Assessing the sociospatial inequities involved in green roof siting for reduced cooling loads during heat waves in Detroit, MI

By

Lino Sanchez

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Dr. Tony Reames

Abstract

Countless studies have been carried out that have quantified the ecosystem services of green infrastructure for both public and environmental health. This study aimed to evaluate accessibility to the cooling benefits of green roofs in Detroit, MI, for low-income marginalized communities, compared to the City's current heat relief system of designated cooling centers. Regions of the city were evaluated for their vulnerability to the urban heat island effect, which can be alleviated by green roofs due to raised surface albedo and evaporative cooling. Spatial data regarding land surface temperature, income, and race were used to locate where green roof ecosystem services are most needed and how communities within these regions are categorized demographically. Green roof efforts were mapped to determine whether siting has been based on where ecosystem services are most needed and how socioeconomic factors might influence the locations of urban heat island-mitigating green infrastructure. Analysis of the spatial data observed in this study revealed that most low-income residents are within walking distance from cooling centers, but not included in the Detroit Future Cities greenspace zone, while green roofs specifically were in the affluent part of Detroit's core, where the population is predominantly white. Beyond these findings, pertaining specifically to Detroit, the methodology employed here shows potential for application to other city's urban greening plans.

Introduction

Urban greening as a solution to the Urban Heat Island (UHI) Effect has filled the energy efficiency and urban planning literature with research pertaining to the cooling benefits of green roofs and other forms of green infrastructure, yet studies often lack necessary nuance regarding optimized performance and whether such implementation strategies are helping the communities that are the most vulnerable to heat-borne illness. The urban heat island consequences experienced in urban cores can be attributed to high concentrations of pavement and buildings and their generally low albedo, resulting in high rates of heat absorption from insolation, causing an excessively warm urban climate [1]. Detroit, MI, has seen the consequences of the urban heat island effect with its built environment density leading to higher temperatures than surrounding rural landscapes [2]. The effects of the urban heat island effect have profound energy justice implications where inner-city temperatures lead to higher cooling loads as residents increase their air conditioning usage and spend more on their energy bills [3]. With 76.28% [4] of Detroit's population living under the poverty line, these increased HVAC (Heating Ventilation Air Conditioning) energy expenses further exacerbate the city's poverty issues. Lack of access to utility energy creates a situation where utilities, such as DTE Energy (formerly known as Detroit Edison), the primary utility for Detroit, will cut households off from their energy connections when bills cannot be paid, exposing residents to the harm of extreme heat [5]. As a broader urban energy issue, the increased peak energy demand resulting from the urban heat island effect tends to overload energy systems, which have the consequence of utility blackouts, thus worsening the problem [6].

Conventional UHI mitigation strategies involve the incorporation of cooling materials into a building’s rooftop, as surfaces with high albedo white paint coating have the potential to significantly reduce air conditioning energy expenditure by preventing heat flux through the roofing membrane [7]. Another popular strategy has been green roofs, which are becoming more prevalent in Detroit as the city implements more green infrastructure projects as part of its urban greening goals. Green roofs are particularly useful for lowering the temperature of areas impacted by high impervious pavement, including rooftops, which add to a city's total area of impervious pavement [8]. While generally more expensive than cool roofs, rooftops covered in light colored paint with high albedo, green roofs can further cool their respective roofing surfaces beyond albedo through evapotranspiration, a type of evaporative cooling, indicating the importance of vegetation in urban heat island mitigation, with low-vegetation urban regions likely the most susceptible to higher temperatures [8]. Importantly, socioeconomic disparities remain a driving force in determining which groups are the most significantly affected by the urban heat island effect, as low-income minority communities are often without access to green spaces and far away from green roofs, leading to greater risk of heat-borne illness [9]. This lack of access to green space often comes because of heavy urbanization, where low-income communities often find themselves living in regions of compact built environment, and thus exceptionally low albedo [10].

