ENVIRONMENTAL EMERGENCY CALLS IN DALLAS, TEXAS: APPLYING THE BRACE MODEL TO ASSESS THE EFFECTS OF MICROCLIMATES ON URBAN DESIGN & HUMAN HEAT STRESS

by

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ABSTRACT

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The objective of the study is to investigate how the practice of landscape architecture can help mitigate the effects of climate change and the urban heat island effect on vulnerable block groups in Dallas, Texas by using a model framework, to assess, project, analyze, develop, and evaluate microclimates in these urban areas.

This study investigated how the physical morphology of urban areas affect the frequency of heat-related environmental emergency calls by applying the Center for Disease Control's (CDC) Building Resilience Against Climate Effects (BRACE) framework. Geographic Information Systems (GIS) was used to identify warm trends in Dallas block groups in relation to urban morphology, demographic vulnerability and the location of heat-related environmental emergency calls. This process will examine if any connections to impacts can be drawn where the practice of landscape architecture may help to mitigate or improve. Mapping this data gives practitioners the ability to identify and assess heat stress vulnerability to prevent disease burden by implementing lacking landscape features such as tree canopy, vegetation, shade structures, or other means of cooling the urban landscape. The BRACE model provides the framework for assessing,

projecting, analyzing, and evaluating microclimates in these urban areas.

Through the use of this framework, several vulnerable areas have been identified, which includes a thorough analysis of three focus areas of Dallas, where bioclimatic interventions are suggested that can be implemented by landscape architects (LA's), planners, architects, city officials and future policy can ideally significantly impact the health of Dallas residents.

Applying the BRACE model is a fundamental step for any region of the world to assess and visualize the potential impacts of future climate change. This model utilizes quantitative data, accessible by many researchers, such as, weather, health, and demographic data. This data offers the ability for planners and designers a lens to focus on areas that may possess critical factors that require further interventions in respect to public health and well-being of individuals in vulnerable localities. The effects of climate change are significant around the world and require more attention. Therefore, the responsibility of entities whose job is to develop safe living spaces for people should take priority and require an acknowledgment that there are ways in which thoughtful design and development can adapt to a warming environment.

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CHAPTER 1 INTRODUCTION

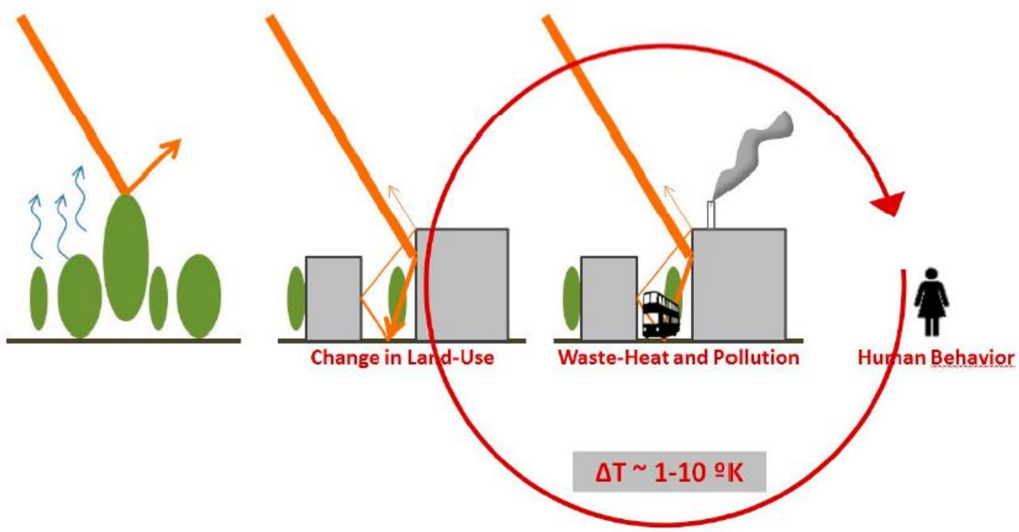
1.1 BACKGROUND

The practice of landscape architecture and its history reviews designs that were practical for local climate and aesthetically pleasing for their time and in many cases continues forward today. Before electric air conditioning, landscapes were bioclimatically designed for humans to coexist in ever-fluctuating environments. However, in the present day, it seems that urban designers have ignored knowledge about the vernacular design of thermally comfortable outdoor spaces and instead follow international universal design trends. The oversight of centuries-old understanding of designing with the urban climate has been a problem since the popularity of Modernism. The "International Style" adopted in the same way all over the world since the 1900s, often had unfavorable repercussive effects on people's indoor climates and outdoor microclimates (Mazhar et al., 2015)

In summary, today, it is easy to overlook the importance of the bioclimatic design of outdoor environments. However, this is also the cause of environmental emergencies (EE's) that can otherwise be mitigated through the proper design of outdoor environments. LA's are vital to designing environments for human health because the main tools LA's use such as permeable paving, water features, ground covers, shade structures, trees and other design strategies that increase passive cooling are capable of preventing overlooked areas exhibiting high temperatures contributing to heat stress.

1.2 PROBLEM STATEMENT

The practice of landscape architecture's central tenant is to uphold the health, safety, and welfare of the users of outdoor environments. Evidence-based research is necessary to examine the relationship of urban morphology and its effects on the thermal comfort and the health of humans to prevent avoidable future health emergencies with the anticipation of a warming climate. Past research has suggested that Dallas has an 'overwhelming abundance' of sites in need of more tree canopy coverage (Peters, 2014; Lin, 2012). Additionally, the importance of the "street section"—which includes the streets, the public space between buildings, which is principally relevant to the environmental microclimate that reflects the "negative loop" of causes and effects of urban microclimatic changes and environmental/built design relationships (Schiano-Phan et al., 2015). This creates a vicious circle coupled by the lack of awareness among city dwellers of the environmental harm of such systems (see Figure 1.1) (Schiano-Phan et al.,



2015).

Figure 1.1 The Negative Loop Contributing to the Deterioration of the Street Section (Schiano-Phan et al., 2015)

Therefore, there needs to be more awareness among stakeholders of all facets of development, planning, design, implementation and the use of urban areas.

1.3 PURPOSE OF RESEARCH

The purpose of this research is to find significant ways in which LA's can improve the quality of life of urban inhabitants in Dallas, Texas. LA's are specially trained to design outdoor environments. Specific goals should be kept in mind and important objective should be kept in mind when performing a site analysis. Site analysis research should be derived which also included consideration for urban form and its implications on human health or thermal comfort in Dallas or warm climate regions in order to reduce the likelihood of environmental emergency occurrences. Ideally, the quantification of existing issues and the thermal comfort benefits, through data accumulation of pre and post-bioclimatic designs could help relate design proposals to health outcomes. The microclimatic impacts in the urban environment are produced by the interaction of the causes of climate change with specific urban morphologies such as alteration of the surface energy balance (i.e., higher albedo, reduced evapotranspiration, and increased thermal storage), waste-heat (from automobiles, air conditioning usage) and localized generation of pollution, human behavior, and other factors (Schiano-Phan et al., 2015). All of the elements above coexist in the design realm of the practice of landscape architecture, architecture, and planning.

1.4 RESEARCH QUESTIONS

In order to gain a sense of direction and purpose in this study, some basic research questions informed research relevancy to the use of the BRACE model in the practice of landscape architecture:

1. How can landscape architects apply the BRACE Model in the site inventory process?

2. What conclusions can be drawn from the use of the BRACE Model in a Study of Dallas?
3. What is the prevalence of vulnerable block groups where microclimates are warmer than the surrounding area in Dallas, Texas?
4. How do microclimates affect the occurrence of environmental emergency calls occurring in Dallas, Texas?
5. What is the relevance to the lack of tree coverage and surface temperatures among other analysis factors in the study Dallas?
6. What types of populations reside in areas with a high occurrence of environmental emergency calls?

1.5 DEFINITION OF KEY TERMS

Albedo: The ability of a surface to reflect solar radiation (Brown, 2010).

Anthropogenic Heat: Heat released to the atmosphere as a result of human activities, often involving combustion of fuels, i.e., industrial plants, cooling, human metabolism, and vehicle exhausts (American Meteorological Society, 2019)

Bioclimatic Design: Effective modification of the biophysical properties of urban spaces (Vanos, 2014).

BRACE Model: The BRACE model is a five-step process that helps health departments to understand how climate has and will affect human health, and enables health departments to employ a systematic, evidence-based process to customize their response to local circumstances (Center for Disease Control and Prevention, 2019).

Environmental Emergencies (EE's): Term used by Dallas Fire & Rescue Department to identify emergency calls attributed to climate conditions. (Dallas Fire & Rescue, 2018)

Evapotranspiration: The loss of water from vegetation & soil through evaporation and transpiration (Marsh, 2010).

G*eographic Information Systems:* (GIS) Computer mapping system designed for ready applications in problems involving overlapping and complex distributional patterns (Marsh, 2010).

Heat Stress: Exposure to extreme heat in hot environments, which can result in illnesses and injuries such as, heat stroke, heat exhaustion, heat cramps, etc.

Impervious Cover: Any hard surface material, such as asphalt or concrete, which limits infiltration and induces high surface runoff rate (Marsh, 2010).

Leaf Area Index: The total one-sided leaf surface area per unit ground area (Spagenburg et al., 2008)

Microclimate: A local set of atmospheric conditions as small as a few square feet or as large as many square miles that differ from those in the surrounding area (Hopper, 2007).

Sky View Factor: This represents the ratio at a point in space between the visible sky and a hemisphere centered over the analyzed location (Oke, 1981).

Solar Radiation: Energy and light from the sun (Hopper, 2007).

Humid subtropical climate: A major climate type of the Köppen classification characterized by relatively high temperatures and evenly distributed precipitation throughout the year (Köppen–Geiger classification).

Thermal Comfort: The energy budget of a person; the human body input and output of energy, whereas a balance fall between overheated or under heated, roughly 97° F to 100° (Brown, 2010).

Vulnerable Populations: Includes populations who are racial or ethnic minorities, children, and elderly, socioeconomically disadvantaged, underinsured or those with certain medical conditions (NCBI, Waisel, 2013).

Urban Design: The process of designing and shaping the physical features of cities, towns and villages and planning for the provision of municipal services to residents and visitors which deals with the larger scale of groups of buildings, streets and public spaces, whole neighborhoods and districts, and entire cities (Boeing et al., 2014).

Urban Heat Island: In urban cities, this effect intensifies with the heating of ground under dry, unshaded streetscapes, exhibiting higher temperatures both day and night compared to more rural landscapes (Marsh, 2010).

1.6 RESEARCH METHODS

The research uses secondary quantitative research methods following a constructivist framework (Deming & Swaffield, 2011) to assess the microclimates of the urban landscape of Dallas, TX. Specifically, GIS and climate data were collected to analyze the relationship between urban morphology, temperatures, and environmental emergency call responses from the city of Dallas Fire & Rescue service for 2016-2018 using the Center for Disease Control & Prevention's BRACE Model. Firstly, the literature review examined significant published research related to the field of the practice of landscape architecture and microclimates as they pertained to climatic comfort and health. Secondly, data were collected from the city of Dallas Fire & Rescue of responses to environmental emergency calls. This data refers to the most recent three years (2016-2018) of environmental emergency calls in the city of Dallas. The data from the National Weather Service and National Oceanic and Atmospheric Administration were obtained that reflected corresponding dates of environmental emergency call data. Further data includes impervious surface and tree canopy data collected from Texas Trees Foundation and the City of Dallas, as well as, the United States Geological Survey and the United States Department of Agriculture for Landsat 8 imagery and land cover datasets (land cover data generated from satellite imagery). Landsat 8 imagery was processed using ArcMap's Composite Bands, Geoprocessing Tool to form a multispectral raster image representing land surface temperature, a method used by the United States Geological Survey to derive land surface temperatures from satellite image data. Additional data for demographic block groups were sourced from the Census Bureau's American Community Survey. Furthermore, this data was analyzed in order to find areas where the practice of landscape architecture elements could affect the areas with the most need, for example, areas with a high incidence of environmental emergencies, heat contributing urban morphological factors, and vulnerable demographic block groups using the BRACE Model framework. Finally, corresponding areas were suggested for bioclimatic redesign in order to address the need for cooling interventions on vulnerable block groups in the city of Dallas, Texas.

