely on location-specific criteria; we did not make independent determinations of extreme heat days in this analysis. If cooling center data were not publicly accessible through a government-developed heat action plan, we identified newspaper articles that cited the location of government-run cooling centers. We confirmed that cooling centers were operational for the year during which location data were collected. We limited our study to public spaces and did not include private locations (eg, movie theaters, coffee shops, malls), which are rarely part of a city's official heat action plan. The Boston University Medical Campus and Boston University Medical Center Institutional Review Board reviewed the research and made the determination that it was not human subjects research and, therefore, had no requirement to obtain consent.

We used the shapefile data from the Centers for Disease Control and Prevention (CDC) to define city limits for each of

Table 1. American Community Survey variable descriptions and table identification (ID) numbers[a]

Variable	Description	Table ID no.
Racial and ethnic minority	Individuals self-identifying as Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or other Pacific Islander, and Hispanic or Latino, inclusive of individuals who identified as "other" or ">2 races"	B03002
Black or African American	Total population self-identifying as Black or African American of any ethnicity	B03002
Hispanic or Latinx	Total population self-identifying as Hispanic or Latinx of any race	B03002
Age	Total population aged ≥65 years	B01001
Poverty status	Total population aged 20-64 years who are living below the federal poverty level	S2301
Poverty status among people aged ≥65 years	Total population aged ≥65 years with annual household income below the federal poverty level	B17001
Education	Total population aged 25-64 years without a high school degree	S2301
Unemployment	Total population aged ≥16 years who are unemployed	S2301

[a] Data source: US Census Bureau.[24]

the 81 cities.[22] We included cooling centers that had any portion of their access area inside the city limit. We identified and evaluated 1402 cooling center locations in the 81 cities.

Demographic and Social Vulnerability Variables

We used CDC's 2018 Social Vulnerability Index (SVI), which describes the relative social vulnerability of a census tract to external stressors, including natural or human-caused disasters, using factors such as socioeconomic status, household composition and disability, racial and ethnic minority status and language, and housing type and transportation.[23] SVI values are nationwide percentile rankings; thus, to assess whether cooling centers are preferentially located in places with greater social vulnerability relative only to that city, we rescaled SVI within each city using the methods outlined by CDC.[23] An SVI value of 0 refers to the census tract with the lowest social vulnerability, and a value of 1 indicates the tract with the greatest social vulnerability in that city. We then selected several markers of vulnerability to assess independently using data from the US Census Bureau's 5-year American Community Survey (ACS) for 2015 through 2019.[24] The ACS combines demographic and household data from multiple years to increase reliability for small geographies.[25] We extracted ACS data at the census-tract level for population estimates and for demographic indicators known or posited to be important in the relationship between heat and health, including race and ethnicity, age, education level, employment status, and annual household income (Table 1). Given that heat disproportionately affects older adults, we further explored the relationship between poverty and cooling center access among adults aged ≥65 years.

Environmental Variables

To assess within-city temperature variations, we used the normalized difference vegetation index (NDVI) and estimated values for surface urban heat island (UHI) intensity. NDVI is a commonly used marker of greenness and vegetation. At local scales within a built environment, places with more vegetation tend to be cooler as compared with areas with higher impervious surface cover; therefore, NDVI can serve as a proxy for relative differences in exposure to ambient heat.[26] We estimated the 2019 annual maximum NDVI from the 16-day 250-m NDVI product of the MODIS Terra satellite (MOD13Q1).[27] To evaluate land surface NDVI applicable to population exposures, we removed negative values to mask water features. We additionally used gridded summer daytime UHI estimates, which are available at a 500-m spatial resolution.[28] UHI values represent the difference between the mean land surface temperature for the area of interest and that of its rural reference.