The green infrastructure strategies of Detroit were planned with multiple ecosystem services in mind, but in many cases, do not meet the needs of the communities they are in. Often with the assumption that green infrastructure projects can meet all ecosystem service simultaneously, the consequences of tradeoffs are neglected [11]. Optimization strategies, specifically focused on efficient siting, are needed to implement green infrastructure projects that will serve the most benefit for Detroit, most crucially the need to cool highly-paved regions and help lower cooling loads for surrounding low-income households. However, urban greening plans are not always easily carried through when residents are not sufficiently included in the urban greening process and do not accept newly installed vegetation, often feeling that it resembles overgrown vacant lots, especially in Detroit, a city with an already significant blight problem [12]. While access to green infrastructure is a problem for low-income communities of Detroit, these inequities are further complicated by development motives, such as Detroit Future City, that while aiming to improve impacted neighborhoods, may very well end up displacing existing efforts of resilience [13].

The Detroit Future City Strategic Framework is Detroit's most comprehensive and established development plan for creating an urban landscape that embodies the ethos of sustainability, providing specific consideration for green infrastructure implementation [14]. Given the known cooling effects of green infrastructure strategies, such as green roofs, the designated greenspace land use plans of Detroit Future City provide an indicator for where green roof projects will most likely be implemented near. Accordingly, this study will use general designated green space as a proxy for where green roofs are likely to be sited. Green roof implementation is in its infancy in Detroit and so a major means of measuring future siting may be most realistic when combined with existing plans for greenspace, with priority for green infrastructure as a general category of sustainable features, in this case referring specifically to those typologies than have the potential to cool the surrounding environment. General research into current urban heat island mitigation efforts via green infrastructure are vague, most often without specific reference to green roofs, and so designated future greenspace must be viewed as an area with the potential to house the specific green infrastructure typologies that have been shown to mitigate the urban heat island effect.

Whereas Detroit seeks to lessen its urban heat island effect and associated increased cooling loads with green infrastructure, such as green roofs, the most immediate and tangible source of heat relief are the designated cooling centers located throughout the city [15]. Providing free air-conditioned space for the public, these library and recreation center locations are too few to serve the entire body of vulnerable Detroit citizens, of whom the majority are not within walking distance [16]. Cognizant of low-cost incentive with repurposing libraries and recreation centers as temporary cooling centers, the City of Detroit can further address disproportionate heat vulnerability by opening more cooling centers, specifically targeting the most heat vulnerable communities downtown where there is a high degree of impervious surface area compared to vegetation [17]. The urban heat island effect highlights profound socioeconomic vulnerability in Detroit, as deaths caused by extreme urban heat disproportionately affect black communities, with causes being attributed to a lack of access to air conditioning [18]. The current lack of energy efficient homes for Detroit's socioeconomically disadvantaged communities [19] creates a disproportionate energy burden and highlights a link between heat-vulnerability and poverty, if energy efficient cooling mechanisms are a standard characteristic of energy efficient homes. Detroit's urban heat island requires further study to identify the specific communities that need the most attention and whether existing heat island mitigation strategies are working.

The lack of access to green space for low-income minority communities in Detroit warrants a necessary investigation into the sociospatial inequities that have led to green space siting that has neglected disadvantaged neighborhoods. Mapping methodologies presented in this study reflect the work of previous researchers who have investigated the lack of access to heat relief in Detroit amongst vulnerable communities. The work of Kisner Corrine et al., has previously investigated issues of proximity to heat relief sites in Detroit, particularly cooling centers, using geospatial buffers as a means of determining accessibility [16]. This study will further contribute to the Detroit Urban Heat Island literature by adding several other demographic and environmental parameters to previous methodologies. As it stands, Detroit's urban greening initiatives and drives to address climatic environmental justice issues are not being sufficiently carried though, and further spatial analysis will be necessary for designing green infrastructure landscapes that effectively meet the needs of communities who are most at risk of heat-related illness.

Energy Justice implications within the urban heat island mitigation efforts of Detroit City government and nonprofit organizations must be considered to ensure that urban greening strategies are benefitting impoverished households by reducing cooling loads and lowering energy bills. Energy insecurity poses a major public health problem for Detroit's poorest households, with inability to pay utility bills leading to major health issues and even fatalities. The issues involved in disproportionate heat island vulnerability and inequitable heat relief sites, both cooling centers and green infrastructure, raise profound examples of distributive injustice and procedural injustice, where the distribution of green infrastructure and other heat island mitigation initiatives are not sourced in an equitable way that includes all demographic groups. Implementation procedure proves inequitable when those who are most in need of heat relief will very possibly not be included in the planning process to determine where these sites will be located.

