Cooling Detroit: A socio-spatial analysis of equity in green roofs as an urban heat island mitigation strategy

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ABSTRACT

Multiple studies have quantified the ecosystem services of green infrastructure for both public and environmental health. This study evaluates and compares accessibility of low-income and marginalized communities to the cooling benefits of green roofs in Detroit, MI in the context of the urban heat island effect and the City's current heat relief system of dedicated 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. Existing green roof efforts were mapped to determine whether siting has occurred where ecosystem services are most needed and how socioeconomic factors might be related to the locations of urban heat island-mitigating green infrastructure. Analysis of the spatial data in this study revealed most low-income residents are within walking distance from cooling centers, but not included in the Detroit Future City Green Neighborhoods, while green roofs specifically were in the affluent part of Detroit’s urban core, where the population is predominantly white. The methodology employed here can be applied to evaluate urban greening plans in other cities.

1. Introduction

Urban greening as a solution to the Urban Heat Island (UHI) Effect has filled the energy efficiency and urban planning literature with research focused on the cooling benefits of green roofs and other forms of green infrastructure. Yet, these studies often lack necessary nuance regarding optimized performance and whether such implementation strategies are helping the communities most vulnerable to heat-related illnesses. 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 (Mohajerani et al., 2017). Detroit, Michigan, has seen the consequences of the urban heat island effect with high density areas having temperatures 2.5°F higher for early hours than surrounding rural landscapes (Sanderson et al., 1973). 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 communities are often without access to green spaces, leading to greater risk of heat-related illnesses (Harlan et al., 2006). Research is lacking regarding methodologies for optimized siting of green roofs in urban areas for reducing urban heat island vulnerability for disadvantaged and marginalized communities.

The effects of the urban heat island effect have profound energy justice implications where higher inner-city temperatures lead to greater cooling demand as residents experience increased energy burden regarding air conditioning needs (Akbari and Hashem, 2005). With 39.4% (United States Census Bureau, 2016a, 2016b) of Detroit’s population living under the poverty line, these increased HVAC (Heating, Ventilation, and Air Conditioning) energy expenses further exacerbate the city’s poverty issues. When households are unable to afford their energy bills, they may experience shutoffs, exposing them to increased harm from extreme heat (Jackson and Franklin, 2017). 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 (EPA, 2017). Low-income communities are often more likely to be heavily urbanized, in compact environments with little vegetation, resulting in low albedo and higher land surface temperatures, leading to a greater need for air conditioning (Cosio, 2013; Huang et al., 2011).

Conventional UHI mitigation strategies involve incorporating
cooling materials into a building’s rooftop, such as surfaces with high-albedo white paint coating, which have the potential to significantly reduce air conditioning energy expenditure through solar reflectance and preventing heat flux through the roofing membrane (Berdahl and Bretz, 1997). Green roofs, rooftops that have been designed to host a vegetative cover, typically composed of a selection of sedum, grasses, and mosses (Obendorfer et al., 2007), on top of several other layers for growing medium and drainage, offer an alternative strategy for UHI mitigation, by reducing urban temperatures through shading and evapotranspiration (EPA, 2019). Though green roofs have a higher albedo than conventional dark roofs (Rosenzweig et al., 2006), their cooling properties are most supported by the role of vegetation to capture sunlight and perform evapotranspiration (Federal Energy Management Program, 2004), which can help lower surrounding urban temperatures by releasing stored water into the atmosphere (Rosenzweig et al., 2006). While generally more expensive than the popular urban heat island-mitigation strategy of cool roofs, evaporative cooling allows green roofs to cool roofing surfaces beyond albedo, indicating the importance of vegetation in urban heat island mitigation, with low-vegetation urban regions likely the most susceptible to higher temperatures (Moody and Sailor, 2013).

Green roofs are particularly useful for lowering the temperature of areas impacted by high impervious pavement surface area, including rooftops, which contribute to a city's total area of impervious pavement (Coseo and Larsen, 2014). High surface area of impervious pavement contributes radiant heat, so green roofs can help reduce the UHI by increasing a city’s vegetated surface area (Stone and Rodgers, 2001). With variation in the physical and physiological characteristics of vegetation, green roofs can help cities by producing a range of ecosystem services beyond urban heat island mitigation, including storm water management, roof preservation, biodiversity, and aesthetic value, making green roofs a much more dynamic solution than cool roofs (Getter and Bradley Rowe, 2006).

The Detroit Future City Strategic Framework remains the most comprehensive and established development plan for creating an urban landscape that embodies the ethos of sustainability, providing specific consideration for green infrastructure implementation (Detroit Future City, 2012). However, the siting of these specific green infrastructure projects must be considered to ensure that the associated ecosystem services are being maximized to their full potential, allowing benefits to be seen by everyone. To ensure urban greening initiatives are serving tangible environmental and public health goals and not solely seen as aesthetic, scrutiny should be placed over where urban vegetation is most needed to address storm water management, air quality issues, and in the case of this study, urban heat island vulnerability. Green infrastructure projects often assume that all ecosystem services can be realized simultaneously, and thus the consequences of tradeoffs are frequently neglected (Meerow and Newell, 2017), allowing valuable green infrastructure resources to be expended in areas that may not realize the most potential benefit, both environmentally and socially. Therefore, optimization strategies, specifically focused on efficient siting, are needed to implement green infrastructure projects that will provide the most benefit for Detroit neighborhoods, and most crucially, the need to reduce the urban heat island effect and help lower cooling loads for marginalized communities and low-income households.

In the City of Detroit efforts to lessen the impact of heat waves on its residents, the most immediate and tangible source of heat relief the City has provided are the designated cooling centers located throughout the city (Kisner et al., 2012). Providing free air-conditioned space for the public, these library and recreation center locations are too few to serve the entire population of vulnerable Detroit citizens, of whom the majority are not within walking distance of cooling centers (Kisner et al., 2012). The UHI 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 (O’Neill, Zanobetti, & Schwartz, 2005). The current lack of energy efficient homes for Detroit’s socioeconomically disadvantaged communities (Bednar et al., 2017) creates a disproportionate energy burden and highlights a link between heat-vulnerability, energy efficiency, and poverty. 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.