1.7 LIMITS, LIMITATIONS, SIGNIFICANCE

The limits, limitations, and significance are dependent on the secondary data available as well as the available models where the methodology was derived. The basis for the study was formed from three previous studies. Derica Peters, the University of Texas at Arlington Alumni in the Planning Program, performed a similar study regarding Urban Forestry among vulnerable populations in Dallas. However, the connection to emergency phone calls was not examined. Instead, the study focused on sensitive or vulnerable areas, medically underserved areas, tree canopy and lack of climate control.

Additionally, a study in Toronto investigated health indicators in connection to heat stress. Lastly, a study in Georgia followed the BRACE model, which examined the relationship of the incidence of renal disease about urban, climatic, and social vulnerability factors. However, no studies examining emergency calls, a health indicator of heat stress in Dallas, TX surfaced in the reviewed references. This study is assumed a first for Dallas. Based on this, there may still be significant parameters that have not been covered in this research that are relevant to the study of heat stress on vulnerable climates based on the researchers chosen parameters.

1.8 ASSUMPTIONS

It is assumed that some of the fundamental mechanisms in which urban morphology affects microclimates could be positively impacted by modification with the expertise of a Landscape Architect. There are ways in which a landscape can be modified to affect the thermal comfort of humans positively. New areas of research and application are needed to create climate-resilient built environments that make a positive impact on the physical, social, and the microclimatic urban environment in response to climate change (Schiano-Phan et al., 2015). The purpose of this research is to take these assumptions and to find a relationship to the locations where environmental emergency calls occur.

1.9 CHAPTER SUMMARY

In summary, today, it is easy to overlook the importance of the bioclimatic design of outdoor environments. However, this is also presumably the cause of environmental emergencies (EE’s) that can otherwise be mitigated with the proper design of outdoor settings. Evidence-based research is necessary to examine the relationship of urban morphology and its effects on the thermal comfort and the health of humans to prevent avoidable future health emergencies with the anticipation of a warming climate, especially in vulnerable areas. Past research has suggested that Dallas has an 'overwhelming abundance' of sites in need of more tree canopy coverage. The purpose of this research is to find significant ways in which LA's can improve the quality of life of urban inhabitants in Dallas, Texas. Ideally, the quantification of the thermal comfort benefits of proposed bioclimatic designs could help relate design proposals to health outcomes. The use of secondary quantitative research methods following a constructivist framework can assess the microclimates of the urban landscape of Dallas, TX. This framework leads to ways in which a landscape can be developed to affect the thermal comfort of humans positively. New areas of research and application are needed to create climate-resilient built environments that make a positive impact on the physical, social, and the microclimatic urban environment. The purpose of this research is to take these assumptions and to find a relationship to the locations where environmental emergency calls occur.

CHAPTER 2 LITERATURE REVIEW

2.1 INTRODUCTION: THE NEED FOR COOLING MICROCLIMATES

Globally, evidence has shown that Earth's climate is changing as well as the growth of Urban Heat Islands (UHI) (Lenzholzer & Brown, 2013). Physical characteristics that contribute to UHI's include less vegetation, impermeable surfaces, and anthropogenic heat sources, often found in high concentrations in urban areas (Kaloush et al., 2008). Studies have shown an increase in energy use for comfort due to microclimatic changes in summer and, specifically, increased urban temperatures raise the peak electricity demands compounding raises in temperature through wasted energy (Schiano-Phan et al., 2015). UHI's combined with anthropogenic heat create urban climate zones that are even warmer because of their little open space, and high population density (Stewart and Oke, 2012). Deforestation and UHI expansion are typical of many urban areas in the United States in the regions that are losing trees at a rapid rate due to the population pressure of urban sprawl (American Forests, 2005). The spread of development creates longer commutes to work, and the increased traffic volume is a significant source of anthropogenic heat that contributes to the UHI (Grossman-Clarke et al., 2005). Cities have an effect on climate change: More than 50% of the expanding population lives in cities responsible for most of the global gross domestic product and 78% of greenhouse gases responsible for climate change (Schiano-Phan et al., 2015). A national goal to focus on the landscapes and the physical reconstruction thereof to cool the microclimates should be of as much importance as maintaining our roadways (Vanos, 2015). Transportation infrastructure, as studies have shown, that increased heating of roads caused by the warming of climate can substantially decrease the lifespan for roads and their asphaltic infrastructure over time (Winguth, Lee & Ko, 2015).

	Population, Census, April 1, 2010	Land area (square miles), 2010	Estimated population (July 1, 2015)	Housing units (July 1, 2015)	Estimated population change (2010-2015, %)
Texas Total	25,145,561	261,231.71	27,469,114	10,587,752	9.2
San Antonio	1,327,407	460.93	1,469,845	524,246	10.7
Dallas	1,197,816	340.52	1,300,092	516,639	8.5
Austin	790,390	297.90	931,830	354,241	14.8
Fort Worth	741,206	339.82	833,319	291,086	12.2

Figure 2.1 Population Statistics from the US Census Bureau

Furthermore, cities lack initiative on the development of resilient climate infrastructure, and the urban population of the world is proportionally increasing by both size and density (Seto et al., 2011). Actions to mitigate both climate change and their environment are underexploited (Schiano-Phan et al., 2015). The importance of climate resilient cities is crucial based on Dallas' estimated population increase of 8.5% from 2010 to 2015. Projections of a growing urban population apply to all major cities in Texas.

This evidence leads to the importance of landscape architects (LA's) role in mitigating the temperature of these growing urban populations by considering the effects of solar radiation, terrestrial radiation, wind, air temperature and air humidity on human comfort, where the implementation of design intervention can help to mitigate. In urban environments, LA's can use precedent studies, site assessments, implement modifications to outdoor spaces, educate, or perform evaluation studies to reduce the heat island effect of cities (Brown, 2010).

Every area of the world has specific climate-related problems. DFW, for example, experiences tornadoes, hailstorms, heavy rains, and flooding, alternates with periods of extreme drought. An alarming prediction by some scientists is that, by the end of the 21st century, extreme temperatures of up to 125 °Fare expected, exceeding historical heat waves by 12 °F (Winguth, Lee & Ko, 2015). Texas, in general, has had more climate-related disasters than any other state in terms of cost (NOAA, 2018).

This study was limited in the scope of factors considered, but microclimate, defined as thermal comfort of humans in general, has been shown to exert a substantial effect on jobs, health, and quality of life (Hsiang et al., 2017). Scientists consider any temperatures that rise above the average human body temperature to increase the stress involved in the human body (Sherwood & Huber, 2010). Globally, temperatures have increased on average 1.8°F in the last century. Dallas' temperature on average has risen 3°F from the early 1900s to the most recent decade (Winguth, Lee & Ko, 2015). According to climatologists, urbanization combined with global warming can be one reason for this discrepancy and difference compared to the worldwide average. One reason for this is that many of the human-made materials that comprise DFW's built environment hold more solar radiation than natural material such as soil and vegetation (Hoerling et al., 2013).

Populations in urban areas throughout the world suffer from EE's caused by overheating of metropolitan regions. There is evidence that global climate change may increase the frequency (Brown et al., 2015) because two critical current environmental aspects, population growth & climate change affect, enhance urban heating. However, some ways LA's can bioclimatically design for cooling microclimates is by studying climate model simulations, specification of materials, implementation of vegetation, such as shade trees, and through the influence of local policy or city design guidelines. To design future urban landscapes for people during hot summertime weather, a landscape architect needs to know how and which design interventions have an impact (Brown, 2011). Planning for future cities must respond to the changing climate and provide safe, resilient outdoor environments for urban residents (Mazhar et al., 2015)

2.2 TYPICAL CLIMATE PATTERN OF DALLAS

The Dallas-Fort Worth climate is humid subtropical with warm summers and characterized by a wide annual temperature range (National Weather Service (NWS)). Also, precipitation fluctuates substantially, ranging from less than 20 to more than 60 inches per year. The maximum temperatures of summer are associated with fair skies, southern to southwesterly winds, and low humidity. Typically, hot spells in summer are broken by occasional heavy thunderstorms. Often, summer evening low temperatures exceed 80° F, and daytime temperatures often exceed 100°F. Air conditioners are very common to cool buildings and vehicles. Precipitation occurs with heavy rainfall over short periods. Thunderstorms happen throughout the year, but are most frequent in the spring (NWS). Hail can be extreme and the wind occurring during thunderstorm activity can become destructive. The average length of the warm season without freezing in the Dallas/Fort Worth Metroplex is approximately 249 days. Usually, the last occurrence of frost is around March 3, and the average frost begins again around November 24. Based on the Köppen–Geiger classification of zones, Dallas is considered ‘Cfa’, a mainly warm temperate climate, fully humid precipitation, and hot summer temperature (see Figure 2.2) (Hopper, 2007).

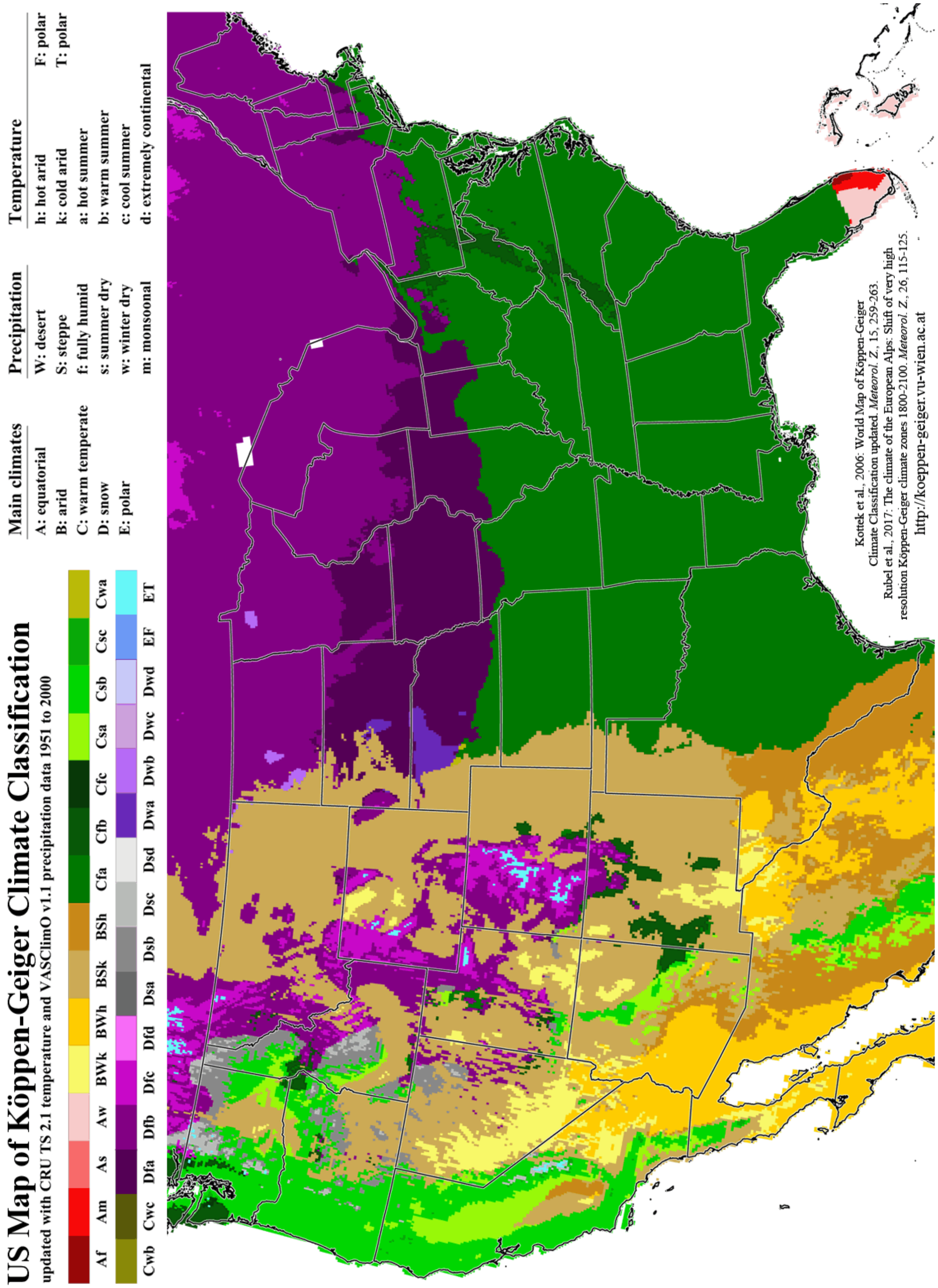


Figure 2.2 Köppen–Geiger classification the zones (Kottek et al., 2006)

2.3 PRECEDENT STUDIES: HEAT RELATED EMERGENCY CALLS & THE BRACE MODEL

Three studies that have used similar have used similar methodologies were reviewed. A study in Toronto, Canada that examined heat-related emergencies, published in 2017, for the 'International Journal of Environmental Research and Public Health.'