A sociospatial analysis of distributional equity for urban heat island mitigation sites necessitates the consideration of proximity as a function of demographic group. By combining spatial interpretation of urban public health and energy issues, such as the urban heat island effect, inequities can be visualized based on which economic classes and racial groups can seek out shelter from heat waves and which groups are left stranded. The goals of a sociospatial analysis are normative in nature, where distributive inequities, in this study concerning energy insecurity, are highlighted and equitable solutions are proposed for increasing resource distribution in the most effective way, where efforts specifically seek to assist the most vulnerable, rather than relying only on one parameter, such as temperature. As such, sociospatial analysis serves the purpose of evaluating urban greening strategies by locating the communities most in need of specific ecosystem services and determining whether they can walk to the nearest cooling center or are close enough to green roofs to benefit from the associated cooling benefits.

By acknowledging how green roofs can help building owners and homeowners save money on cooling in the summer, this study adds to the urban greening literature by addressing the effectiveness of green infrastructure through an energy justice lens, revealing how green roofs may not always be placed in the communities that would benefit the most.

Methods

Heat vulnerability for this study was defined as an amalgamation of poverty, financial assistance with air conditioning needs, access to green space, and distance to cooling centers, with additional speculation placed on racial divide. As Detroit's green roof stock is still developing, with roughly twelve sites in existence, green roof data is scarce, and so plans for future green roof development were included in green roof mapping. To account for future green roof plans that were not explicitly mentioned within urban greening files, proxies were established for this study, using existing and future green space as a likely site for future green roof development. While this study seeks to focus specifically on green roof siting in Detroit, the existing number of green roofs will not be sufficient for producing useful data regarding sociospatial insight, leading to the necessity to consider green space, assuming all vegetation will share similar albedo and evapotranspiration characteristics. The Detroit Future City plan will be used as a backdrop setting for where green infrastructure will be sited, and will thus serve as the primary basis for determining which demographic groups are included or excluded from such plans. Green roofs were input manually into ArcMap by entering addresses of existing and future sites into the Geocoding tool, with locations found from independent research.

Geospatial and sociospatial analysis of Detroit's urban heat island was performed using ArcMap of the ArcGIS suite by ESRI (Environmental Systems Research Institute), with data being compiled from several open-portal data sources, primarily the United States Census American Community Survey [4], the City of Detroit, and USGS. Data was mapped within Detroit political boundaries by census block groups via a United States Census TIGER file, with demographic data displayed as quantities, with larger quantities displayed as darker colors per block group. All data within this study was of vector format, except for land surface temperature, which was purely raster. US Census data extrapolated from the American Community Survey for 2016 was selected for specific relevance to financial disadvantage regarding heat vulnerability, which included total households living below the poverty line and total households receiving public assistance with air conditioning and heating needs. Data regarding the Detroit Future City plan was downloaded as vector data to be displayed within census block groups, highlighting the organization's land use plans for the next fifty years, with green residential and green mixed-rise serving as indicated greenspace for this study (**Figure 1**). Heat Island data as a displayed by land surface temperature was calculated from aerial Landsat 8 imagery, as a function of impervious surface area relative to surface area covered with vegetation. Lastly, cooling center addresses were individually entered into ArcMap's Geocoding tool after specific locations were identified from City of Detroit documentation [15].

Various toolsets within ArcMap were utilized to extract information regarding access to heat relief in Detroit. The Buffer tool was used to generate a polygon representing walking distance to cooling centers, which this study set at one mile. The number of households below the poverty line within walking distance to cooling centers was discovered via the Clip tool, which cut demographic data regarding both number of households below the poverty line and receiving heating and cooling assistance down to only the area within these proximity buffers. The Clip tool further provided a means for summing the number of disadvantaged households within designated greenspace areas, positing "disadvantaged" in this instance as living both below the poverty and receiving public assistance for heating and air conditioning. To determine the total number of heat vulnerable households not included in urban greenspace plans and not within walking distance to cooling centers, the total number of disadvantaged households within clipped features were subtracted from the total number of disadvantaged households within Detroit's political boundaries.

Since green roofs were mapped as points, there was no consideration for area of green roofs or density and albedo of vegetation, as such data is not available. Green roof access was measured by simply counting the number of green roof points within block groups designated as having the most households living below the poverty line and receiving public assistance for heating and cooling. This could be easily visually analyzed with no need for analytical toolsets within ArcMap. As data regarding the spread of a green roof's cooling effect has not been quantified as a means of proximity, a buffer would serve no factual purpose.