Mapping methods can be used to investigate whether low-income and minority communities from disadvantaged neighborhoods in Detroit lack access to green space. Previous researchers (Kisner et al., 2012) investigated proximity to heat relief sites for Detroit’s most vulnerable communities, particularly cooling centers, using geospatial buffers as a means of determining accessibility. This study will add several other demographic and environmental parameters to previous methodologies, with these new variables reflecting the idea that green roofs are a means of UHI reduction and can lower cooling expenditure for low-income communities. Therefore, this paper not only emphasizes the importance of green roofs as a means of UHI reduction and lowering cooling expenditure for low-income communities, but further emphasizes the necessity for green roof projects to consider the environmental justice and land cover factors that indicate a greater need for green roofs in certain areas than in others.

Energy Justice implications within urban heat island mitigation efforts must be considered to ensure that urban greening strategies offer additional benefits to low-income households by reducing cooling loads and lowering energy bills. Defining energy justice as the pursuit of equity in benefits from energy systems, this study aims to account for the energy justice implications of green roofs, a factor of green infrastructure ecosystem services that is not often discussed throughout the urban greening literature, further adding to the energy justice literature by incorporating the cooling benefits of vegetated spaces into a discipline that largely focuses on disproportionate distribution of sustainable energy supply (Sovacool and Dworkin, 2015). Whereas most research into alleviating energy justice issues may focus on appliances and utility assistance, this study aims to bridge a gap between urban greening strategies and energy affordability by highlighting how green roofs can help lower air conditioning expenditure for communities vulnerable to the urban heat island effect. Household energy insecurity, or the inability to afford and maintain energy services, poses major public health risks for low-income urban households, leading to acute health issues and even fatalities (Hernández, 2013). The issues involved in disproportionate heat island vulnerability and inequitable heat relief sites, both cooling centers and green infrastructure, raise profound examples of inequity, where the distribution of green infrastructure and other heat island mitigation initiatives are not implemented in a way that benefits everyone.

This paper uses socio-spatial analysis to addresses distributional equity in green infrastructure for UHI mitigation in Detroit, considering both racial and ethnic identity, as well as economic status. The goals of a socio-spatial analysis in this study, defined here as a methodology that incorporates social and spatial data to identify equity disparities in access to resources for demographic groups, are to locate the areas of Detroit that are lacking in necessary green infrastructure for reducing UHI, and propose where future green infrastructure implementation plans should focus their efforts to address the cooling needs of the neighborhoods most affected by UHI. This work can improve future green infrastructure plans for mitigating UHI by providing information on whether residents can walk to the nearest cooling center, or are close enough to green roofs to benefit from the associated cooling benefits. Here, proximity will be used as a proxy for accessibility, understanding that not everyone may have access to a car or public transportation. While this paper mainly focuses on access to the cooling benefits of green infrastructure, particularly green roofs, cooling centers are used to evaluate who already has access to protection from heat.

Whereas green space-related terminology, including green infrastructure, may appear ambiguous, and mindful of the cooling effects of
various green infrastructure strategies, this study specifically focuses on green roofs for cooling Detroit. Since the Detroit Future City (DFC) Strategic Framework does not explicitly mention green roofs in its urban greening plans, this study will use DFC’s designated space for Urban Green Neighborhoods (UGNs) as a proxy for where green roofs could likely be sited, given DFC’s goal of implementing green infrastructure in its “Framework Zones”, which seek to convert vacant spaces to green spaces (Detroit Future City, 2012). DFC’s UGNs, made up of designated “Green Mixed-Rise” and “Green Residential” zones of Detroit Future City’s 50-year land use zones, will represent DFC’s future green roof plans for this study, mindful that not all green space may include green roofs. However, to not limit the potential of UGNs to serve as green space, this study will use UGNs and “green space” interchangeably. This study aims to assess the feasibility of a socio-spatial analysis for identifying inequity in green infrastructure distribution, particularly green roofs in Detroit, and conclude whether the city’s urban heat island vulnerable communities are benefiting from associated cooling.

2. Methods

2.1. Description of the study area

Like many metropolitan areas, hot days in urban Detroit disproportionally affect the city’s black population (O’Neill et al., 2005). With a 5.3% higher mortality rate for Detroit’s black population during heat waves than the city’s white population, this racial disparity has been attributed to a lack of access to air conditioning, related to economic disadvantage (O’Neill et al., 2005). Detroit’s UHI effect is characterized by its degree of impervious land cover surface, with 59% of air temperature being related to the degree of imperviousness (Zhang et al., 2011). As Detroit has an urban center that has alarmingly low levels of vegetation compared to impervious surface, the city remains particularly vulnerable to experience the urban heat island effect. Detroit has been ranked as the second most vulnerable large city in the U.S. to extreme heat events (Knowlton et al., 2012). Within Detroit’s most vulnerable regions, mainly the city’s urban core, where the highest degree of impervious surface is located, the populations that are most at risk consist of “the elderly, the infirm, young children, the poor, as well those comprising minority ethnic and racial demographics”, creating the need to address Detroit’s UHI issue as a matter of not only heat mitigation and albedo, but of environmental justice (Knowlton et al., 2012).