GIS and Statistical Methods

We geocoded cooling center locations by using the World Geocoding Service in ArcGIS Pro version 2.8 (Esri) and used the generate service areas network analyst tool in ArcGIS to create individual walking distance networks around each center; we referred to these as "cooling center access areas." Consistent with previous work, we defined "access" as populations living within a 0.5-mile walk from ≥1 cooling center (an access area clipped to the city boundary), and we defined populations without access as those living more than a 0.5-mile walk from any cooling center.[21]

We compared the environmental and sociodemographic characteristics of the areas with access to cooling centers (ie, portions of the city located within the access area) with characteristics of the areas without access (ie, all other portions of the city). For environmental variables, we calculated conventional land-weighted averages, whereby the contribution of a grid cell to the mean was equal to the proportion of the grid cell within the city or cooling center access area boundaries. For sociodemographic variables, we calculated population percentages inside and outside cooling center access

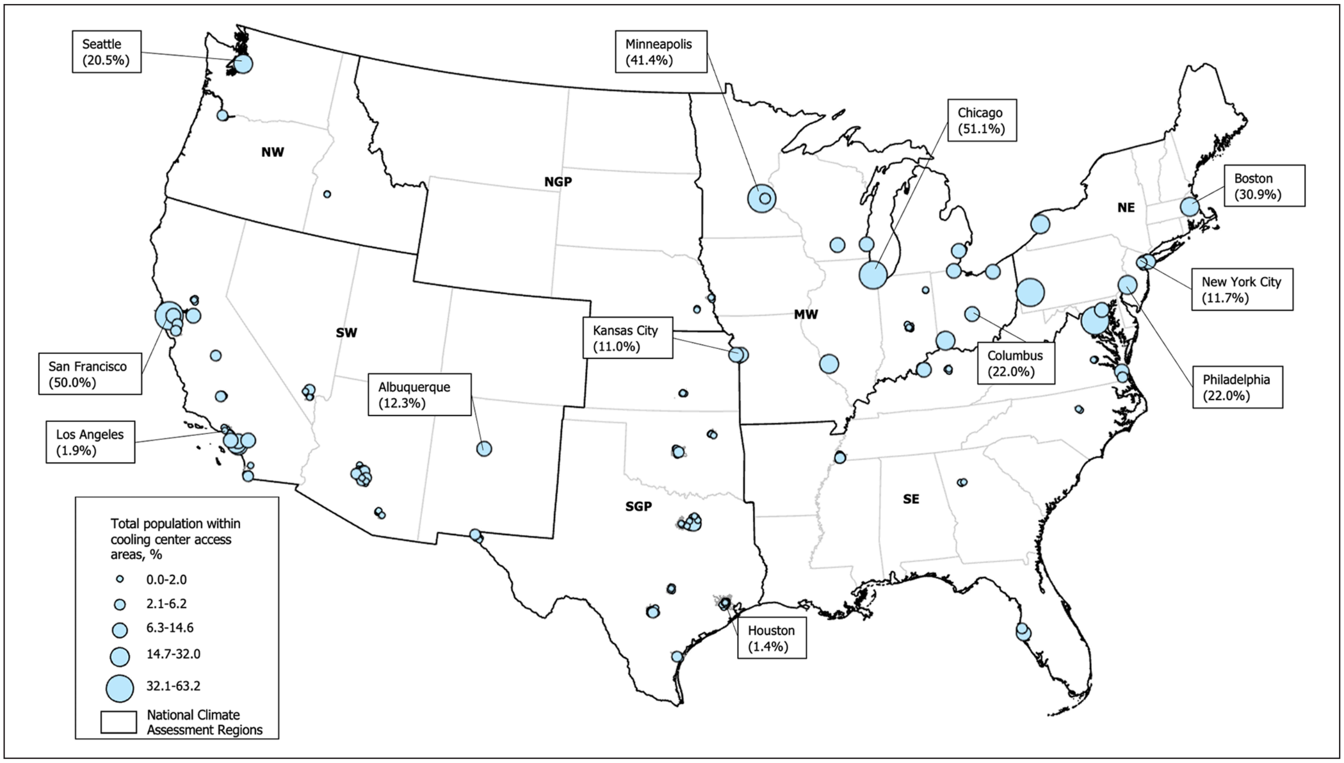

Figure 1. Cooling center locations in 81 US cities, 2017 through 2020, and percentage of total population with access to cooling centers. Map created in ArcGIS Pro version 2.8 (Esri).

areas (1) by identifying the proportion of each census tract within the city boundary and/or cooling center access area and (2) by proportionally allocating count populations for each variable of interest based on land areas covered. We repeated this calculation for each variable, summed the totals inside and outside cooling center access areas, and calculated population percentages specific to that variable.