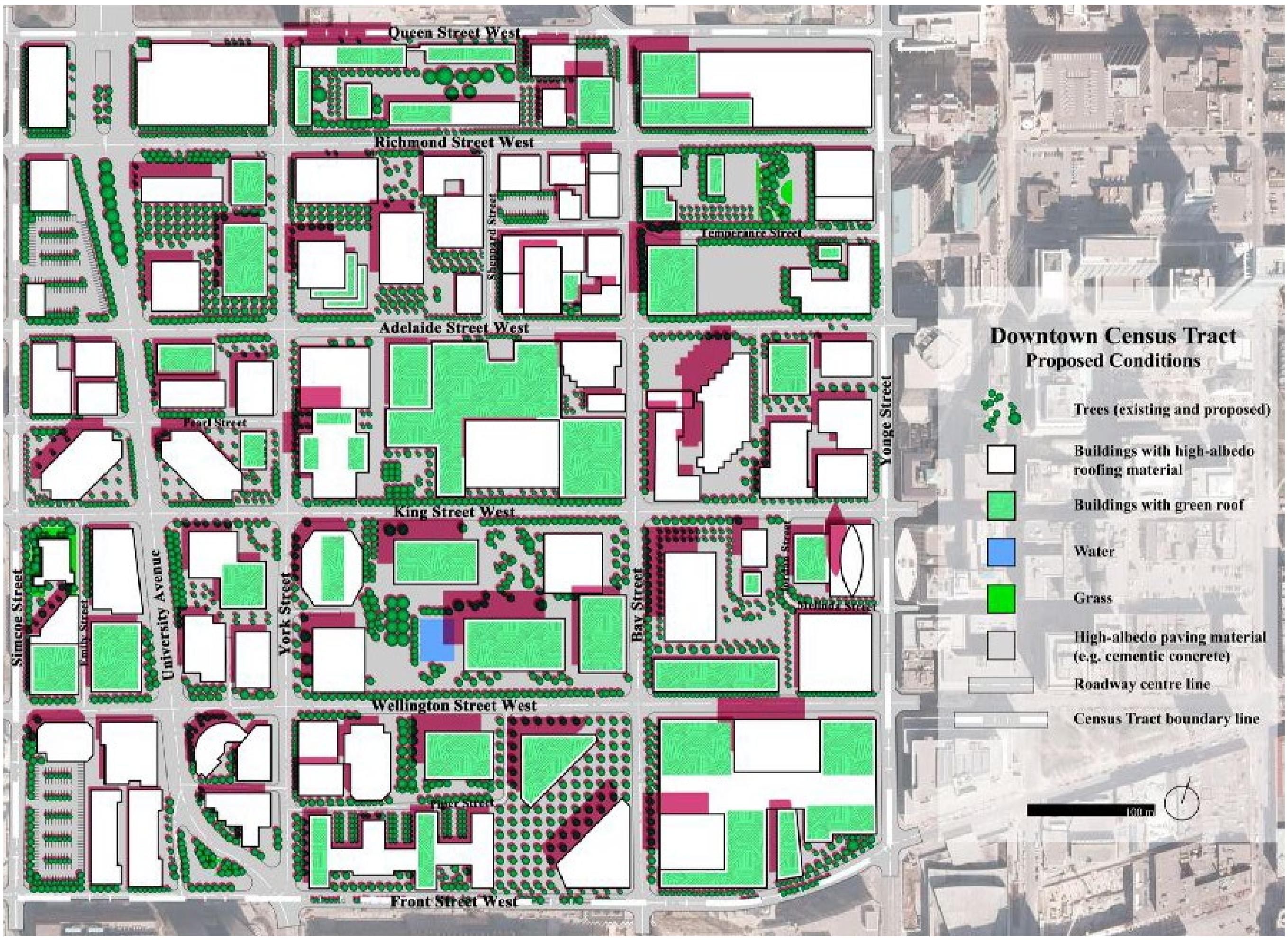


Figure 2.3 Redesign of Downtown Toronto (Graham et al., 2017)

The study included a redesign of two areas expected to have high emergency calls due to microclimate conditions (see Figure 2.3; 2.4 & 2.5). The incorporated redesign principles are based on a human energy budget model that would potentially reduce

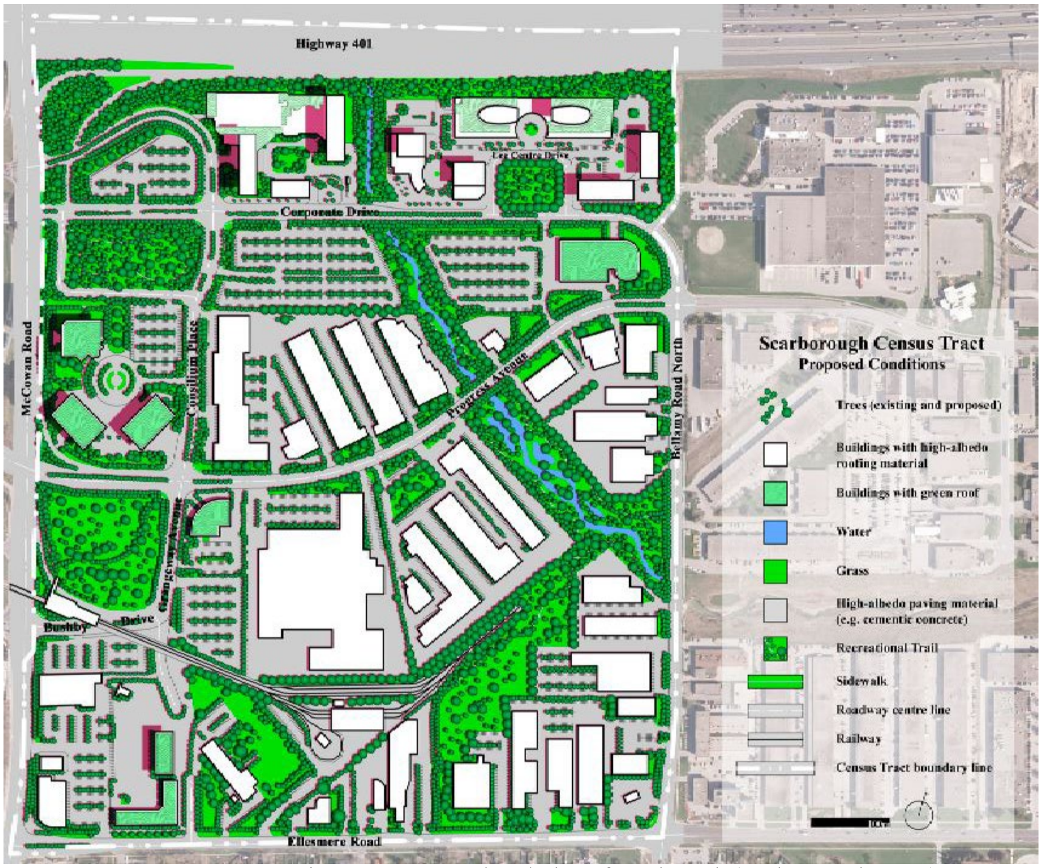


Figure 2.4 Proposed Redesign of Scarbrough (Graham et al., 2017)

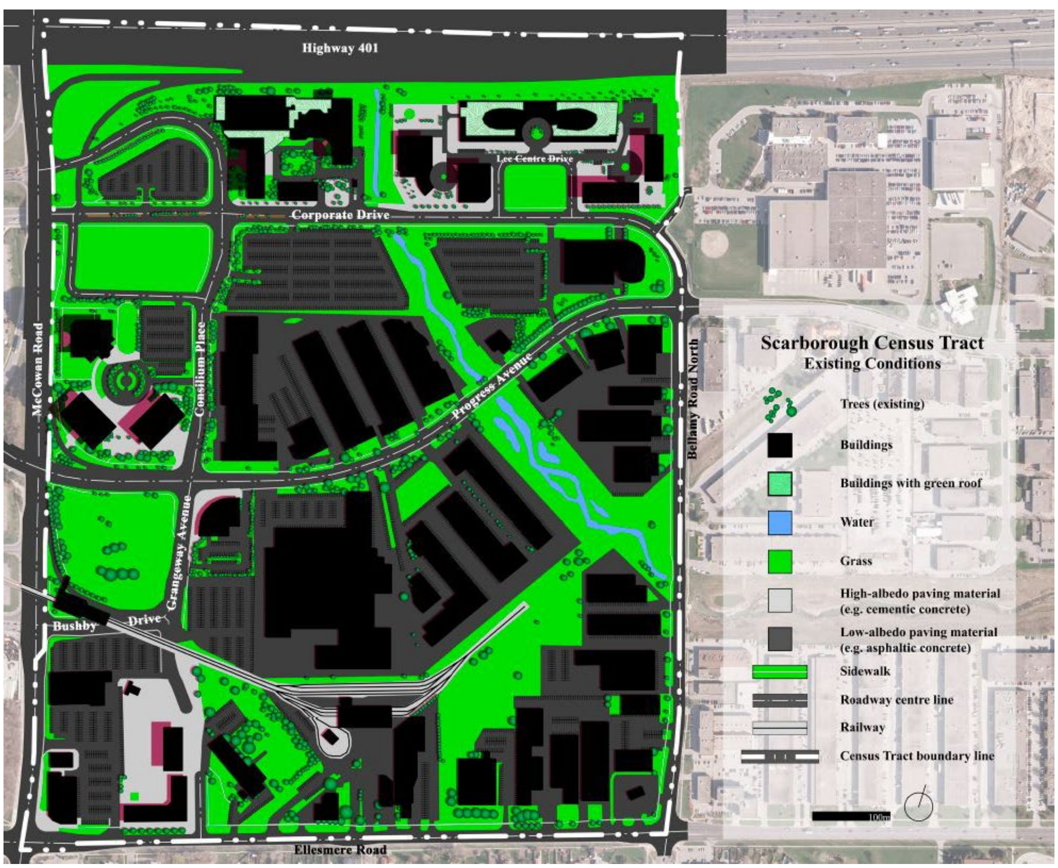


Figure 2.5 Scarborough Existing Conditions (Graham et al., 2017)

emergency calls by 40-50%. Additionally, a University of Texas at Arlington, graduate thesis of the Planning Program submitted in 2014 (Peters), applied a suitability model to the preservation and urban reforestation on vulnerable populations in Dallas using the BRACE Model. Peter's framework included the following (see Figure 2.6):

	Factor	Data Source
Sensitivity	Minority (Race)	U.S. Census Bureau American Community Survey
	Level of poverty (Income)	U.S. Census Bureau American Community Survey
	Age Group	U.S. Census Bureau American Community Survey
Exposure	Condition of climate control	Dallas Central Appraisal District
	Ambient temperature	HARC, Texas Tree Foundation
	Land Cover/Land Use	City of Dallas
	Tree Canopy Cover	Texas Trees Foundation
Adaptability	Medical Professional Shortage Area	US Dept of Health and Human Services - Health Resources and Services Administration
	Medically Underserved Area	US Dept of Health and Human Services - Health Resources and Services Administration

Figure 2.6 Data Set Based on BRACE Model (Peters, 2014)

A third study illustrates an application of the overlay analysis approach using the BRACE Model (see Figure 2.8). Heat-related illness in Georgia and the impacts of urban morphology provided more insight into how to help mitigate future environmental fluctuations due to climate change on vulnerable populations. The Georgia study utilized (see Figure 2.7) data of populations below the poverty line, populations over 65

Determinant	Determinant Type	Source/ (Resolution)	Literature Source
% population below poverty line	Social	US Census (Tract)	(Currero et al. 2002; Reid, O'Neill et al. 2009)
% population ≥ 65 years of age living alone	Social	US Census (Tract)	(Naughton et al. 2002; Reid, O'Neill et al. 2009)
Non-vegetated areas (e.g. impervious surfaces, non-green space)	Environmental	USGS (30m)	(Harlan, Brazel et al. 2006; Reid, O'Neill et al. 2009)
Prevalence of renal Diseases	Biological	Medicare (Zipcode)	(Semenza, Rubin et al. 1999)

Figure 2.7 Determinant Factors of Georgia Study (Managan et al., No Date; Retrieved 2019)