Detroit Future City is Detroit’s primary urban greening initiative, as a policy think tank that envisions a sustainable future for the city within a 50-year timeline, with plans that are not limited to urban greening, including economic growth and civic engagement (Detroit Future City, 2018). First proposing its strategies in a 2013 framework, Detroit Future City has gained the support of city government as a city-wide revitalization initiative that seeks to support communities by developing the city’s blighted and vacant plots with a strong consideration for equity and inclusivity (Detroit Free Press, 2017). Having already implemented projects in Detroit, Detroit Future City is still in its early stages in implementing local sustainability policy, and exists as a public/private initiative, with City support and funds from donor organizations (Jackson, 2016). With the initiative’s green infrastructure goals centering on addressing the City’s storm water management issues and vacant lot blight issue, addressing urban heat island does not seem to be a current primary goal of Detroit Future City (MLive, 2014). As it stands, Detroit Future City’s green infrastructure plans have, for the most part, only focused on addressing storm water management and improving the environmental and aesthetic conditions of vacant lots, with no clear plans of using green infrastructure to lower cooling loads for local buildings. While any increased surface area of vegetation may support urban heat island mitigation, Detroit Future City’s green infrastructure plans appear to lack strategies to optimize green infrastructure for urban heat island mitigation.

2.2. Defining urban heat island vulnerability

Urban heat island vulnerability for this study was defined as a situation where one resides within an area that is prone to high levels of heat, outside of an UGN, and with no immediate access to a cooling center. Mindful that increased vegetation area is associated with UGN development, this study defines UHI resilience as being located within an UGN, with immediate access to a cooling center. This makes the vital point that while having access to a cooling center may provide relief from risk to heat-related illness associated with the urban heat island effect, it will not help mitigate Detroit’s urban heat island effect. For the purposes of highlighting the fundamental difference between access to cooling centers and inclusion in UGN, this study makes a distinction between heat risk and urban heat island vulnerability, where heat risk (HR) is when people are within a region that is at or above 32.222°C (32.2°C to round for simplicity) and without access to a cooling center, whereas urban heat island vulnerability (UHIV) concerns people within heat risk zones (HRZs), without cooling centers, and excluded from a UGN, make the latter the more severe of the two. The threshold of 32.2°C was based on documentation by the National Weather Service that details this specific temperature as the point that defines a heat wave and therefore a beginning point for risk of heat-related illness (National Weather Service, 2011).

Note: A community who is within a designated HRZ without access to a cooling center, yet within an UGN, may not be classified as urban heat island resilient, as mitigating Detroit’s urban heat island through increased urban vegetation is a long-term process that will not provide the immediate relief of cooling centers. It is important to mention that for the purposes of this study, residing within a HRZ does not denote “heat risk”, given the potential presence of cooling centers. As well, “heat risk” does not equate to “urban heat island vulnerability”, as “urban heat island vulnerability” specifically requires a community to not be included in an UGN.

This study uses Boolean logic to identify urban heat island vulnerability, based on three parameters, 1) access to cooling centers, 2) location within HRZ, and 3) location within an urban green neighborhood (as seen in Fig. 1), where:

- **Within heat risk zone (HRZ)**: within the boundaries of a designated heat risk zone (HRZ)
- **Heat risk (HR)**: within the boundaries of a designated HRZ and without access to a cooling center
- **Urban heat island vulnerability (UHIV)**: within the boundaries of a designated HRZ, without access to a cooling center, and not included in an UGN.

Given the involved social and economic complexity that cannot be mapped spatially, this study uses proximity to assess who has access to cooling centers and green roof cooling benefits and containment within urban heat island vulnerability boundaries to assess who is urban heat island vulnerable.

3. Assumptions and data required

To appropriately make use of the data acquired for this study and to most accurately represent Detroit’s Urban Heat Island issue, several proxies and indicators were used to represent Detroit’s heat situation. First, land surface temperature calculated from NDVI (Normalized Difference Vegetation Index) and Bands 10 and 11 was used to represent the severity of the Urban Heat Island effect, assuming that such severity was caused by both a lack of high-albedo vegetation and heavy surface area of low-albedo pavement. While Detroit weather data, such as a weatherfile, could be used to assess the urban heat island effect over a given time period, such as the summer time, it cannot be mapped spatially, and therefore would not be suitable for a socio-spatial analysis. Making use of Landsat imagery has allowed a means for land...
surface temperature to be visualized and analyzed with other data parameters involved in this study, which has allowed for the identification of areas where the urban heat island might be most severe. Though it may not be reasonable to conclude land surface temperature is the ultimate indicator of urban heat island severity, it is reliable in that it identifies urban heat island severity as a function of low albedo through lack of vegetation identified through NDVI (Zaeemdar and Baycan, 2017). It must therefore be assumed that higher absorption rates of heat through high land surface temperature will therefore lead to higher ambient temperatures that will result in conditions that leave people at risk.

To account for the socioeconomic assessment of which groups are most vulnerable to Detroit’s urban heat island effect, racial and ethnic population density was mapped alongside economic factors consisting of both living below poverty level and receiving public assistance income. Whereas mapping those of Detroit’s population living below poverty level served as a simple means of assessing the financial resilience of vulnerable communities, receiving public assistance income served as a means of inferring who was receiving government assistance on energy bills, primarily for air conditioning, incorporating the theme of energy justice into this study. “Vulnerability” as measured in this study was determined by simple geometric overlapping of data layer polygons, to reveal how many of each demographic group was housed in each UGN network polygon, urban heat island zone polygon, or cooling center access polygon. If a community were to be housed within a polygon, it would then be subject to the conditions of that polygon.

As Detroit’s green roof stock is still developing, with ten existing or planned sites discovered, green roof data is scarce. To account for future green roof plans that were not explicitly mentioned within the Detroit Future City plan, proxies were established for this study, using future greenspace as a likely site for future green roof development, not considering the suitability of individual buildings to support green roofs. While this study seeks to focus specifically on green roof sitting in Detroit, the lack of data on existing green roof locations makes this difficult, thereby warranting a consideration of all types of green space, regardless of green infrastructure typology, assuming all vegetation will share similar urban heat island mitigation benefits, primarily higher albedo and evaporative cooling. The Detroit Future City plan will be used as a backdrop setting 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. To complement the potential sites of green roofs via the Detroit Future City Framework Zones, existing green roof locations were identified through online searching, and ArcMap’s Geocoding Tool used to enter those addresses into the analysis.