We used analogous methods to determine total counts of the population with access to cooling centers and the extent of the population per city with access by calculating its percentage as follows: (number of people within the access areas/total number of people in a city) × 100. We also calculated the number of individuals who were covered by a single cooling center access area per city as follows: number of people within access areas/total number of access areas in a city. We used the latter calculation to account for differences in the number of cooling centers in each city and to provide additional information about the average population density surrounding centers in a given city. This standardized value reflects the average number of people served by a single cooling center access area; thus, a smaller value indicates a lower population coverage for a single center.

We then compared characteristics of social vulnerability among populations with and without cooling center access. Weighted averages of demographic variables (race and ethnicity, age, education level, employment status, and annual household income) represent the average percentage of the population with each demographic characteristic.

We analyzed the results by city and by National Climate Assessment region to account for climate-relevant regional differences.[29] We used 1-way analysis of variance and Tukey tests to compare sociodemographic and environmental means within cooling center access areas, outside access areas, and for each city overall and to determine significant differences between groups, comparing all possible pairs. We used a significance level of .05 for all tests. We used R version 4.1.3 (R Foundation for Statistical Computing) to conduct the statistical analyses.

Results

The 81 cities had a combined population of ~53 384 461 people. Approximately 6 197 300 (11.4%) people lived within a 0.5-mile walk to a designated cooling center (percentage of the population with access across all cities, mean [SD] = 9.7% [12.8%]). Population-level cooling center access varied substantially by city, ranging from 0.01% in Atlanta, Georgia, to 63.2% in Washington, DC (Figure 1).

We observed considerable regional differences in the average number of cooling centers and average percentage of the total population within access areas. On average, coverage was highest in the Northeast and Midwest and lowest in the Northern Great Plains and Southern Great Plains (Table 2).

Standardized population coverage within a single cooling center access area was highest in New York City and Washington, DC, with 59 100 and 47 655 people covered,

Table 2. Total population within cooling center access areas and number of cooling centers in 81 US cities, 2017 through 2020, by NCA region[a]

			Within cooling center access areas		Percentile	
NCA region	No. of cities	Merged access areas (cooling centers), mean (SD)	Total population across cities, no.	Percentage, mean (SD)	25th	75th
Midwest	14	16 (38)	215 173	17.1 (15.5)	9.3	26.6
Northeast	9	11 (33)	2 239 194	25.2 (17.8)	12.8	30.9
Northern Great Plains	2	2 (2)	5864	0.8 (0.3)	0.7	0.9
Northwest	3	8 (13)	183 524	8.9 (10.3)	3.1	12.9
Southeast	10	8 (10)	161 012	4.5 (3.8)	2.0	7.4
Southern Great Plains	15	10 (12)	343 140	3.0 (2.8)	1.2	4.1
Southwest	28	6 (9)	1 110 392	7.2 (10.1)	2.0	10.2
All regions	81	9 (17)	6 197 300	9.7 (12.8)	1.6	11.7

Abbreviation: NCA, National Climate Assessment.
[a] Data source: US Global Change Research Program.[29]

respectively. Standardized coverage was lowest in Tempe, Arizona, and Atlanta with approximately 29 and 34 people covered by a single access area (eTable 1 in Supplemental Material).

When we considered all 81 cities together, the SVI value was higher within cooling center access areas (mean [SD] = 0.64 [0.14]) than outside them (0.48 [0.03]). Patterns were similar when we considered the individual markers of social vulnerability collected from the ACS. We found that a larger proportion of the population with ≥1 vulnerability marker resided within cooling center access areas, as evidenced by differences in the social vulnerability markers and in summer daytime UHI and annual maximum NDVI in populations within and outside access areas (Figure 2). In contrast, adults aged ≥65 years were less represented than people aged <65 years among populations within cooling center access areas.

We found that a significantly greater percentage of adults aged ≥65 years living below the federal poverty level ($P <$ .001) resided within cooling center access areas (mean [SD] = 16.9% [6.9%]) as compared with outside such areas (11.2% [3.7%]). Variations in cooling center access by population subgroup were similar regionally (eTable 2 in Supplemental Material).