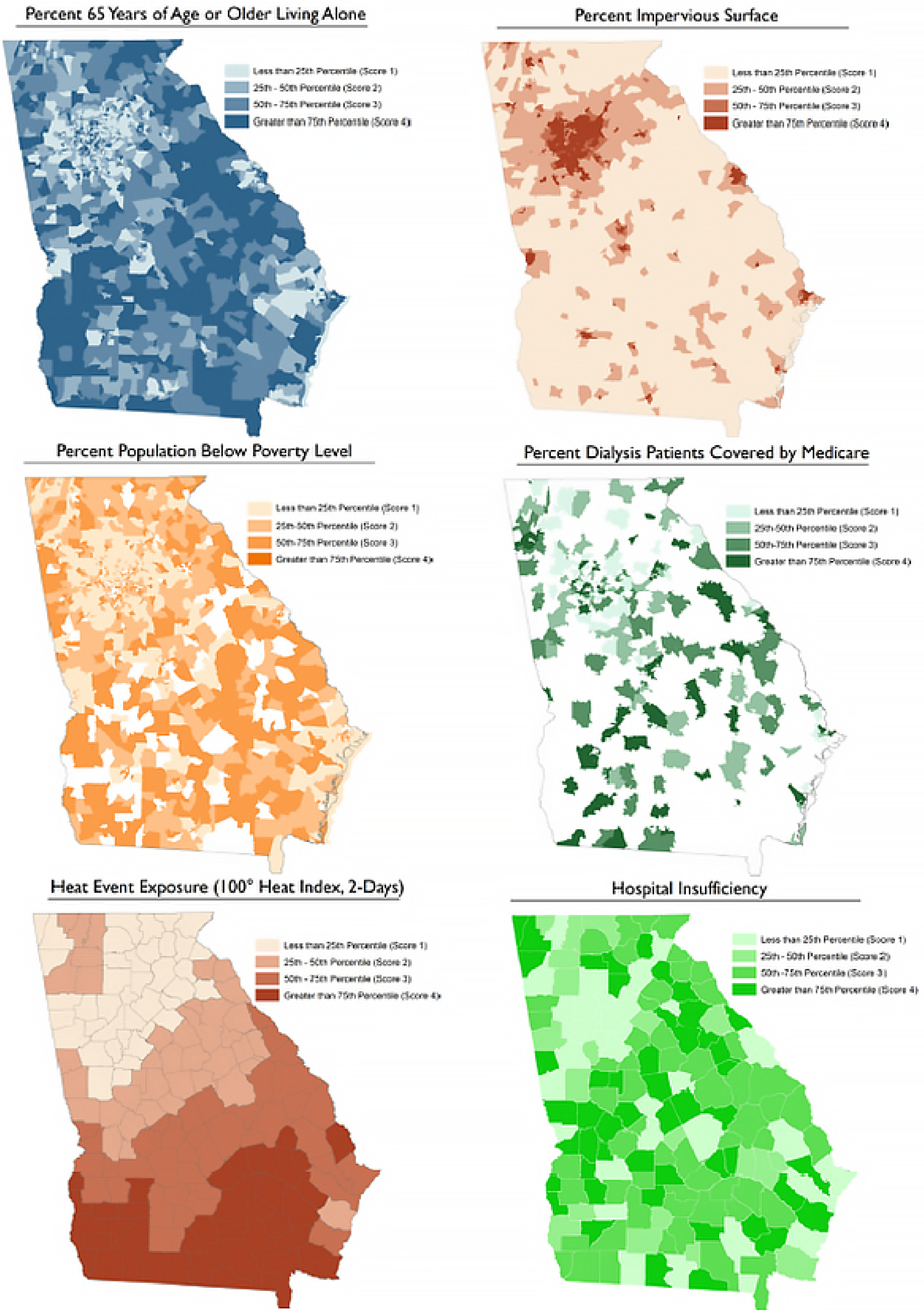


Figure 2.8 Block Group Weighted Analysis Components of Georgia Study (Managan et al., 2019)

living alone, non-vegetated areas and the prevalence of renal disease. The conclusion drawn from the study in Georgia identified communities and places susceptible to climate-sensitive health outcomes in order to assess health interventions and health adaptation strategies tailored to those specific areas.

Consideration of the BRACE model and its applicability to EE's in Dallas, TX:

> "The climate and health vulnerability assessment is a critical tool that can be used to help build resilience against the health effects related to climate change because it identifies where susceptibilities to hazardous exposures are likely to occur, provides community characteristics for the development and implementation of a climate and health adaption plan, and ultimately offers knowledge on viable public health interventions to implement (Managan et al., 2019 accessed)."

The three previously mentioned case study approaches and methodologies that can be applied to the City of Dallas. Assessing climatic, spatial, socioeconomic, and health implications of the landscape are vital to know the current state of Dallas microclimates in reference to human heat stress. Past research and evidence of how crucial urban morphology can influence the health of populations in cities set a base point for future research. A climate and health vulnerability assessment intends to identify the people and places that are most susceptible to extreme exposures resulting from a changing climate. Previous vulnerability assessments have used overlay analysis for climate health effects such as heat-related illness. The objective to keep in mind is to understand the connections of how LA's can consider urban form when bioclimatically designing outdoor spaces to prevent heat-related EE's in the future.

2.4 A STUDY OF DALLAS BASED ON OTHER MICROCLIMATE STUDIES

Microclimate studies have taken place in many areas of the globe, such as Toronto, Phoenix, Melbourne, Hong Kong, and Shanghai. In Hong Kong, with a sub-tropical climate, open spaces such as parking lots are generally warmer than adjacent narrow street canyons (Lau et al., 2016). Planners can combine the physical morphology-based planning with site-specific bioclimatic design approaches to offer comfortable green spaces in the city (Tan, Lau & Ng, 2016). The DFW region has been the setting for studies in regards to the growing influence of the Urban Heat Island (UHI) effect. The Houston Advanced Research Center (HARC) conducted a review of the Dallas UHI effect for the Environmental Protection Agency (EPA) in 2009, in partnership with North Central Texas Council of Governments (NCTCOG), to identify a base parameter to improve air quality in DFW (Houston Advanced Research Center, 2009). The recommended interventions would not only help clean the air, but aid in the reduction of the UHI effect in the urban areas of DFW. The availability of land for vegetation is generally limited in urban areas of high-density cities; trees should help promote cooling for locations where heat stress exists (Lau et al., 2016).

2.5 HEALTH INDICATORS: ENVIRONMENTAL EMERGENCY CALLS & STATISTICS OF HEAT RELATED MORBIDITY

Heat has significant effects on environmental emergencies, mortality, and disease rates. Four hundred heat-related deaths occurred in Chicago, IL during July in 1995 (Semenza et al., 1995). Thirty-nine thousand deaths across 12 European countries occurred during an extreme heat event in August of 2003 (Robine et al., 2003). When it comes to a human’s energy budget, if the total amount of energy received is higher than the amount lost, a person will heat up over time. As a person overheats, they might experience a wide range of symptoms. Consequently, morbidity for ambulance calls is categorized as a complaint of symptoms of heat, such as "light-headed" or "poor breathing'', rather than as environmental heat stress (Vanos et al., 2012).

Given the awareness of physiological responses to variations in radiation, investing in more climate stations will improve the spatial modeling of heat stress-prone zones, by influencing the deployment of EMS to EE's and coping resources. Subsequently, urban planners and designers can become aware of areas of high heat stress, and during most oppressive hours of the day, thereby knowing the most vital areas in which to implement the corrective bioclimatic design (Vanos et al., 2012). Heat is predicted to remain the most critical extreme weather-related killer in the United States (Sheridan et al., 2009). The results of a meta-analysis of eleven papers showed, in the analyses, people living in warmer urban areas (based on land surface temperature or estimates of air temperature) had a 6% higher risk of loss of life or disease compared to those in cooler areas (Schinasi, Benmarhnia & De Roos, 2018). Also, those living in less vegetated areas had a 5% higher risk compared to those living in more vegetated areas (Schinasi, Benmarhnia & De Roos, 2018). Heat-related emergency calls in Toronto were negatively correlated to tree canopy cover and positively related to hardscape cover. The Toronto study suggests that even a marginal increase in the tree canopy cover from <5% to >5% could reduce heat-related ambulance calls by approximately 80% (Graham et al., 2016). Population projections along with future climate projections in Houston measured heat-related mortality, which found that mortality increased across both population/demographic/economic and climate forecasts (Marsha et al., 2018). With appropriate design planning, urbanization processes can be optimized to promote health (Schinasi, Benmarhnia & De Roos, 2018). Research topics of how heat and city morphology relate to health provide essential information about the complicated relationship between the urban landscape, ambient temperature, and human health, all of which should take consideration within the context of public design conversations.

2.6 HEALTH ISSUES RELATED TO HIGH TEMPERATURES

Deaths and illnesses from air pollutants and infectious diseases also increase during hot weather (Easterling et al., 2000). Symptoms such as heat stroke, heat exhaustion, cardiovascular, and respiratory problems, rise during the hottest spells of the year (Semenza et al., 1999). The list goes on including fatigue, headaches, nausea, (Mazhar et al., 2015). Therefore, people who are suffering from breathing problems, headache, stroke/heat stroke (cerebrovascular accident), unconscious/fainting, cardiac/respiratory arrest, and chest pain may all be having symptoms of heat exposure (Luber & McGeehan, 2008). The ‘‘Extreme Caution’’ range where people are likely to feel extremely hot and prolonged outdoor exposure can result in sunstroke, heat cramps, and heat exhaustion (Harlan et al., 2006).

High-temperature warm environments can cause lower work productivity (Daanen et al., 2013 and health hazards in circumstances such as heat waves (Harlan et al., 2006). The effects of oppressively warm weather and uncomfortable atmospheres lead to lethargy, decreased work and athletically decreased performance, poor behavior (Eliasson et al., 2006; Watkins, Palmer & Kolokotromi, 2007), and ultimately a degradation of social and outdoor activity (Johansson & Rohinton, 2006; Vanos, 2015). Many studies address adult health associated with weather. However, few have addressed children (Vanos, 2015).

A recent report suggests the critical need for increased opportunities for children to use recess for play to promote cognitive development (Wenner, 2009). Children exposed to hot conditions may limit cognitive ability (Vanos, 2015). Aggression and irritability in children also increase with temperature and heat duration (Anderson, 2001; Ciucci et al., 2013). A study found that weather fluctuations that affect children's behavior tend to be those presenting extreme values, such as higher temperature and relative humidity in the warm season (Ciucci et al., 2013). Evidence also exists showing the effect of humidity on school and work achievement and aggressive behavior in children (Lagacé-Séguin & d'Entremont, 2005). Environmental exposures strongly relate to behavior, activity, health, and overall child well-being. Currently, research indicates that a changing climate, growing urban population and unsustainable bioclimatic design is projected to pose increasing complications (Vanos, 2015).

2.7 THE EFFECT OF MICROCLIMATES ON VULNERABLE POPULATIONS

Projections show that the temperature difference between urban and surrounding areas will grow more extensive in the future, and may increase the relative health risks for poor and minority populations who reside in urban areas (see Figure 2.9) (Congressional Black Caucus Foundation, 2004). Lower socioeconomic groups were more likely to live in warmer neighborhoods with more significant exposure to heat stress due to density, little vegetation, and lack of open space significantly correlated with higher temperatures, as well as, more vulnerability to high temperatures because of lack of appropriate social resources to cope with extreme heat (Harlan et al., 2006). The higher summertime air temperatures will cause these problems to become worse (McCarthy, Best & Betts, 2010). Moreover, are projected through future climate predictions based on current trends. Places with vulnerable groups are found in some of the warmest areas of Dallas with the least tree cover and the highest amount of impervious surfaces (Peters, 2014).