4. GIS methodologies and data acquisition

Geospatial and socio-spatial 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 American Community Survey (United States Census Bureau, 2016a, 2016b), the City of Detroit, and United States Geological Survey. 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 income, with the assumption that this helps pay for air conditioning and heating needs. Detroit Future City plan data 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 green space for this study (Fig. 2). While Detroit Future City’s plans for “open space”, which consist of sustainable landscape networks, share much resemblance with the zones this study considers as “green space”, they are not included in the analysis since spatial data of DFC’s open space networks was not accessible. While GIS drives the methods of this study, it should be noted that GIS is utilized as a tool and does not serve as the sole avenue for carrying...
out this topic of research, acknowledging the possibility of other mapping methodologies that integrate the same data used in this study.

5. GIS tools and data extraction

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 the designated reasonable walking distance to cooling centers, which this study set at 0.775 miles, based on the total distance a person would walk within 15 min, a maximum time for outdoor activity when temperature is at 90°F (Gregg et al., 2012). The number of households below the poverty line and receiving public assistance income 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 green space 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 green space plans and not within the designated 1-mile 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 existing 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. Mapping of green roof points served as a means of only visualizing access and representation in Detroit’s larger urban greening efforts, both private and public, excluding urban heat island mitigation effectiveness, as lack of green roof surface area data made this infeasible.

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 Landsat 8 data. Once this raster layer was produced, high-risk heat zones were set at threshold of 32.222°C and converted to polygons to serve as boundaries for regions experiencing the most severe urban heat island effect (Fig. 3). To discover how well the Detroit Future City plan will meet the necessary spatial measures for reducing the city’s urban heat island effect, the area of urban heat island polygons within green space 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 that did not overlap with green space were then used to reveal the percentage of economically disadvantaged households, along with racial and ethnic groups, living within the regions experiencing the highest land surface temperatures. To reveal this, 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.

6. Calculating Detroit’s urban heat island

Urban heat island impact data was calculated from aerial Landsat 8 imagery (Acquired May 24th, 2018 and processed on June 5th, 2018. Landsat 8 imagery courtesy of the U.S. Geological Survey) as a function of land cover imperviousness and NDVI (normalized difference vegetation index), and represented as polygons. NDVI was calculated from the thermal bands within the Landsat 8 imagery, consisting of Band 10 and Band 11. As this imagery is made up of raster data, calculations were processed through the Raster Calculator within the ArcGIS toolset. NDVI calculation methodology was adopted from USGS documentation (USGS, 2017). These calculations followed pre-established protocols using ArcGIS tools to calculate NDVI (O’Neil-Dunne, 2013) and land surface temperature estimate (Buhari, 2015).

NDVI was calculated using the following equation:

\[
NDVI = \frac{(NIR - R)}{(NIR + R)}
\]

\[
NDVI = \frac{(\text{Band 5} - \text{Band 4})}{(\text{Band 5} + \text{Band 4})}
\]

Land surface temperature was estimated by using the following equation (Basayigiti et al., 2017) and implemented using various tools, primarily Raster Calculator, within ArcGIS:

\[
LST = \frac{BT}{1 + \frac{w}{(BT / p) \sin(e)}}
\]

Where

\[
BT = \text{At Satellite Brightness Temperature}
\]
Fig. 3. 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 32.2222°C. For both a) and b) Green Mixed-Rise and Green Residential polygons were made the same color to show they both make up Urban Green Neighborhood area. Green Mixed-Rise and Green Residential polygons were made transparent to show underlying block group delineation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).
7. Identifying UHIV

To provide insight into which areas of Detroit would benefit the most from green roofs and other urban heat island mitigating green infrastructure, data findings concerning land surface temperature and demographics were overlayed to identify areas that are most vulnerable to HR, since to identify UHIV, it was first necessary to identify HR. The Raster Calculator tool within ArcGIS was set to isolate pixels that contained values of 32.2222°C and above, creating the polygon boundaries that identified HRZs. As the land surface temperature layer calculated for this study displays temperature values as a spectrum, HRZs served as a boundary-delineated indicator for the areas within Detroit that are most severely affected by the Urban Heat Island effect, essentially based off low-albedo surface area detected by analyzing NDVI imagery. Since it is difficult to conclude where precisely the border lies for where someone might be in danger of heat stroke or other heat-related illness, this study works on the claim that within HRZ polygons, one is at risk of heat-related illness, and on the outside of HRZ polygons, one is not. To identify HR, cooling center access buffer polygons were subtracted from HRZ polygons, revealing areas that were within a HRZ, but also lacked access to a cooling center. UHIV was then identified by taking HR polygons and subtracting the UGN polygons, revealing areas that were vulnerable to HR, but also not included within an UGN.

The main processes involved in analyzing UHIV in this study made use of the Clip tool and Raster Calculator tool within ArcGIS to both delineate HRZ, HR, and UHIV polygons, and then determine which demographic groups fell within these boundaries. To identify which demographic groups were most subject to HR and UHIV, it would be necessary to count the numbers of each demographic group within each HR and UHIV polygon. To extract these demographic counts, demographic data contained within Detroit block group polygons were clipped to HR and UHIV polygons. The values extracted from these newly created polygons determined how many within each demographic group were affected by HR and UHIV, providing the quantitative basis for the socio-spatial analysis implemented in this study.

8. Existing and planned green roofs

Addresses for existing and planned green roofs were geocoded and mapped as data points and layered over each demographic group data layer. Since there is no definitive means of measuring access to green roofs, given a multitude of factors, access was inferred by simply counting the number of green roofs per block group and reviewing the demographic characteristics of such block groups, thus determining which demographic groups were most represented by green roof projects.