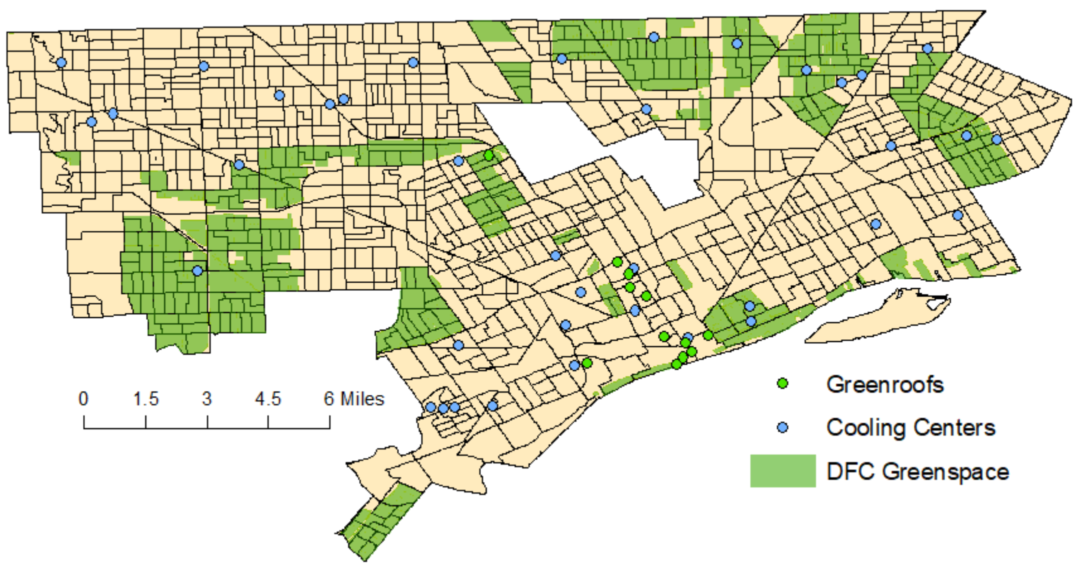
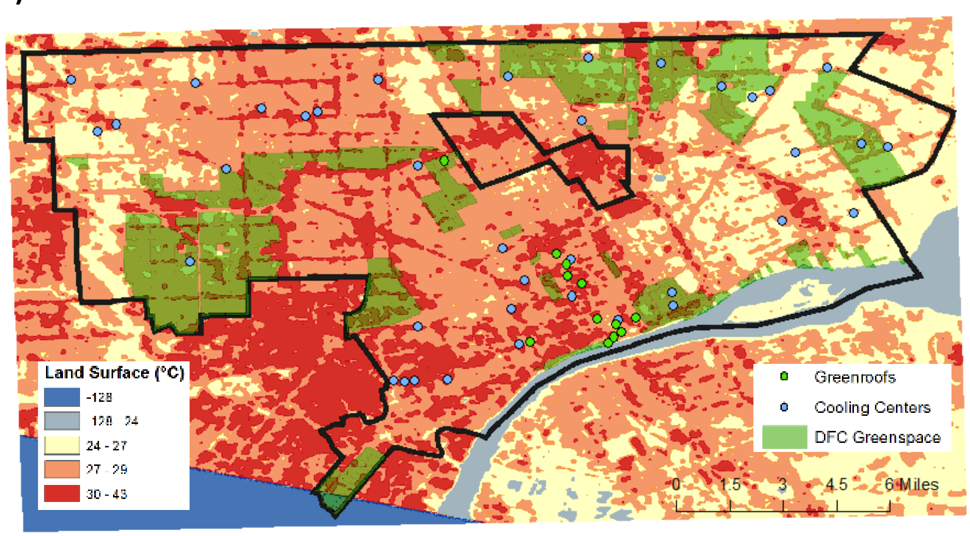


Figure 1 Detroit's existing and future urban heat island mitigation sites, including green roofs, cooling centers, and future greenspace as part of the Detroit Future City plan.