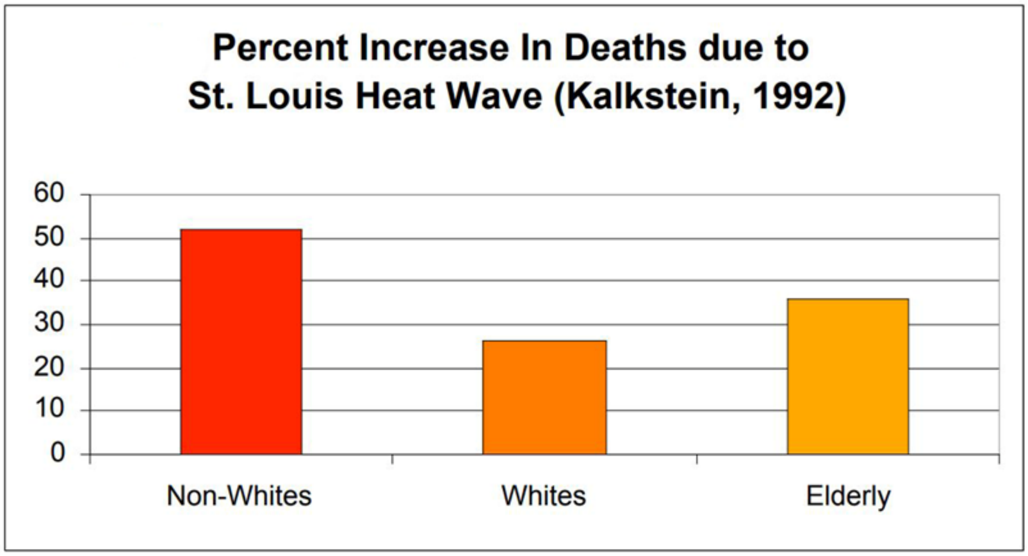


Figure 2.9 Percent of Heat Deaths based on Race (Congressional Black Caucus Foundation, 2004)

A study in Phoenix, one of the two cities (Louisville, KY is the other) with the highest UHI temperatures in the nation above Dallas, showed higher-income, predominately white neighborhoods, were more comfortable places than lower-income, predominately Hispanic neighborhoods (Harlan et al., 2006). Aerial photography has revealed the proximity of the freeway, a source of anthropogenic heat from asphalt pavement and high vehicular traffic can affect these populations where low-income areas may reside (Harlan et al., 2006). UHI reduction policies should specifically address vulnerable people, and propose equitable distribution and preservation of urban forests to locations of neighborhoods near transportation and industrial corridors, a result from historical patterns of imposed segregation, zoning regulations, and other city-wide decisions, which are part of an continuous system of environmental inequality patterns (Pellow, 2000) (Harlan et al., 2006). For vulnerable areas, bioclimatic design can provide 'heat refuge spaces' or cooling benefits on warm days (Brown et al., 2015).

Children are particularly vulnerable to their ambient environments due to numerous physiological workings, such as higher metabolism and less skin surface area for cooling, a reduced ability to regulate body temperature compared with adults. As critical aspects of the lives of many humans, the health of children can be protected and improved through precautionary environmental health measures (Vanos, 2015). The microclimatic design of outdoor spaces is a central aspect of the thermal environment, which can enhance or hamper a child's overall health, functionality, and development based on factual information and in addition to health, understanding children's susceptibility to atmospheric conditions can also have wide-reaching implications for guidance and learning, as well as behavioral concerns and parenting response (Vanos, 2015). Examples of considerations that pertain to children and heat stress are outlined (see Figure 2.10). Relationships between subsidized housing and socioeconomic conditions have been studied extensively among planners, for example, as described in the World Health Organizations (WHO) focus on the topic of social determinants of health (SDH), a global monitoring initiative started in 2007 (WHO, 2019). However, there is a necessity for literature that connects as to how natural environments, such as parks and tree forests, affect microclimate among subsidized households (Kim & Woo, 2015).

Neighborhoods in low-income areas could benefit from a blanketed improvement of cooling outdoor environments, as well as the accompanying infrastructure, which may affect social capital by providing a thermally neutral space where people can gather (Harlan et al., 2006). Public expenditure to improve the quality of existing housing and provide shade, green parks, and community swimming pools would be an effective heat mitigation measure and would increase the health and comfort of residents. Additionally, the vulnerability of warmer neighborhoods is exacerbated by residents' lack of adequate social and material coping resources with extreme heat (Harlan et al., 2006).

Research area	Specific need
A. Heat	
(A.1) Energy budget modeling	• Adapting human energy budget models to children
(A.2) Heat stress indices	• Assessing the cause-specific morbidity of children associated with heat stress index levels • Address differences between adult and child (also for (A.1)) for a more objective assessment
(A.3) Observations	• Satellite remote sensing techniques to characterize neighborhood scale, enabling land use and thermal profiles (Mackey et al., 2012) • Superspectral high resolution data acquired over urban parks/schoolyards of surface temperature and vegetation density (Stefanov et al., 2004)
(A.4) Health outcome associations	• Mortality versus morbidity responses in children • Project future impacts under changing climates (Patz et al., 2005; Ebi and Paulson, 2010)
(A.5) Vehicle studies	• Temperature thresholds and awareness, policy and guidelines (Grundstein et al., 2010)
B. Air pollution	
(B.1) Health impacts	• Age group specific air quality standards – Identify influential factors that may cause a child to be vulnerable to traffic pollution and aeroallergens (Cakmak et al., 2002, 2012; Gauderman et al., 2004) • Identify impacts under a changing climate (Ebi and Paulson, 2010; McConnell et al., 2010)
(B.2) Spatiotemporal studies	• Account for potential autocorrelation and time dependency of air pollution data (Baxter et al., 2007) • AQI or AQHI adapted to the at- risk child population (To et al., 2013) • Improved localized observations and understanding of more precise air pollution estimations and connections with health outcomes in both children and the full population (Jerrett et al., 2004)
(B.3) Individual child exposure assessments	• Link indoor-to-outdoor levels for children (EPA, 1996, 2009b; Institute of Medicine, 2011)
C. Urban design	
(C.1) Radiation exposure	• Incorporate individual UVB exposure into design of outdoor spaces spatiotemporally, and exposure-health assessments (Balk, 2011; Cox, 2013)
(C.2) Shading	• Research and policy to mandate and protect or implement natural trees vegetation to shade and cool schoolyards and parks (Vanos et al., 2012b) • Impact of mobile shading objects (Dobbinson et al., 2014) • Cost-benefit analysis of trees (e.g., Soares et al., 2011)
(C.3) Bioclimatic design	• Green infrastructure; evidence-based bioclimatic design for cooling (Brown, 2011; Noble et al., 2014)
D. Behavior	
	• Studies addressing the effects of weather localized playground climates on children's learning and behavior, moods, aggression; across seasons (Ciucci et al., 2013) • Address implications for parenting and teaching practices
E. Child health stressors related to climate change	
	• Provide and determine the essential services of public health concerning environmental and biometeorological risk factors to address the child health risks of climate change (Ebi and Paulson, 2010) • Understand uncertainty in ozone concentrations based on climate change, emissions, precursors, and child vulnerability (Ebi and McGregor, 2008)

Figure 2.10 Research Areas for Microclimates and Corresponding Specific Needs for Children (Vanos, pg. 11, 2015)

2.8 EFFECT OF NATURAL & BUILT LANDSCAPE ELEMENTS ON MICROCLIMATES

Through remote surface temperature studies, land surface temperature variation among Local Climate Zones with compact building densities showed higher temperatures than Local Climate Zone ‘open types’, and the most cooling Land Surface Temperatures corresponded to water bodies (Zhao, 2018). Goggins 2013 produced an urban climate map, which showed the dynamic potential of ventilation and cooling (natural landscape, water bodies, prevailing wind, and land and sea breeze). Lack of water bodies in urban settings, which have evaporative, cooling effects, contributes to warmer temperatures and high-rise buildings trap heat and absorb solar radiation (Schinasi, Benmarhnia & De Roos, 2018). At the regional scale, land-use patterns, and land cover are the most reliable drivers of urban temperatures (see Figure 2.11) (Harlan et al., 2006).

Adopting standards for overhangs (see Figure 2.12), pavilions, and replacement of roofing materials with green roofs, white roofs, or reflective roofing can reduce air conditioning & terrestrial radiation. Additionally, shade sails increased school students' use of the newly shaded areas; shaded spaces result in non-direct radiation, which is safer for outdoor use/activity for more extended periods (Vanos, 2015). Also, a study has shown that the combination of grass and the use of a mesh with 70% opacity have been found to significantly reduce the thermal stress on humans (Shashua-Bar, Pearlmutter & Erell, 2011). Avoiding dark furniture or shade structures are imperative (Brown, 2010).

Albedo considerations, such as avoiding the use of dark pavement to reduce terrestrial radiation and replacement of existing dark-colored asphalt pavements with light-colored concrete pavements, light-colored stones or avoiding dark furniture or shade structures are imperative, as well as the albedo of built structures (see Figure 2.13).

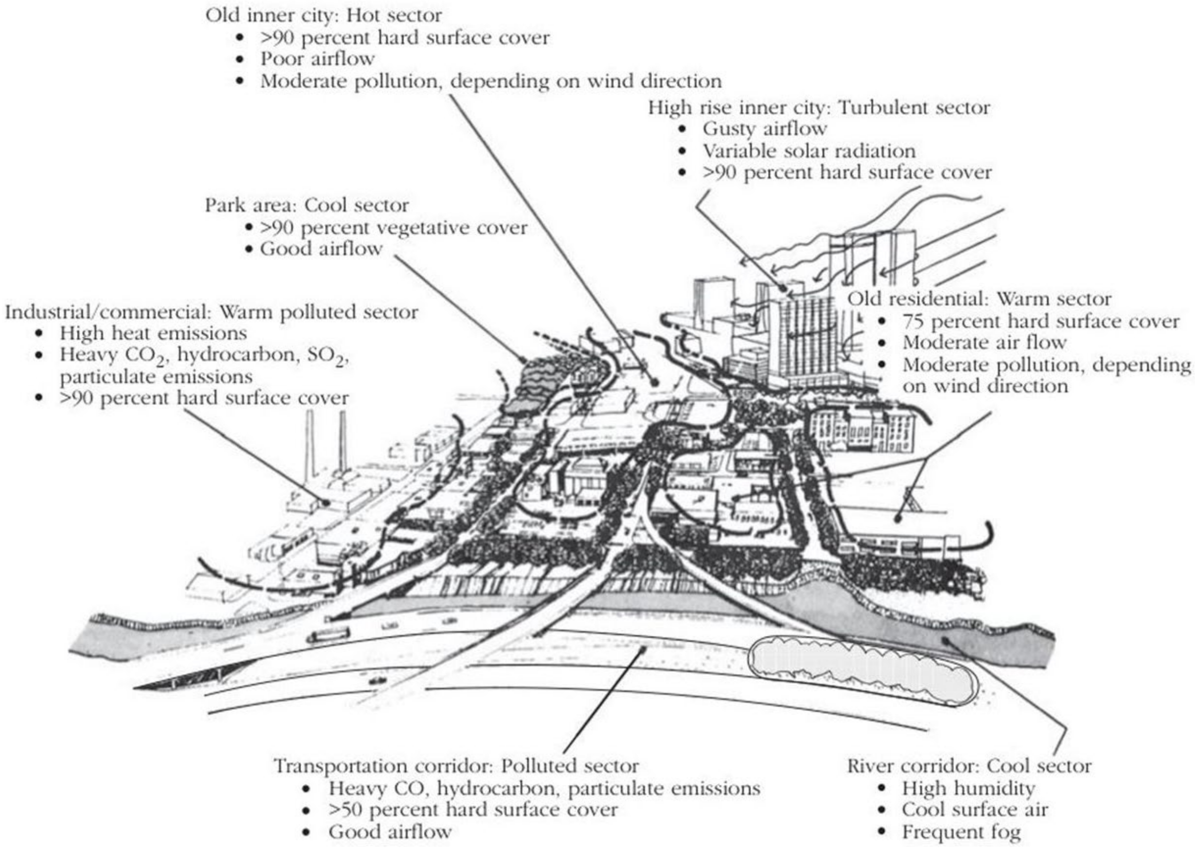


Figure 2.11 City Microclimates (Marsh, 2010)