9. Results

Spatial analysis of Detroit’s green infrastructure landscape, consisting of green roofs and proposed green space development, revealed several apparent socio-spatial disparities concerning access for vulnerable communities to the city’s urban heat island relief sites, consisting of any type of green space or green infrastructure with cooling potential. Percent values concerning population counts of demographic groups were able to be extracted from clipped polygons, revealing the counts of each racial and ethnic group, along with economic status of living below poverty level and living with public assistance income, within urban HRZs, without access to cooling centers and within UGNs. From this, the percentage of each population that was labelled as vulnerable to each situation (i.e. without access to a cooling center) was able to be calculated. Findings will reveal urban heat island vulnerability by two measures: 1) Which demographic groups are the most vulnerable based on percentage of that demographic group; 2) Which demographic groups are the most vulnerable ranked by sheer count.

Green roof cooling access was able to be estimated by mere observation of point location within census blocks, and reviewing the demographic data of each block group to reveal whether certain racial and ethnic groups or economic groups had access while others did not.

9.1. Race and ethnicity

Dot density proved reliable for visualizing the racial distribution of...
Table 1

Access to cooling centers and Urban Green Neighborhoods, alongside containment within urban heat island zones, defined as having land surface temperature at or above 32.2°C, for racial/ethnic group. Total – Percent of total Detroit population; WOACC – Without access to cooling center; HRZ – (Heat risk zone) Within heat risk zone and without access to cooling center; UGN – (Urban Green Neighborhood) located within a designated Detroit Future City UGN; UHIV – Urban heat island vulnerability, defined as within heat risk zone, without access to a cooling center, and not included in UGN. Racial/ethnic acronyms are: Black or African American alone (BoAaA); American Indian and Alaska Native alone (AIaANa); Native Hawaiian and Other Pacific Islander alone (NaHoPIa); Some other race alone (Sora); Hispanic or Latino (HoL). Data is presented at the block group scale. Percentages greater than 1 have been rounded up to nearest whole number. Percentages greater than 0.1 and less than 1 have been rounded up to nearest tenth of a percent. Total counts are listed in parentheses.

<table>
<thead>
<tr>
<th>Race/Ethnicity</th>
<th>Total</th>
<th>WOACC</th>
<th>HRZ</th>
<th>HR</th>
<th>UGN</th>
<th>UHIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>White alone</td>
<td>19%</td>
<td>60%</td>
<td>67%</td>
<td>51%</td>
<td>22%</td>
<td>51%</td>
</tr>
<tr>
<td>BoAaA</td>
<td>73%</td>
<td>53%</td>
<td>69%</td>
<td>55%</td>
<td>34%</td>
<td>55%</td>
</tr>
<tr>
<td>AIaANa</td>
<td>0.4%</td>
<td>49%</td>
<td>72%</td>
<td>55%</td>
<td>28%</td>
<td>55%</td>
</tr>
<tr>
<td>Asian Alone</td>
<td>2%</td>
<td>23%</td>
<td>86%</td>
<td>22%</td>
<td>12%</td>
<td>22%</td>
</tr>
<tr>
<td>NaHoPIa</td>
<td>0.02%</td>
<td>88%</td>
<td>28%</td>
<td>25%</td>
<td>0%</td>
<td>25%</td>
</tr>
<tr>
<td>Sora</td>
<td>3%</td>
<td>36%</td>
<td>76%</td>
<td>41%</td>
<td>25%</td>
<td>41%</td>
</tr>
<tr>
<td>HoL</td>
<td>7%</td>
<td>38%</td>
<td>72%</td>
<td>44%</td>
<td>23%</td>
<td>44%</td>
</tr>
</tbody>
</table>

Detroit’s population with spatial reference to urban heat island mitigation strategies (Fig. 4). With most of Detroit’s population identifying as black, followed by white, it was shown that Native Hawaiian and Other Pacific Islander alone experienced the highest percentage of its own group without access to cooling centers, followed by White alone, and then Black or African American alone (Table 1).

The Asian alone population had the highest percentage located within the HRZs, followed by some other race alone, and then Hispanic or Latino. Regarding percentage of population within HRZs, the Native Hawaiian and Other Pacific Islander population was the least vulnerable to HR given 27.6% of its population within the HRZs. Black and African American alone had the highest percentage of its population with access to UGNs, followed by American Indian and Alaska Native alone, and then Sora. Native Hawaiian and Other Pacific Islander alone revealed 0% of its population within UGNs, given this group total count of 0 for total count within UGNs. Detroit’s Black or African American alone population was the most prone to HR with 55.4% residing within a HRZ and without access to a cooling center, followed by White alone, and then American Indian and Alaska Native alone.

9.2. Below poverty level and receiving public assistance

It was revealed that roughly half of households living below poverty level and depending on public assistance for meeting heating and air conditioning were not within walking distance of a cooling center (Table 2) at 52% and 53.2% respectively, and most households living below poverty level and depending on public assistance income within HRZs at 69.4% and 67.2% respectively. Both demographic groups were revealed to have most of their populations excluded from area designated as future UGNs, with only 32.5% of households below poverty level included and 34.5% of households receiving public assistance income included.

9.3. Urban heat island vulnerability

It was revealed that roughly half of both the population living with public assistance and half the population living below poverty level were identified as urban heat island vulnerable, indicating their location within a designated HRZ, without access to a cooling center, and not included in a Detroit Future City UGN. Regarding race and ethnicity, it was revealed that the groups most vulnerable to the urban heat island were White alone, Black or African American Alone, and American Indian and Alaska Native alone, with roughly similar degrees of vulnerability. American Indian and Alaska Native alone was the most urban heat island vulnerable group with 55% of its population vulnerable to the urban heat island effect, followed by Black or African American Alone with 54.7% of its population vulnerable, and then White alone with 51.3% of its population vulnerable.

9.4. Mapping of existing and planned green roofs

For green roof ecosystem service accessibility, six of the recorded ten green roofs were in the block groups determined to be most severe for number of households living below the poverty level (threshold of 154 households) and only one green roof was located within block groups determined to be most severe for 10% of households depending on public assistance (threshold of 31 households) for meeting heating and air conditioning needs (Fig. 5). When spatially referenced to racial makeup of the city, it was shown that five of the ten 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. Given the lack of data regarding these specific existing green roofs and plans for future green roofs, a simple classification as within or outside of racial and ethnic block groups and economic block groups is as far as this assessment of existing and planned sites can go.