Heat vulnerability as a function of land surface temperature, without consideration for demographic census information, was generated from an NDVI (normalized difference vegetation index) layer that was calculated from aerial Landsat8 data. Once this raster layer was produced, high-risk heat zones were set at 30°C and converted to polygons to serve as boundaries for regions experiencing the most severe urban heat island effect (**Figure 2**). To discover how well the Detroit Future City plan will meet the necessary spatial measures for reducing the city's urban heat island effect, area of urban heat island polygons within greenspace polygons were totaled and then subtracted from the total area of urban heat island polygons within Detroit's political boundary. These urban heat island polygons were then used to reveal the percentage of disadvantaged households living within the regions experiencing the highest land surface temperatures. Layers denoting households living below poverty line and receiving heating and air conditioning assistance were clipped to the boundaries of these urban heat island zones.

a)



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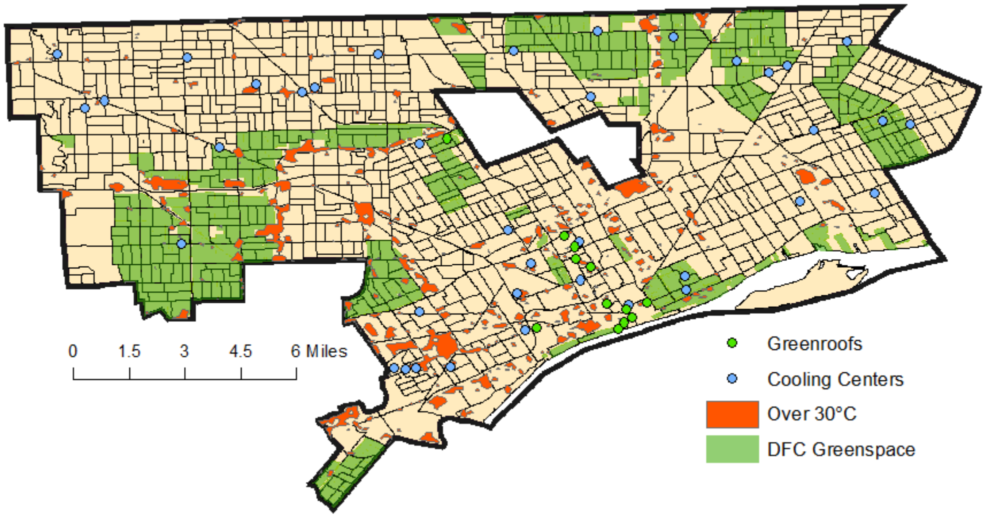


Figure 2. Detroit's urban heat island is displayed as land surface temperature, juxtaposed within existing and future cooling sites, including designated green space, green roofs, and cooling centers. **a)** displays Detroit's urban heat island as a spectrum of intensity. **b)** displays Detroit's urban heat island as only the zones above 30°C. Data Sources: Landsat 8 Aerial Imagery. USGS, Data Driven Detroit.

Results

Spatial analysis of Detroit's green infrastructure landscape, consisting of green roofs and proposed greenspace development, revealed several apparent sociospatial disparities concerning access of vulnerable communities to the city's urban heat island relief sites. While green roof cooling access was able to be estimated by mere observation of point location within census blocks, speculation on the demographic relation to the Detroit Future City plan revealed more precise insight when values were compared between block groups.

Dot density proved reliable for visualizing the racial distribution of Detroit's population with spatial reference to urban heat island mitigating strategies (**Figure 3**). With most of Detroit's population identifying as black, followed by white, it was shown that Alaska Indian or Native American experienced the highest percentage of its own group without access to cooling centers, followed by black, and then white (**table 1**). "Other" were located within the regions with the highest land surface temperature, followed by whites, and then American Indian or Alaska Native. Blacks had the highest percentage households with access to future greenspace, followed by whites, and then American Indian or Alaska Native.