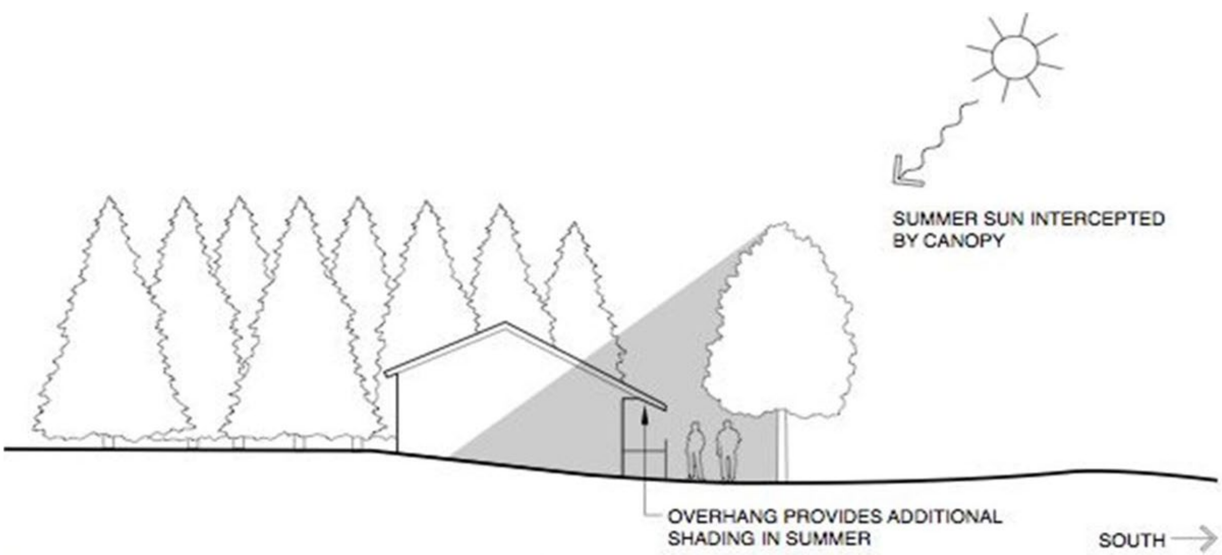


Figure 2.12 Example of Solar Modification of Surrounding & Use of Overhangs (Hopper 2006)

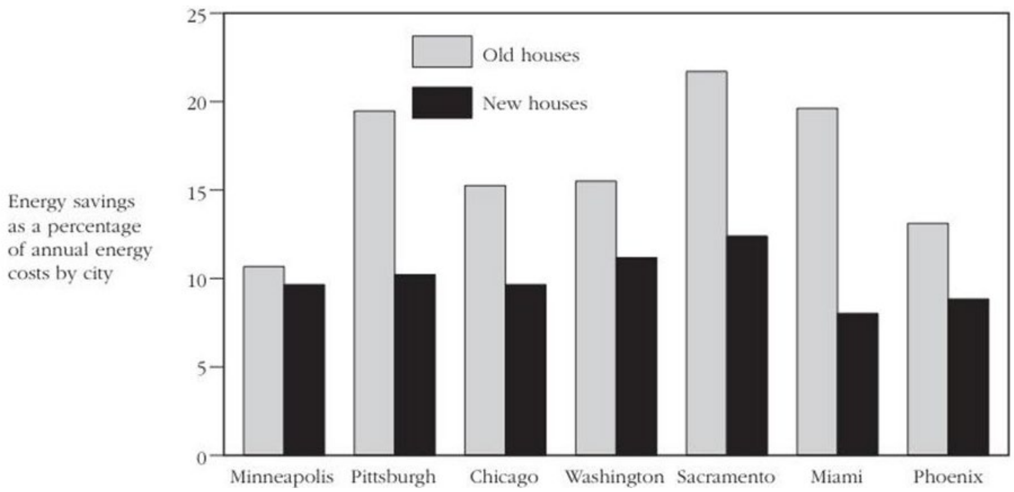


Figure 2.13 Example of energy savings of increase of albedo from 30 to 40% (Marsh, 2010)

2.9 EFFECT OF TREE CANOPIES & VEGETATION ON MICROCLIMATES

In a study by Klemm et al., (2015) pedestrians evaluated their overall thermal perception in streets with trees combined with front gardens and found them more comfortable than in streets with just trees, even though they disagreed with the actual physical conditions. Streets with trees and front gardens showed street averaged radiation values up to 3 Kelvins higher than streets with trees because due to a lesser presence of shade; thus, despite the higher radiation, in streets with trees and front gardens, perception in thermal comfort was rated more positively in those streets than in streets with trees. This finding could be explained by the more varied view of different types and heights of vegetation in streets with trees and front gardens than streets with trees only. Streets with front gardens offer views of arrangements of low vegetation beds, medium-high hedges, small trees or climbing vegetation to provide ample street greenery as people prefer vegetated over non-vegetated streets from an esthetic point of view (Klemm et al., 2015).

Consequently, urban planners and bioclimatic designers are advised to use deciduous trees in streets to create microclimates of sun and shade for the winter and summer, in order cool in the summer and offer warmth from solar radiation in the winter

(Graham et al., 2017). However, street trees should not be implemented everywhere, but effectively in areas of high activity. Street greenery forms a useful adaptive strategy to create thermally comfortable and attractive living environments. Research indicates that both physical and psychological aspects of thermal comfort must be considered in urban bioclimatic design processes (Klemm et al., 2015).

Synergistic mechanisms with meteorological parameters, such as high air temperatures and radiation levels, also influence air quality and the formation of secondary pollutions (e.g., ozone, hydrocarbons) (Krzyzanowski et al., 1992). The relationship between ozone concentrations and lung function were studied in 287 children, finding an inverse relationship with increasing O3 levels (Krzyzanowski et al., 1992). Sheffield et al. (2011) who projected an increase in summer ozone-related asthma climate interactions demonstrated emergency department visits for children across New York City by the 2020s compared to the 1990s. Variation in ground-level ozone production is of concern at the regional-to-local urban scale level due to meteorological interactions, increased urban temperatures, heightened anthropogenic pollution, and abundant daytime radiation trapping by paving and structures, acting in synergy to impact human health (Knowlton et al., 2008; Vanos et al., 2014; Watkins et al., 2007). Other built environmental characteristics (e.g., height-to-width ratios, proximity to traffic, vehicle traffic distribution, presence of trees) are directly linked to pollution exposure and the onset of adverse health conditions that limit physical activity, such as asthma (Jerrett et al., 2010; McConnell et al., 2010; Buonanno et al., 2013). Ozone, although a short-lived pollutant, can also reduce exposure of ultraviolet radiation by absorbing the harmful rays; further, it has been demonstrated that O3 concentrations below a tree canopy are

SOLAR MODIFYING CHARACTERISTICS OF VARIOUS SPECIES OF TREES

The density of the shade varies with species. Some species (e.g., *Acer platanoides*) have a denser shade than others (e.g., *Gleditsia triacanthos* var. *inermis*). This table lists the range of densities, with and without leaves, of various tree species, as well as their approximate leaf period.

Botanical Name	Common Name	TRANSMISSIVITY RANGE % (REPORTED IN THE LITERATURE)				Maximum Expected Height (ft)
		Summer	Winter	Foliation[1]	Defoliation[2]	
Acer platanoides	Norway Maple	5–14	0–75	E	M	48–80
Acer rubrum	Red Maple	8–22	63–82	M	E	65–110
Acer saccharinum	Silver Maple	10–28	60–87	M	M	65–110
Acer saccharum	Sugar Maple	16–27	60–80	M	E	65–110
Aesculus hippocastanum	Horse Chesnut	8–27	73	M	L	70–100
Amelanchier canadensis	Serviceberry	20–25	57	L	M	20–25
Betula pendula	European Birch	14–24	48–88	M	M–L	50–100
Carya ovata	Shagbark Hickory	15–28	66	L	M	75–100
Catalpa speciosa	Western Catalpa	24–30	52–83	L	E	58–100
Fagus sylvatica	European Beech	7–15	83	L	L	58–100
Fraxinus pennsylvanica	Green Ash	10–29	70–71	M–L	M	58–80
Gelditsia triacanthos inermis	Honey Locust	25–50	50–85	M	E	65–100
Juglans nigra	Black Walnut	9	55–72	L	E–M	75–140
Liriodendron tulipifera	Tulip Tree	10	69–78	M–L	M	85–140
Picea pungens	Colorado Spruce	13–28	13–28			85–130
Pinus strobus	White Pine	25–30	25–30			75–140
Platanus acerifolia	London Plane Tree	11–17	46–64	L	M–L	100–110
Populus deltoides	Cottonwood I	0–20	68	E	M	75–100
Populus tremuloides	Trembling Aspen	20–33	*	E	M	40–48
Quercus alba	White Oak	13–38	*	M	M	75–100
Quercus rubra	Red Oak	12–23	70–81	M	M	75–100
Tilia cordata	Littleleaf Linden	7–22	46–70	L	E	58–68
Ulmus americana	American Elm	13	63–89	M	M	58–75

[1]*Foliation:* *E* = *Early* = *Before April 30*; *M* = *Middle* = *May 1–15*; *L* = *Late* = *After May 15*

[2]*Defoliation:* *E* = *Early* = *Before November 1*; *M* = *Middle* = *November 1–30*; *L* = *Late* = *After November 30*

**No data available*

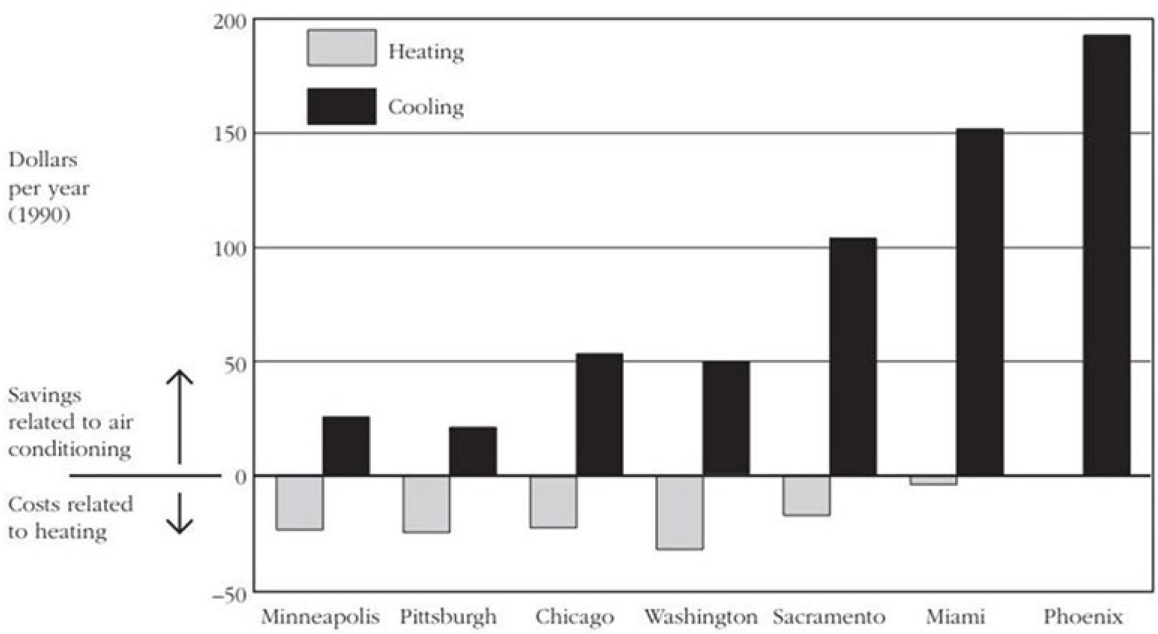
Figure 2.14 Solar Modifying Characteristics of Various Trees (Hopper, pg. 40, 2007)

Figure 2.15 Local Climate Zones, Dallas Typologies (Zhao, 2018)

LCZ 1 Compact high-rise LCZ 4 Open high-rise LCZ 9 Sparsely built

generally lower than those above the canopy (United Kingdom Forestry Service, 2002), indicating some canopy uptake and less photochemical creation. The forestry commission lists the average, maximum, and minimum transmissivities for 32 common trees worldwide. For example, a Norway maple ranges from 9.5% (summer) to 67.5% (winter) transmissivity (see Figure 2.14). Brown et al. (2014) modeled the energy budget modifying effects of adding 50% shade as compared to clear skies. Results demonstrated a decrease in the energy budget on hot summer days in five cities worldwide. It has shown that employing proper bioclimatic design strategies for urban parks through the use of shade can decrease the air temperature imposed on a human by 1–6 °C or 1.8-10.8 °F (Chow et al., 2011; Vanos et al., 2012; Declet-Barreto et al., 2013), but dependent on location climate zone (see Figure 2.15). Trees have a relatively more significant impact in playgrounds and parks when used in highly dense urban areas with impervious materials. The benefit of shade was demonstrated by Gulyás et al. (2006), finding that street canyons with the addition of trees have a lower temperature than without trees. A lower temperature substantially decreases the physiological stress to children on warm-hot days, with Ketterer & Matzarakis (2014) environments measuring a positive outcome of reducing the surface and air temperatures of overheated schoolyards, backyards, and parks is the reduced cooling costs of the nearby buildings as well as many other benefits of implementing more urban vegetation in parks; specifically trees, must be accounted for a cost-benefit analysis in any given climate (Harlan & Ruddell, 2011). Researchers in Lisbon, Portugal quantified the economic value of trees in the city, finding that for every $1 invested in tree management, residents benefitted $4.48, based on factors such as energy savings, CO2 reduction, and air pollutant deposition (Figure 2.16) (Soares et al., 2011). Trees that reduce solar radiation have the most significant