10. Discussion and conclusions

A socio-spatial analysis was carried out using GIS methodologies to assess equity in the accessibility of urban heat island mitigation strategies in Detroit, Michigan, primarily cooling centers and existing or potential
green roof sites. 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, both existing and potential, were analyzed to determine if implementation favored certain demographic groups. Socio-spatial 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-related 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.

While research into the disproportional effects of the urban heat island effect tend to suggest that low-income minority groups are the most severely at risk for heat-related illness, particularly concerning the elderly and homeless (Gregg et al., 2012), geospatial analysis of demographic data in conjunction with heat-relief strategies reveal a great complexity within the goal of equitable access. Concerning race and ethnicity and economic situation, it can however be concluded that an environmental injustice exists with regard to UHIV and living in UGNs. This study was able to identify which demographic groups are most vulnerable to the urban heat island effect and which demographic groups are most represented in Detroit Future City’s UGNs by providing percentage ranking for each group to identify who are the most urban heat island vulnerable and who are most included in UGNs. Given that the complexity surrounding the social and economic issues suggested in this study is beyond the scope of a simple ranking, this study has shown that based on the given data parameters used in this study, the demographic groups most in need of urban heat island relief and resilience strategies can be identified based on a socio-spatial analysis.

The findings of this study reveal that Detroit’s Native Hawaiian and other Pacific Islander and Asian alone populations are the most excluded from Detroit Future City’s green space, and Detroit’s Black alone and American Indian and Alaska Native alone populations are the most urban heat island vulnerable. Regarding a connection between race and ethnicity and urban heat island vulnerability and resilience, it must be considered that while identifying these groups might have been a goal of this socio-spatial analysis, there is more complexity and nuance that must be evaluated beyond the findings of Table 1. Detroit’s black population, which is stated in the literature as being exceptionally impoverished, is in fact the most included racial group within the Detroit Future City green space, suggesting a diversion from the common consensus within the urban greening literature that low-income minority groups are generally the most excluded. Detroit is also a majority...
black city, with 73% of the city’s total population reporting as Black or African American identified in this study. 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, which coincides with the trend of Detroit’s white population mostly residing in the downtown region (Jay, 2017).

What was revealed through this analysis was that while Detroit’s black population had the highest percent access to green space within DFC’s future Framework Zone, with 34% compared to 22% of Detroit’s white population, Detroit’s black population had the second highest percent of its population identified as UHIV after AlaaNas (both 55% of each population after rounding). However, it must be considered that while more of Detroit’s black population has access to this future green space than of Detroit’s white population, the City’s black population is significantly larger than the City’s white population. This finding reveals that approximately 117,534 (78%) white residents, the lowest amount, will be excluded from DFC’s green space framework zone, while 376,766 (66%) black residents, the highest amount, will be excluded from the UGN area.

Demographic groups regarding poverty, consisting of 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 to green space, 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.

From Table 2, it can be concluded that since roughly half of those identified as living below poverty and receiving public assistance income have been identified as being urban heat island vulnerable, it can be speculated that there is a connection between financial preparedness and urban heat island vulnerability. Noticing that only roughly a third of these two populations are located within Detroit Future City UGN, it can be speculated that there is a financial disparity between Detroit’s financially vulnerable populations and inclusion in urban greening initiatives, suggesting that these urban greening initiatives may be inclined to assess whether the financially vulnerable are included in the benefits.

Concerning the siting of existing green roofs, a socio-spatial disparity was much more apparent than in the Detroit Future City plan, suggesting that perhaps this strategic plan should include demographic analysis like this study in their future design proposal to help make future green infrastructure implementation in Detroit more equitable. 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 reflects 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 (Safransky, 2014). Since gentrification within Detroit is an ongoing process, it is difficult to draw concrete conclusions regarding equitable 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 (Orr and Stoker, 1994). It is vital to note that this study’s investigation of existing and planned green roof sites only serves to assess the socio-spatial analysis of inclusion in Detroit’s larger urban greening efforts and cannot be used to feasibly assess any measurable reduction in urban heat island intensity, as surface area detail was not found to be available.

11. Further considerations

Attention to demographic inequity regarding the siting of urban heat island mitigation strategies presents a practical dilemma that poses 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 urban 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. Further, green infrastructure master plans, such as the Framework Zones of Detroit Future City, should consider implementing green roofs on both industrial and commercial buildings, such as industrial facilities and schools, to increase the vegetated surface area of the city and further contribute to reducing the impact of the urban heat island effect, and thus lowering cooling loads for all households and facilities. A data-driven socio-spatial 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 (MDHHS, 2019). The positive externalities associated with green roofs extend well beyond their cooling and energy savings potentials to further economic and public health benefits that result from the physical and physiological properties of the plant and substrate layers, primarily including improved storm water management and cleaner air (Oberndorfer et al., 2007).

Racial and economic disparities were identified in terms of access to Detroit Future City’s UGNs, as exemplified through Tables 1 and 2. Though it can be speculated that salient energy justice issues exist in Detroit based on higher cooling loads due to lack of accessibility to cooling centers, green roofs and UGN, urban heat island resilience and energy justice are too complex to be properly addressed through the minimal parameters utilized in this study. In multiple cases, the social and economic policy issues that must be addressed are simply beyond the scope of that which can be mapped especially, including through a socio-spatial analysis. However, from the findings of this paper, it was still found to be apparent that certain demographic groups should be given further consideration in terms of urban greening initiatives, such as Detroit Future City’s UGNs. While data limitations warrant it unreasonable to make any declarative claims on Detroit Future City’s efforts to incorporate inclusivity into its sustainability plans for the city, it should definitely be concluded that urban greening plans that claim to mitigate the Urban Heat Island effect pay sufficient attention to the demographic groups and communities that are most at risk, mindful.
that HR may affect different people differently. 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 (Kisner et al., 2012; Gregg et al., 2012).