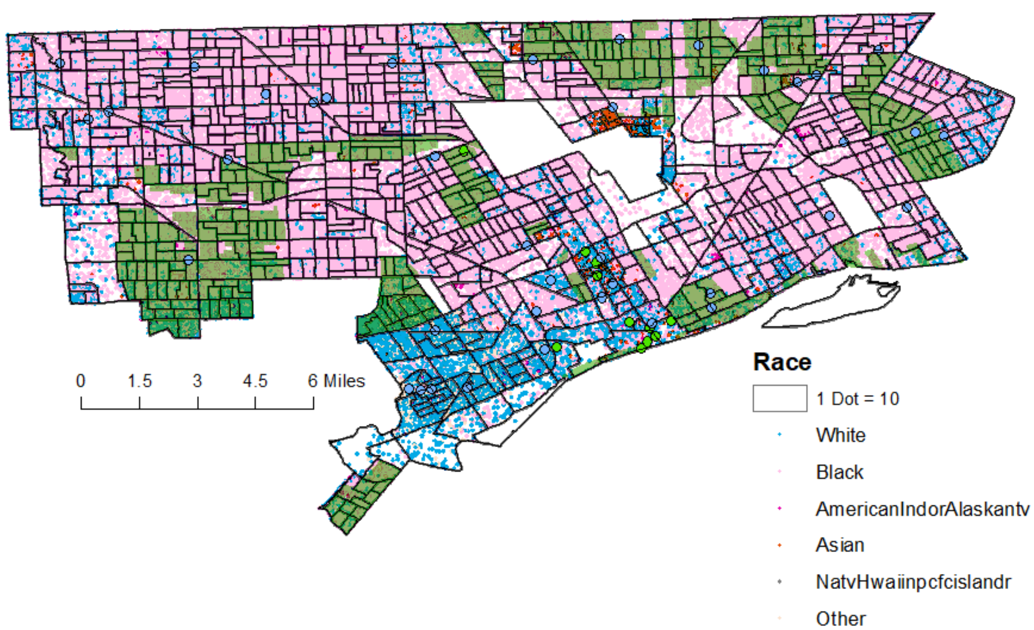


Figure 3 The racial composition of Detroit is displayed with spatial reference to greenspace plans, green roofs, and cooling centers.

Table 1. Access to cooling centers and greenspace, alongside containment within urban heat island zones with land surface temperature at or above 30°C, by racial group. **%OTD** – Percent of total Detroit Population; **WOACC** – Without access to cooling center; **W30CZ** – Within 30°C land surface temperature zone; **WGS** – located within designated Detroit Future City greenspace.

Race	Total	%OTD	WOACC	W30CZ	WGS
White	98230	14.41%	22.16%	57.66%	32.82%
Black	550798	80.82%	24.06%	34.87%	34.9%
AIOAN	2441	0.36%	25.85%	47.93%	30.15%
Asian	9748	1.43%	5.12%	26.17%	14.8%
NHOPI	75	0.01%	36%	42.67%	0%
Other	20182	2.96%	8.39%	74.15%	25.96%

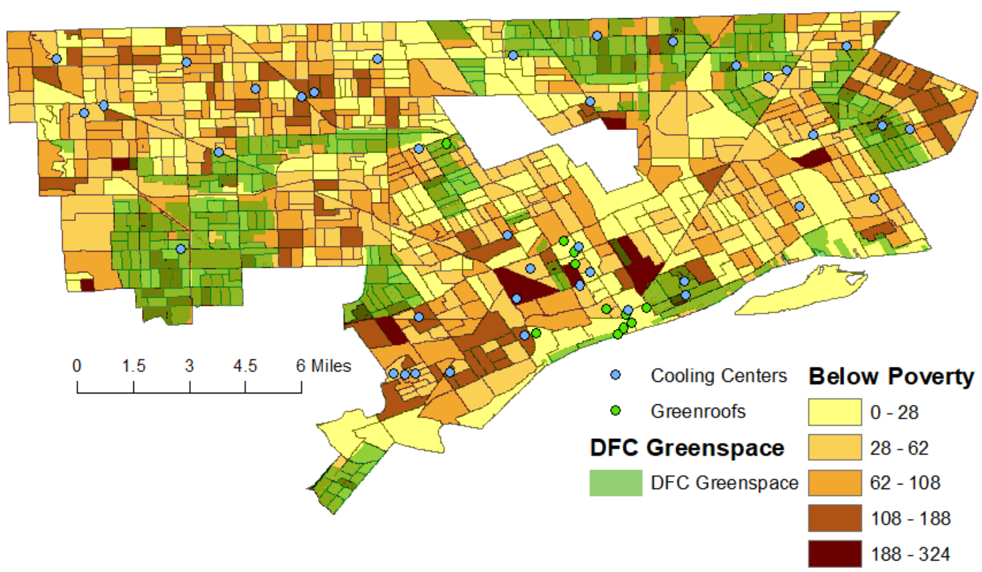
It was revealed that most households living below the poverty line and depending on public assistance for heating and air conditioning were within walking distance of cooling zones (**Table 2**), with the majority not within regions determined to experience the highest land surface temperature. However, both demographic groups were revealed to have most of their populations without immediate access to future greenspace as part of the Detroit Future City plan.