Figure 2.16 Energy Savings with Trees of Typical Houses (Marsh, 2010)



impact on thermal comfort (Brown et al., 2015). Dense tree areas were found to be cooling elements that can extend hundreds of meters beyond their boundaries (Zhao, 2018). In Germany, the cooling effects of urban forests were shown to be more critical than urban parks (Jaganmohan et al., 2016). Small urban parks in the high sky view factor (SVF) areas with high percentages of tree planting significantly cool down the temperature and mitigate the daytime UHI effect; additionally, mid-size greenspace and small tree percentage under medium and low SVF reduce the radiation during the early-afternoon period (Tan, Lau & Ng, 2016). Distinctive treed areas showed a more significant decrease than did open park areas (Vanos et al., 2012). Park cool islands (PCI) studies have targeted on how urban green spaces reduce temperature, and others have determined that the type of green space makes a difference, especially ‘shaded green space’ (Vanos et al., 2012). Some obvious actions can be taken to provide more of these thermally comfortable open spaces. In a published interview with Matt Grubisich, an urban forester with the Texas Trees Foundation, it was stated that

> ”What we found out was that the city (Dallas), believe it or not, has 30% canopy cover and that seems really high. But once you start looking across the city, if I show you the map of the City of Dallas, which is all focused into a very small area of the city. Dallas is 375 square miles, and in this part, we have a very, very large inland urban forest, the runs along the Trinity River, which is the main river that runs through town. And that’s where the bulk of our tree canopy was. When you got into the surrounding neighborhood, that tree canopy averaged closer to 8 to 9%. And so we realized that we really have a problem, even though we look on the large scale when you actually start to focus down to the individual neighborhood and individual council district the tree canopy cover wasn’t all that great.” (EPA pg. 23, 2019)

Existing trees should be preserved and more trees planted wherever possible, but especially on public lands (Mazhar et al., 2015)

2.10 COMPLEXITIES OF MICROCLIMATE MEASUREMENTS

Radiant exchange can significantly affect thermal comfort; vegetation can block solar radiation and can limit radiated heat reflected by surfaces (Shashua-Bar, Pearlmutter & Erell, 2011). Human energy budgets were more closely related to incoming solar radiation than to air temperature (Vanos et al., 2012). A study in the Journal of Applied

Meteorology and Climatology (Vanos et al., 2012) observed and emphasized how vital vegetation can affect microclimates and also underlines the need for LA’s to be aware of the fundamental ways in which bioclimatically designing spaces with plants can reduce the effects of solar radiation on human comfort. Heat Index (HI) cannot predict how many people will get sick or die from heat exposure because the threshold temperature and individual physiology that trigger illness varies according to many unique and contextual factors (Local Governments for Sustainability, 1998) for example, children are more vulnerable to heat compared to adults (Vanos, 2015). Moreover, this index is not suitable to capture the experience and effects of temperature on children as the initial development used higher surface-area-to-body-mass ratio in children would result in the current HI underestimating the heightened heat impacts on children under extreme heat; children do not individually interpret the values from the HI and Humidex; it is left up to the parents physiological data from healthy, college-age students based on work the of Fanger 1970); to explain this information and to make decisions on the child's behalf (Vanos, 2015). The most general and widely used index in North America is the apparent temperature, or the heat index (HI) (see Figure 2.17), used by the National Weather Service (NWS) as well as environmental health studies (Smoyer-Tomic & Rainham, 2001).

Climate researchers, however, have documented a strong relationship between NOAA’s Heat Index and mortality rates in cities (Davis et al., 2003). Predicting effects on the human energy budget can provide vital information to LA’s in bioclimatically designing for future climates (Brown et al., 2015).

NWS Heat Index — Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution · Extreme Caution · Danger · Extreme Danger

Figure 2.17 Heat Index Chart (NOAA, 2019)

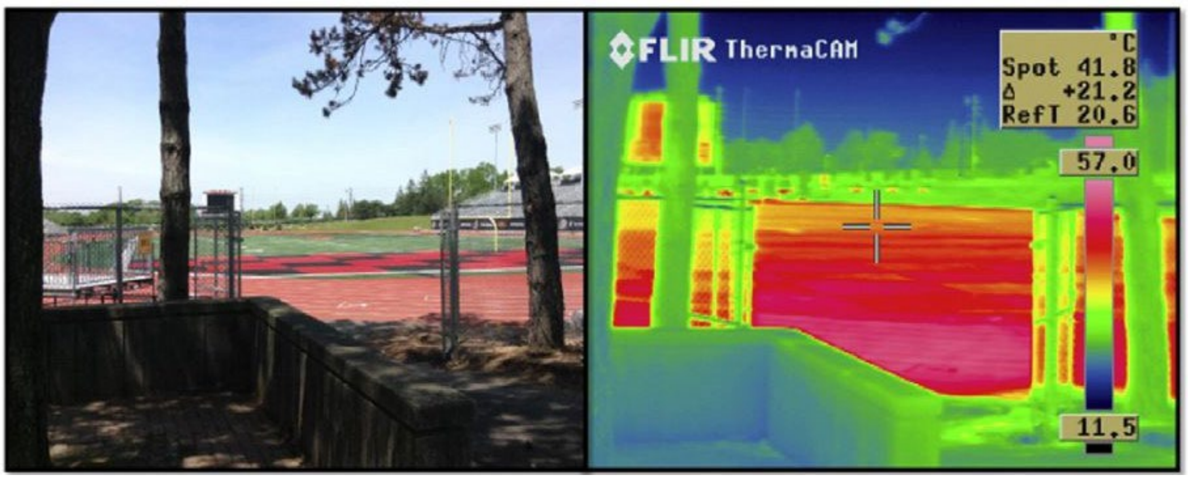


Figure 2.18 Visible and the Infrared Spectrum (Brown, 2013).

The previous image (see Figure 2.18) displays the surface temperatures of an outdoor soccer/football field and running track taken in Guelph, ON, Canada (June 21, 2013) on a warm-hot day, in both the visible and the infrared spectrum (Brown, 2013). The inner field is artificial turf grass, the track is a dark pink/red rubber, and the outer area is natural vegetation. Both unnatural surfaces display surface temperatures in the range of 107.6- 131° F; however, the surfaces within the shade of maple trees (e.g., concrete and brick) display a range of 75.2- 80.6°F and portions of vegetation (trees, grass, shrubs) in the surroundings have surface temperatures ranging from 77-86°F. Such contrasts are due to the radiative properties of the surface, where both a lack of evapotranspiration from the artificial surfaces and higher absorption of heat result in higher temperatures (Vanos, 2015). Evaporative cooling in the surrounding areas results in a lower surface and near-surface temperature, highlighting the potential benefits of conserving natural and porous surfaces.

2.11 COOLING BIOCLIMATIC DESIGN STRATEGIES ARE STRAIGHTFORWARD

Such treed parks also result in cooling from evapotranspiration with moisture available, which also increases the relative humidity. Buildings, shade sails, overhangs, portable vegetative platforms, pavilions, and other landscape objects (oriented to maximize shade at the warmest time of the day) are examples that also reduce overall shortwave radiation, and hence surface temperature (Santamouris, 2013; Vanos, 2015). For instance, Dobbinson et al. (2014) demonstrated that in a sunny, warm climate, shade sails increased school students' use of the newly shaded areas; shaded spaces result in non-direct radiation, which is safer for outdoor use/activity for more extended periods (Vanos, 2015). Many cities and coalitions of cities, supported by national and international organizations, such as the US Environmental Protection Agency and the International Council for Local Environmental Initiatives, have initiated programs for heat island mitigation using three principle strategies: increasing vegetation cover in public spaces, adopting standards for reflective roofing and paving materials, and lowering anthropogenic emissions (City of Phoenix, 2004; Rosenfeld et al., 1998; Rosenfeld et al., 1995).

To design spaces that will have the most significant cooling effect on people during hot summertime weather, a landscape architect needs to know the relative impact of various design interventions (e.g., Brown, 2011). Particularly critical in summer, bioclimatic strategies such as natural ventilation and passive cooling could reduce the use of mechanical systems (Schiano-Phan et al., 2015). In humid regions, the presence of a strong wind often dominates over the effect of high humidity, and evaporative heat loss was found to be greater with higher wind speed, which helps to 'wisp' perspiration away from the skin, resulting in heat loss via evaporative cooling and a lower energy budget (Brown et al., 2015). Places less densely settled with some open space and more abundant vegetation were environments that are more comfortable in the summertime (Harlan et al., 2006).

There are ample avenues to take when modifying a microclimate based on season for increased activity, where factors such as sun orientation, plant characteristics, ground surface type, climate zones, precipitation, temperature, and humidity can impact year-round type and amount of physical activity (Ciucci et al., 2011; Vanos, 2015).

Vegetative and sun angle exposure considers the sun angle during programmed features on a landscape. Bioclimatic design strategies include implementing deciduous trees, especially on pedestrian paths with south and west facing exposure, as well as on hardscape (streets & parking lots) or against a building with south & east-west, orientation is recommended (Graham et al. 2017). Replacement of roofing materials with a green roof, therefore, reducing air conditioning & terrestrial radiation is also recommended. Species of trees that are more efficient at cooling environments, usually by possessing the qualities of having a dense, broad canopy structure should be used (Sanusi et al., 2017).

Realignment of rows of parking to allow tree planting in an and west facing exposure (see Figure 2.19) maximizes shade in order to keep vehicles cooler during the day and into the evening (Graham et al. 2016)

Figure 2.19 Parking Lot Row Alignment East to West with Shade Trees

Using plant materials to shade walls can lessen radiant heat, as well as, using plant materials or shade structures to reduce solar radiation. The combination of shade trees and grass is found to be the most effective combination to reduce the thermal stress on a human in hot climates (Shashua-Bar, Pearlmutter & Erell, 2011). In all parks of hot regions, problems might occur because irrigating the parks can bring about water shortages (Gober et al., 2009).

On the other hand, generally, higher irrigation is needed in landscapes dominated by turf grass than landscapes comprised of desert-adapted trees and shrubs due to the high evapotranspiration rates of turf areas. When the ‘forest parks’ in dry cities consist of suitable species, the tree cover will provide the necessary shade and generate a forest microclimate that contributes to moisture penetration in the ground. Tree plantings are used to fight desertification, so we can expect that they will also work in urban environments (Pasternak & Schlissel, 2001). However, in the Dallas area, the climate goes through periods of drought and extreme rain inundation. Therefore, desert-adapted plantings should have proper, sufficient drainage or use native species able to adapt to both climate extremes. In the parks of other cities, the species should also fit the local climate, and indigenous species should be used to provide other ecosystem services (Boone-Heinonen et al., 2010; Spronken-Smith & Oke, 1998). Hence, urban planners and bioclimatic designers should focus on developing 'shaded green space' in urban parks, not simply 'green space' (Vanos et al., 2012). Designers should thus consider the shading performance of vegetation type for incorporation into urban spaces. Concentrating species with high leaf area index (and therefore shading potential) in urban parks can significantly improve the thermal comfort experienced during warm, summertime conditions (de Abreu-Harbich, Chaves & Brandstetter, 2018). In the hot and sunny climate zones that have little seasonal variation, the amount of shade should be maximal all year round.

With considerations to wind circulation and ventilation, in urban areas, with low green space, recommendations are to plant the trees in the wind paths to enhance the cooling effects. Increasing wind circulation to cool landscapes in the summer is the ultimate goal. Using low energy, mechanical ways to cool outdoor environments and pruning lower tree branches to allow more wind to flow through an outdoor space also helps to keep it cool. Professionals need to bear in mind that careful, evidence-based microclimate design (Brown & Corry, 2011) can mitigate the dangerous effects of heat waves, providing environments that are not only safe but are also thermally comfortable

(Brown et al., 2015).

2.12 COMfA: A HUMAN ENERGY BUDGET MODEL TO TEST THE EFFECTS OF LANDSCAPE MODIFICATIONS & OTHER MODELING METHODS

The comfort formula (COMfA) is a model that estimates a person's energy change in outdoors and reports the balance as an energy budget. It can determine the thermal comfort experienced by a person. This model takes into account the heat absorbed and radiated by a person. Human thermal comfort models include several biophysical and microclimatic parameters that infer thermal comfort outdoors, providing quantitative evidence of heat stresses (Harlan et al., 2006).