Discussion

Population-level cooling center access varies widely across US cities. By mapping cooling center locations alongside the environmental, social, and demographic characteristics of 81 US cities, we characterized populations with access to ≥1 cooling center within a 0.5-mile walk. The total number of cooling centers and population density of the surrounding area may play a role in the differential population coverage observed across cities. In cities where fewer people live within close proximity to a cooling center, opportunities may exist to prioritize placing new centers in densely populated areas.

Despite the low total percentage of the population within cooling center access areas, we did find that, at the national and regional levels, populations within access areas as compared with those outside of them tended to be more socially vulnerable, as defined by race and ethnicity, education level, unemployment, poverty status, and UHI exposure. However, consistent with previous research, we found that within cooling center access areas, populations tended to be younger, with a lower percentage aged ≥65 years.[20,21] We speculate that buildings being used as cooling centers often include community centers or libraries with services that may be intended for younger populations.[30] Given the risk of heat-related morbidity and mortality for adults aged ≥65 years, future allocation of cooling centers should consider targeting areas that have more residents aged ≥65 years. Social isolation has also been identified as a heat-related risk factor among older adults in cities; therefore, community cooling centers for older residents could have additional health benefits beyond heat exposure reduction by decreasing isolation, loneliness, and other indicators of well-being.[31,32]

We found that cooling centers were generally well placed to provide access to those with ≥1 vulnerability marker who may be at risk for adverse health outcomes. However, because a large proportion of the population lacked access to a cooling center and some people at risk of extreme heat exposure, including older adults, may be unable to walk to one, cooling centers should be accompanied by other interventions, such as air-conditioning subsidies,[33] increased transportation services during heat waves,[34] and education programs to ensure that the needs of those with risk of heat-related health effects are being thoroughly met. Because of limited evidence showing which interventions are most effective in which settings, further research is needed on the implementation and effectiveness of various extreme heat interventions.

Limitations

We recognize some limitations. First, access to cooling centers reflects more than just physical proximity and