12. Versatility of methodology

Beyond Detroit, the methodology presented in this paper is versatile and can be used by cities with similar green infrastructure plans, such as Portland, Oregon, Baltimore, and Chicago (Brown, 2017), to assess the role of socio-spatial justice in their own urban heat island resilience strategies, mindful that the appropriate demographic and environmental data is used. Since this methodology essentially assesses socio-spatial justice by measuring proximity to structures and sites supporting sustainability and climate change resilience, it can be adapted to different sustainability and climate change initiatives if the target structures and sites have physical locations that can be mapped spatially. By using proximity as a proxy for access, socio-spatial analysis can be used to indicate the degree to which underserved communities are benefiting from green infrastructure ecosystem services beyond urban heat island resilience, including access to green space, protection from storm water flooding, and access to biodiversity.

Though the backbone of this study, the authors of this paper recognize that socio-spatial justice in green infrastructure planning is much more complex than simple proximity, specifically when issues such as urban heat island and storm water flooding vulnerability are analyzed as a spectrum of severity, versus within the solid polygon boundaries that make up the urban heat island zones used in this paper. This “spectrum of severity” thus refers to areas of environmental risk that gradually increase in intensity around of focal point, such as with the scenario of land surface temperatures gradually increasing towards areas with high impervious pavement surface area. For analyzing these spectrums of severity, socio-spatial analysis should be based on raster imagery, rather than polygons, cognizant that subjects such as biodiversity and public participation exist on a spectrum, allowing for more accurate assessments of socio-spatial vulnerability. Further, more advanced modelling methodologies that incorporate nuanced parameters regarding use of green space are encouraged to supplement the socio-spatial analysis in terms of assessing the inclusion of underserved communities in green infrastructure ecosystem services.

13. Limitations and future improvements

Concerning environmental justice speculation on demographic groups represented through Detroit Future City’s urban greening plans, it must be recognized that the simple ranking of results presented in this paper will not adequately describe inequity, primarily due to fact that representation percentages were influenced by that group’s overall population. For instance, consulting Table 1 reveals that Asian alone are the racial and ethnic group that are least vulnerable to the urban heat island effect in Detroit. However, while this is true, population must be taken into consideration, as while by percentage, Asian alone is the least vulnerable, this does not mean that there are more individuals belonging to Asian alone that are UHIV than the other groups. By sheer count, Black or African American alone would be revealed to have the most individuals labeled as UHIV, most apparently given that this group has the largest population within Detroit. This may mean that from a population perspective, American Indian and Alaska Native alone might not be representative of the most urban heat island vulnerable population in Detroit, given this group’s population count relative to that of Black or African alone, as well as White alone. Truly assessing the scope of inequity issues pertaining to Detroit’s urban greening future, and particularly, Detroit Future City, is incredibly complex, and so it must be acknowledged that this study only aims to offer one means of identifying which groups are most urban heat island vulnerable and left out of future green space plans. Ranking each demographic groups level of vulnerability by percentage may be an incomplete representation of true urban heat island vulnerability, yet this study aims to present this assessment as a starting point.

Implementing a socio-spatial analysis such as that presented in this paper, further necessitates a consideration of values regarding what is perceived as vulnerability, in the case of Detroit’s urban heat island effect, calling into question whether a population’s heat vulnerability is determined by the proportion of individuals within that specific group who are vulnerable compared to those who are not vulnerable, or the pure number count of individuals who are vulnerable relative to the counts of other populations. Relativity remains a key consideration, as it must be determined if a population’s status of vulnerability is determined by passing a threshold count, unrelated to other groups, or is determined by it’s ranking of vulnerability relative to other groups.

Several factors revealed the limitations of using existing and planned green roof data in the sociospatial analysis calculations of this study, leading to a lack of green roof access data for the studied demographic groups, such as what is displayed in Tables 1 and 2. Unlike the 0.775 distance radiance that determines what is reasonable walking distance to a cooling center there was no specified radius that would dictate the distance required to benefit from the urban heat island mitigating effects of green roofs. Even if there was a scientific consensus on this distance, displaying green roofs as points neglects their varying surface areas, which could significantly misrepresent individual cooling potentials. Since UGNs were depicted as polygons depicting building footprints of varying surface areas, merging in green roofs as equally-sized dots would not be compatible, which is why they could not accurately be used as a factor in identifying UHIV, since UGN polygons could not extract demographic counts from the available green roof points, leading to a lack of values that would fit into Tables 1 and 2. To create a more accurate representation of access to green roof urban heat island mitigation, and thus a more accurate representation of potential UHIV, one might create a GIS shapefile based on polygons traced from satellite imagery of identified green roofs. This would further involve setting an access radius that took into consideration the urban climate fluctuations of Detroit.

14. Closing points

While Detroit Future City has a very strong commitment to alleviating the environmental and economic stress that storm water flooding has on Detroit’s existing infrastructure, this paper suggests that any priority in addressing further urban environmental issues, primarily the urban heat island effect, cannot be simply an added benefit of existing green storm water infrastructure (GSI), but as a different ecosystem service that will require its own considerations and planning efforts. Therefore, this paper shows how spatial planning can be used to optimize the cooling benefits of urban vegetation for mitigating the urban heat island effect for the neighborhoods that are most at risk.

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. 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.
Appendix A

**Geospatial methods for mapping UHIV**

**Without Access to Cooling Center (WOACC)**
To show which demographic groups within Detroit did not have access to cooling centers, cooling center locations first were geocoded and mapped as data points. Buffers were subsequently drawn around each cooling center at 0.775 miles to display the total surface area concerning access to cooling centers, setting 0.775 miles as the threshold for the distance that is most reasonably walkable for most people. These buffer polygons were then subtracted from each demographic dataset via clipping to reveal the percent of each demographic group without access to cooling centers.