Table 2. Access to cooling centers and greenspace, alongside containment within urban heat island zones with land surface temperature at or above 30°C, among households living below poverty line and depending on public assistance for heating and cooling needs. **WOACC** –Without access to cooling center; **W30CZ** – Within 30°C land surface temperature zone; **WGS** – located within designated Detroit Future City greenspace.

Vulnerability	Total	WOACC	W30CZ	WGS
With Pub. Asst.	16472	23.45%	38.56%	37.42%
Below Poverty	50163	23.72%	37.33%	35.65%

For green roof ecosystem service accessibility, none of the recorded twelve green roofs were in the block groups determined to be most severe for number of households living below the poverty level and for households depending on public assistance for meeting heating and air conditioning needs (**Figure 4**). When spatially referenced to racial makeup of the city, it was shown that that seven of the twelve green roofs mapped were located within census blocks that were majority white, and five being located within census blocks that were majority black, with white and black representing the largest racial groups in Detroit.

a)



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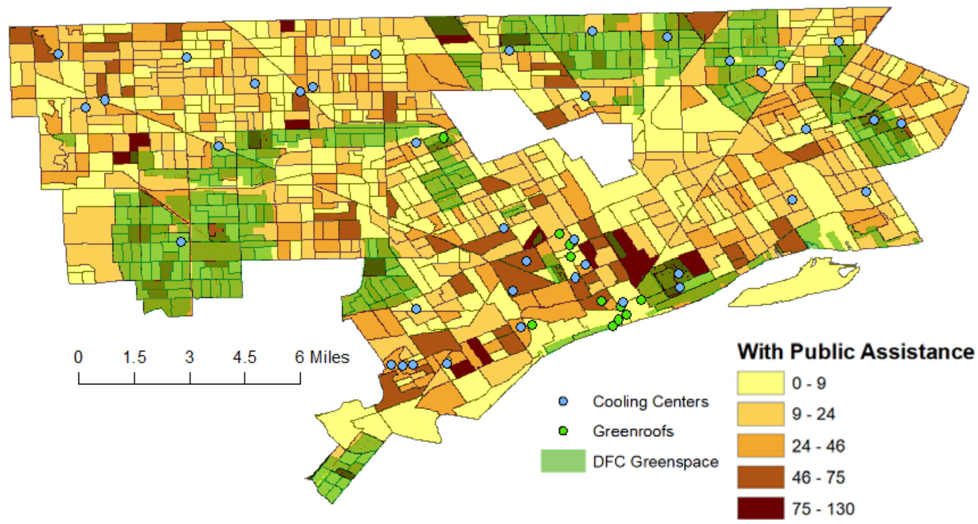

Figure 4. Financial disadvantage demographic data displayed by census block group with spatial reference to cooling centers, green roofs, and designated Detroit Future City greenspace. **a)** number of households living below poverty line. **b)** Number of households receiving public assistance for meeting heating and cooling needs.

Discussion and Conclusions

Geospatial analysis was carried out using GIS methodologies to assess the accessibility of marginalized Detroit communities to access relief sites from dangerously high urban heat. Census data was used as a means of identifying households that were living in poverty and unable to afford air conditioning on their own, and to measure the degree to which residents could walk to nearby cooling centers or benefit from nearby green infrastructure cooling. Green roofs were highlighted as a key urban heat island mitigation strategy and site locations were analyzed to determine if implementation favored certain demographic groups. Sociospatial disparities were determined by analyzing walking access and how well urban heat island relief sites reached communities that this study determined to be the most vulnerable to heat-borne illness. This study proved insightful in producing results that determined where vulnerable communities were being served, and where certain vulnerable communities had no immediate access to cooling, whether through cooling centers or nearby vegetation. By viewing access through a demographic lens, this analysis was further able to determine whether certain racial groups were being served more effectively than others.