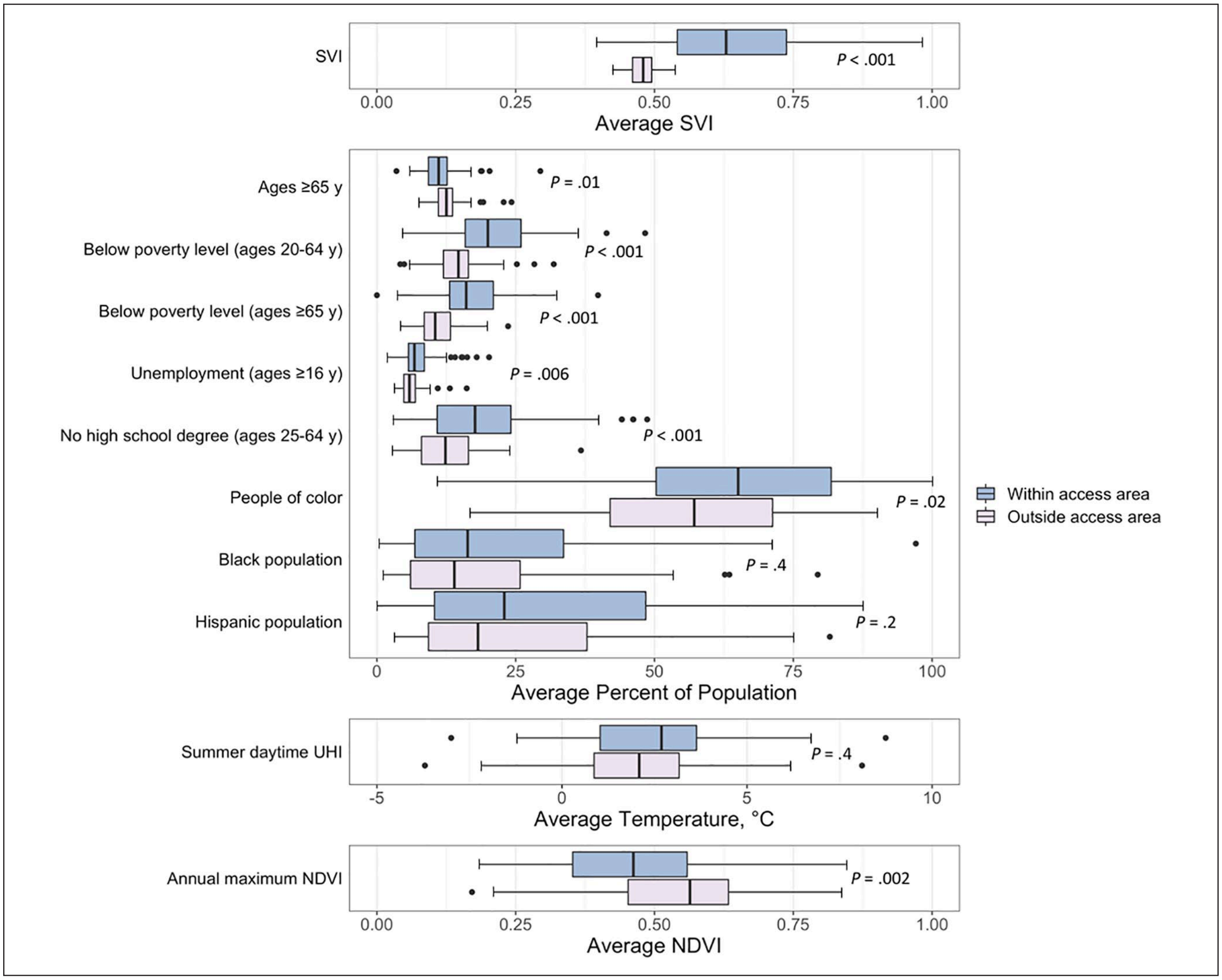

Figure 2. Distribution of vulnerability markers within and outside cooling center access areas averaged for 81 US cities, 2017 through 2020. Vertical bar inside the box, median; whiskers, maximum and minimum; dots, outliers. Data source: US Census Bureau.[24] Abbreviations: NDVI, normalized difference vegetation index; SVI, Social Vulnerability Index; UHI, urban heat island.

includes time, availability, convenience, and safety among other factors.[35] Here, we evaluated only potential accessibility, as defined by physical proximity based on place of residence. Similarly, we were not able to analyze which of the populations in this study actually use cooling centers and which might have access to alternative heat adaptation interventions. Second, we were not able to assess the prevalence or location of unhoused people, given the limitations in data availability at this scale. People experiencing homelessness may be at a particularly increased risk for extreme heat–related health effects. Future work would benefit from an evaluation of access to cooling centers among people experiencing homelessness.[6,8] Lastly, we did not consider the importance of public transportation in urban areas and, therefore, likely underestimated cooling center access.

Conclusions

Cooling centers are a common and often central component to heat action plans across the United States.[6] We identified potentially underserved areas and populations. The findings from this study can help inform the placement and number of cooling centers needed to reach a greater proportion of people who would benefit the most and to meet the needs of a growing population who will be increasingly exposed to extreme heat with continued climate change. To improve the accessibility of this information for public health practitioners and city planners responsible for extreme heat adaptation, we have provided a StoryMap template (ArcGIS) that can be used to map the city-specific distribution of vulnerability markers within the population in relation to existing cooling centers for any of the 81 cities analyzed (eFigure in Supplemental Material).

In general, cooling centers are preferentially placed in areas that have populations who may have increased risks for adverse health outcomes from extreme heat. However, cooling center access areas are less inclusive of adults aged ≥65 years than among people aged <65 years, and disparities exist in access among the overall population. Therefore, a large proportion of people vulnerable to the health effects of extreme heat may still have limited access to cooling centers. We suggest that new cooling centers be placed in more densely populated areas or in areas that are convenient for older adults. Opportunities may exist to use additional extreme heat interventions, such as air-conditioning subsidies or education programs, to promote cooling for people who do not live in proximity to cooling centers.

Declaration of Conflicting Interests

The authors declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: G.A.W. currently serves as a consultant for Google, LLC and the Health Effects Institute.

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Supplemental Material

Supplemental material for this article is available online. The authors have provided these supplemental materials to give readers additional information about their work. These materials have not been edited or formatted by *Public Health Reports*'s scientific editors and, thus, may not conform to the guidelines of the *AMA Manual of Style*, 11th Edition.

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