**Within Heat Risk Zone (HRZ)**
To show which demographic groups within Detroit were within a HRZ, HRZ polygons (shown in Fig. 3b) were subtracted from each demographic dataset via clipping to reveal the percent of each demographic group within a HRZ.

**Heat Risk (HR)**
To show which demographic groups within Detroit were within a HRZ and also without access to a cooling center, therefore at risk for heat-related illness, polygons denoting within a HRZ and without access to a cooling center were subtracted from each demographic group data layer. To create these new HR polygons, polygons denoting access to cooling centers were subtracted from polygons denoting presence within a HRZ.

**Within Urban Green Neighborhood (UGN)**
To show which demographic groups within Detroit were located within Detroit Future City UGNs, UGN polygons were subtracted from each demographic group data layer. UGN polygons resemble a building footprint for Detroit, and so each polygon is an individual building site. While the UGN polygons layer consisted of many individual building sites, instead of larger UGN boundaries that included individual building sites, clipping demographic layers to these UGN polygons still revealed which households and facilities were included in an UGN. When demographic data layers were clipped to these UGN polygons, the population of each demographic group within each UGN building site was revealed.

**Urban Heat Island Vulnerable (UHIV)**
To show which demographic groups within Detroit were vulnerable to the urban heat island effect, each demographic layer was clipped to the HRZ layer, but after the access to cooling center layer and UGN layer were subtracted from the HRZ layer. Accordingly, the surface area corresponding to urban heat island vulnerability would be smaller than the surface area corresponding to HR, given the added parameter of exclusion from an UGN.

Appendix B

**Geocoded Green Roofs (existing and planned) in Detroit, MI used in study:**

- Cobo Center
- Damon J. Keith Center for Civil Rights at the Law School – Wayne State University
- A. Paul Schaap Chemistry Building and Lecture Hall – Wayne State University
- Coleman A. Young Municipal Center
- Detroit School of Arts
- Joe Louis Arena station – Detroit People Mover
- Blue Cross/Blue Shield of Michigan Parking Garage
- Detroit Suburb Office Building
- Lumen Detroit restaurant - Beacon Park
- Detroit Zen Center
- Southwest Solutions
- Detroit Farm and Garden
- Gravel Garden
- 6568 Woodward LLC
- Ducharme Place
- Green Garage

**Geocoded Cooling Centers in Detroit, MI used in study:**

- Williams Recreation Center: 8431 Rosa Parks Boulevard
- Coleman A. Young Recreation Center: 2751 Robert Bradby Drive
- Patton Recreation Center: 2301 Woodmere Street
- Farwell Recreation Center: 2711 East Outer Drive
- Crowell Recreation Center: 16630 Lahser Road
- Northwest Activities Center: 18100 Meyers Road
- Adam Butzel Complex: 10500 Lynden St
- Butzel Family Center: 7737 Kercheval
- Clemente Center: 2631 Bagley
- Crowell Recreation Center: 16630 Lahser Road
Appendix C

Population Counts

Total population surveyed for Race (including Hispanic/Latino): 777,813
Racial/Ethnic counts for Detroit:
White alone: 150,766
Black or African American alone: 571,286
American Indian and Alaska native alone: 2,697
Asian alone: 14,227
Native Hawaiian and other pacific islander alone: 163
Some other race alone: 21,224
Hispanic or Latino: 54,827
Total population surveyed for living below poverty level: 288,700
Total population surveyed for living with public assistance: 288,700
Below poverty level with access to cooling center sum: 49,243
With public assistance with access to cooling center sum: 8,486
Below poverty level within heat risk zone sum: 71,232
With public assistance within heat risk zone sum: 12,195
With public assistance in Urban Green Neighborhood (Green Residential and Green Mixed-Rise) sum: 6,252
Below poverty Level within Urban Green Neighborhood (Green Residential and Green Mixed-Rise) sum: 33,327
Total with public assistance sum: 18,149
Total living below poverty level sum: 102,592

Race/ethnicity with access to cooling center

Total sum: 362,027 of the units surveyed for race/ethnicity are within access to cooling center
White Alone sum: 60,997
Black or African American alone sum: 268,048
American Indian and Alaska native alone sum: 1,374
Asian alone sum: 10,963
Native Hawaiian and other pacific islander alone sum: 20
Some other race alone sum: 13,585
Hispanic or Latino sum: 33,991

Race/ethnicity within heat risk zone

Total sum: 538,155 of the units surveyed for race/ethnicity are within heat risk zone
White alone sum: 101,233
Black or African American alone sum: 394,921
American Indian and Alaska native alone sum: 1,942
Asian alone sum: 12,283
Native Hawaiian and other pacific islander alone sum: 45
Some other race alone sum: 16,038
Hispanic or Latino sum: 39,669

Race/ethnicity within Urban Green Neighborhood (Green Residential and Green Mixed-Rise)

Total sum: 239,504 of the units surveyed for race/ethnicity are within heat risk zone
White alone sum: 33,232
Black or African American alone sum: 194,520
American Indian and Alaska native alone sum: 748
Asian alone sum: 1,744
Native Hawaiian and other pacific islander alone sum: 0
Some other race alone sum: 5,205
Hispanic or Latino sum: 12,703
Appendix D

Data Utilized:

City of Detroit Boundary
Boundaries of the City of Detroit clipped from mcd_v14a
City of Detroit
https://data.detroitmi.gov/Government/City-of-Detroit-Boundary/vqqa-wgrj

Detroit Future City Framework Zones
City of Detroit, Planning and Development

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Imagery
Landsat 8 OLI/TIRS CI Level-1
LC08_L1TP_020031_20180524_20180605_01_T1
Data courtesy of the U.S. Geological Survey

Cartographic Boundary Shapefile
Ch_2017_us_county_5m.zip
U.S. Census Bureau, 2017

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https://www.youtube.com/watch?v=-uDQo2a5e7dM


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