While research into the disproportional effects of the urban heat island effect tend to point in the direction that suggests low-income minority groups are the most severely at risk for heat-borne illness, particularly concerning the elderly and homeless [20], geospatial analysis of demographic data in conjunction with heat-relief strategies reveal a great complexity within the goal of equitable access that disproves the notion of a single conclusion for Detroit. The findings of this study reveal that Detroit's black population, which makes up the clear majority of the city's overall population, are in fact the most included racial group within the Detroit Future City plan, despite remaining the most impoverished racial group in the city [21], a diversion from the consensus within the urban greening literature that low-income minority groups are the most generally the most excluded. Though this access to green space might come as a surprise, Detroit's black community was revealed to have the second least access to cooling centers within the city, following American Indian or Alaska Native, verifying claims of heat vulnerability for minority populations. However, any conclusions to be drawn from this finding will be complicated by this spatial analysis which revealed that whites make up the greatest single racial population within Detroit's hottest regions in terms of land surface temperature.

Most demographic groups regarding poverty, specifically number of households living below the poverty line and households needing public assistance for heating and air conditioning, were located within walking distance of cooling centers, and were not located within UHI zones, suggesting that low income groups might not be the most heat vulnerable in Detroit regarding these specific parameters. Still, most of these financially disadvantaged groups were not included in the Detroit Future City plan concerning spatial access, which signifies a heat vulnerability based on lack of vegetative cooling. Though this study shows financially disadvantaged demographics lying outside the hottest regions of the city, a lack of access to green space translates to a lack of climatic resilience, which may prove to be much more consequential than this study can elaborate on.

Concerning the siting of green roofs, a sociospatial disparity was much more apparent than for the Detroit Future City plan, suggesting that perhaps this strategic plan included demographic analysis like this study in their future design proposal. Though Detroit's existing green roofs are in effective areas regarding the city's distribution of land surface temperature intensities, with most green roofs existing within the city's urban core with highly dense concentrations of impervious pavement, the siting of green roofs reflect a preference for placing green infrastructure in areas that are most affluent, particularly Downtown Detroit. With a majority white population, this region of the city, and its relative abundance of green infrastructure, presents a likely relationship between development and urban greening, reflecting racial inequity, given the city's current gentrification dilemma [22]. Though as gentrification within Detroit is an ongoing process, it is difficult to draw concrete conclusions regarding economic injustice over urban greening within the city's downtown region, as while this study highlights the affluence of the downtown region, past research highlights the impoverished state of this area [23].

Attention to demographic inequities regarding the siting of urban heat island mitigation strategies presents a practical dilemma that posits the value-based judgement over whether green infrastructure siting should prioritize socioeconomic vulnerability or simply temperature. For this reason, special consideration must be given to integrated optimization strategies that weigh the socioeconomic inequities of disadvantaged communities with the practical siting of green roofs and other heat island mitigating green infrastructure typologies in areas with the lowest land surface albedo. When viewed on a macro-level, efforts to address Detroit's energy poverty issues concerning lack of access to air conditioning may benefit from strategies that place greater priority on targeting the hottest regions of the city, regardless of demographic placement, with the goal of lowering city summer temperature for everyone, and thus leading to a lowered cooling load for poor families as a result. Such speculation over the degree to which these urban heat island mitigation strategies are effective at lowering heat-stroke risk and energy bills call into question social justice dynamics that cannot be properly addressed through the means of quantitative GIS data.

Beyond individual households, optimized green roof siting can improve the heat resilience and overall health of vulnerable communities on a larger scale by being implemented on affordable housing complexes, which may serve as a cost-effective way for the City of Detroit to address the disproportional health burden of the urban heat island effect. A data-driven sociospatial analysis of urban greening plans may further benefit Detroit by offering strategies for lowering costs associated with hospital visits, storm water management, and air-borne pollution. Such saved expenditures can be utilized for improving Weatherization Assistance Program (WAP) initiatives and providing career training workshops for low-income individuals, as well as other social services. The positive externalities associated green roofs extend well beyond the energy and cooling benefits.

Though a daunting challenge, addressing the need for optimized green infrastructure strategies can be profoundly supplemented by thorough analysis of demographic and climatic data to create urban greening plans that focus resources on improving the communities most in need, while incorporating nuanced methodologies, such as interviews, to incorporate qualitative data that factors public perception and cultural resonance into the equation.

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