The COMfA energy budget model, requires meteorological data inputs and physiological inputs (see Figure 2.20) (Vanos et al., 2012).

ENERGY BUDGET COMFA:

20 to 120 considered neutral (thermally comfortable)

121–200 warm

>201 hot, for a standing person (Harlan et al., 2006; Kenny et al., 2009).

In terms of effects on health:

−20 and 1 vulnerability to heat stress range

201 and 339 heat stress danger is likely

340 or higher extreme danger of heat stress (Harlan et al., 2006)

Figure 2.20 Energy Budget COMfA (Vanos et al., 2012))

This process shows that human comfort at any point in the environment is measurable and quantifiable for urban bioclimatic design and management using the COMfA energy budget model (Vanos et al., 2012). The creators of this model have developed a table for application towards several cities around the world, including an application to the climate conditions of Amarillo, TX but researchers, such as Dr. Robert

Brown at Texas A&M, are still working towards a model to apply to the city of Dallas.

The numerical model, Solar and Longwave Environmental Irradiance Geometry (SOLEIG) has been used to examine the spatial variations of radiant temperature, as a gauge of heat stress in subtropical urban areas in summer (Lau et al., 2016). Also, the popular Physiological Equivalent Temperature (PET) Index takes into account comfort-related environmental parameters, i.e., air temperature, radiation, humidity, and wind speed. There is also the three-dimensional microclimate model ENVI-met ™ used to analyze the proposed planting methods for trees. The model simulates the micro-scale interactions between surfaces, vegetation, and air temperatures. Finally, the Heaton et al. Model is statistical and relates the relative risk of non-accidental mortality in a census block group to various predictive variables from the US census. This model shows simulated heat-related death based on expected climate change projections.

2.13 CHAPTER SUMMARY

Still, there are many examples of urban design that do not consider the climate-modifying effects; such urban design examples have the potential to create environments that people experience as much warmer, and in some cases uncomfortably hot (Mazhar et al., 2015). Many outdoor spaces all over the world and especially in the warmest zones need in-depth examinations to learn better lessons from the past. These lessons can help to provide thermally comfortable and safe outdoor spaces without using artificial cooling that often uses fossil fuels and as such worsens carbon dioxide production (Mazhar et al., 2015) Future research will need to explore vernacular urban bioclimatic design with the latest microclimate measurement and simulation tools to assess the effects and value of these designs. Climate responsive urban design can create microclimates that people experience as feeling more cooling than the prevailing climate, making urban areas, both safer and more pleasant (Mazhar et al., 2015). LA's can critically evaluate the physical morphology of a space through site analysis to find ways in which unexpected assets may aid disadvantaged communities. Quantitative evidence of the thermal comfort benefits of proposed designs and measurements of current conditions can demonstrate a need that the practice of landscape architecture can facilitate, by designing landscapes with cooling interventions, in order to have an essential role in potential health outcomes, such as EE's on vulnerable populations. This potential benefit provided LA's go along with the paramount concern of practice, which is the focus on the health, safety, and welfare of the public illustrates the value of evidence-based research. The practice of landscape architecture organizations, practitioners, college faculty, and students should consider the many trade-offs of how bioclimatic design in urban areas has implications for health & human comfort for vulnerable populations.

CHAPTER 3 METHODOLOGY

3.1 INTRODUCTION

This chapter describes the research methods used in this study. The rationale of these methods derives from known and recorded locations of environmental emergencies (EE's) that occurred in the City of Dallas and how they may relate to the surrounding urban morphology. Previous studies have used similar methods. However, this study combines EE's overlaid on the surrounding urban context is reviewed in the examined literature about Dallas. This study identifies vulnerable populations that climate change adaptation may benefit. In order to delve deeper into these possibilities, this study utilizes quantitative research methods (Deming & Swaffield, 2011), secondary data collected from public sources as well as data obtained from the City of Dallas Fire and Rescue. This methodology chapter outlines the framework for conducting a suitability analysis using *ArcMap*, a GIS application, and combines the mapping of various data inputs to conclude how existing conditions may influence EE's that have occurred in Dallas using the BRACE model. Relationships between variables using a descriptive GIS mapping model and a weighted analysis of graphing techniques provides a mapping model or simplification of layers of data to generate new knowledge of the locations and characteristics thereof, that impact human heat stress in the city of Dallas. This chapter includes the research design based on the city of Dallas, data analysis, and data acquisition.

3.2 STUDY POPULATION AND LOCATION

Close observations of the population and urban form within the City of Dallas, Texas were taken into consideration. Dallas is the ninth most populated city in the United

States and the third most populated in Texas, behind Houston and San Antonio according to the 2010 US Census. This study examines all 962 block groups in Dallas County, in the city limits of Dallas specifically. A small portion of Collin County exists to the northern tip of the Dallas city limits and is not included in the demographic analysis of this study. Additionally, block groups to the far eastern side, that border Lake Ray Hubbard, which are not in the central city limit boundaries, were not included. The ACS 2017 1-year estimates of the population of Dallas, TX at 1,341,103 with 3,944.9 persons per square mile. Dallas has a population of 18.5 percent that lives below the poverty line, more than 1.5 times the rate in Dallas-Fort Worth- Arlington Metro Area (ACS 2017 year). The mean travel time to work of residence of Dallas is 26.8 minutes and 6.3 of the population, walks, bikes or use public transportation to travel to work (ACS, 2017 5-year). 77.5 percent of the population has a High School Graduate education or higher and 32.2 percent have a bachelor's degree or higher. The per capita income in $32,114 and $50,627 is the median household income, three-quarters of the amount in the Dallas-Fort Worth-Arlington Metro Area (ACS, 2017 year). Census Block Groups were used to achieve the smallest sample sizes, which are recommended by the CDC when examining vulnerable populations.

3.3 RESEARCH DESIGN

The framework used is based on the BRACE Model, which includes steps in order to identify and assess health implications, such as environmental emergency calls, on vulnerable populations. The research design is based on a constructivist framework; this classification typically depends upon theoretical or practical values to select and organize data (Deming & Swaffield, 2010). The data inventory includes data sets such as topographic maps for GIS layers, demographic, and environmental emergency calls. Secondly, the analysis involved classification through spatial correlation of significant urban morphologies, geocoding of environmental emergencies and mapping demographic block group statistics. Thirdly, evaluation through a weighted overlay analysis of site information along with specific parameters and priorities, defined by the BRACE model (CDC) and literature review. Significant patterns were found which indicated vulnerable areas where opportunities for site interventions were the highest. Three focus areas were isolated, analyzed, to reveal opportunities for intervention using a variety of climate cooling strategies. Finally, the site synthesis offered a realignment of these data, a redefinition of sites, which exposed existing patterns of urban morphology, limitations of design strategies, and other considerations based on values of the BRACE model. The BRACE framework and research questions guided this systematic process of inquiry.

The use of McHarg's suitability analysis ranked areas based on vulnerability to urban morphology, climate, the occurrence of EE's, and social determinants of vulnerability. This GIS graphics technique helped discern logical, spatial relationships and areas of focus. The evaluation was deductive based on the BRACE model framework.

3.4 DATA COLLECTION

This study uses a quantitative research methods approach that uses numerical & mapping data. The criteria used to map significant periods of reported heat-related stress derived from data obtained from a GIS Analyst at the City of Dallas Fire & Rescue classified as "Environmental Emergencies" or emergency calls on problems related to the environment. This detailed data included response date, address, city, longitude, latitude, map information, month, day, hour and fire station. Data ranged from incidents from January 2016 to October 2018, approximately three years' worth of data on environmental emergencies. Additionally, detailed climate data for yearly, monthly and daily observations that corresponded to the incident periods were accessed online from the National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA); these included:

CLIMATE TERMINOLOGY DEFINITIONS & ABBREVIATIONS
MAX - Highest temperature in °F during the 24hrs from midnight to midnight standard time.
MIN - Lowest temperature in °F during the 24 hrs from midnight to midnight standard time.
AVG - The average (rounded) of the MAX and MIN temperatures
DEP - Departure of the AVG temperature from the 30-year mean temperature for the day.
HDD - Heating Degree Days when AVG is less than 65°F. (HDD = 65°F- AVG).
CDD - Cooling Degree Days when AVG is above 65°F. (CDD = AVG - 65°F).
WTR - This is the total (melted, if ice or snow) precipitation for the day in inches.
AVG - The average wind speed for the day, in Miles per Hour
SPD - The fastest 2-minute (average) wind speed, in Miles per Hour.
DIR - The direction the fastest 2-minute wind was blowing FROM in tens of degrees, i.e., 27 would be 270 degrees = wind was blowing from the west to the east
SPD - Peak wind speed (5 second average) in Miles per Hour
DR - The direction the peak wind was blowing FROM in tens of degrees, i.e., 27 would be 270 degrees = wind was blowing from the west to the east (36 = North, 09 = East, 18 = South, 27 = West)

Figure 3.1 Climate Terminology Definitions & Abbreviations (Source NWS)

3.5 GIS MAPPING OF DALLAS

GIS was the primary tool for developing several layers for the analysis. A combination of environmental, health and vulnerable population factors map a relationship of how climate, urban morphology, and social demographics coincide to reveal focused areas of vulnerability.

GIS data obtained from the City of Dallas, GIS website, which includes building footprints or structures, city limits, impervious surfaces, roads, and hydrology (see Figure 3.2). Furthermore, tree canopy data from 2011 data from the National Land Cover database what obtained, as well as, detailed tree canopy data and surface temperature information from the Texas Trees Foundation. Land surface temperature data were also obtained from the United States Geological Survey, specifically Landsat 8 satellite imagery that contains composite bands that, upon further processing, provided views land surface temperatures and normalized difference vegetation index (NDVI).

GIS DATA LAYERS			
Layer Name	**Data Source**	**Website**	**Year accessed**
Physical Features			
Streets Shapefile	City of Dallas Streets	https://gis.dallascityhall.com/shapefileDownload.aspx	2018
City of Dallas City Limits - Polygon	City Limits and Service Areas	https://gis.dallascityhall.com/shapefileDownload.aspx	2018
Hydrologic features - Polygon.	Planimetric Data	https://gis.dallascityhall.com/shapefileDownload.aspx	2018
Impervious Areas - Polygon.	Planimetric Data	https://gis.dallascityhall.com/shapefileDownload.aspx	2018
Structures (Building Footprints) - Polygon.	Planimetric Data	https://gis.dallascityhall.com/shapefileDownload.aspx	2018
Playgrounds - Point	Parks and Recreation	https://gis.dallascityhall.com/shapefileDownload.aspx	2018
USFS Tree Canopy	USGS National Land Cover Dataset (NLCD) Downloadable Data Collection	https://catalog.data.gov/dataset/usgs-national-land-cover-dataset-nlcd-downloadable-data-collection	2018
Dallas Block Group Shapefile	City of Dallas GIS	https://gis.dallascityhall.com/shapefileDownload.aspx	2019
Tree canopy	Texas Trees Foundation	www.texastrees.org	2019
Land surface Temperatures	Texas Trees Foundation	www.texastrees.org	2019
Land surface Temperatures	USGS Landsat 8 OLI/TIRS C1 Level2	https://earthexplorer.usgs.gov/	2019
Health			
Environmental Emergency FY16-FY18	Dallas Fire Department	sourced in through City of Dallas GIS Department	2018
Demographics per Census Block Group			
Sex by Age	US Census Bureau ACS 2017 5 year Estimates, Dallas, TX Block Groups	https://www.census.gov/programs-surveys/acs/	2019
Total Population	US Census Bureau ACS 2017 5 year Estimates, Dallas, TX Block Groups	https://www.census.gov/programs-surveys/acs/	2019
Race	US Census Bureau ACS 2017 5 year Estimates, Dallas, TX Block Groups	https://www.census.gov/programs-surveys/acs/	2019
Hispanic or Latino Origin by Race	US Census Bureau ACS 2017 5 year Estimates, Dallas, TX Block Groups	https://www.census.gov/programs-surveys/acs/	2019
Means of Transportation to Work	US Census Bureau ACS 2017 5 year Estimates, Dallas, TX Block Groups	https://www.census.gov/programs-surveys/acs/	2019
Poverty Status in the past 12 Months	US Census Bureau ACS 2017 5 year Estimates, Dallas, TX Block Groups	https://www.census.gov/programs-surveys/acs/	2019
Occupants per Household	US Census Bureau ACS 2017 5 year Estimates, Dallas, TX Block Groups	https://www.census.gov/programs-surveys/acs/	2019

Figure 3.2 GIS Layers Used in Study

Lastly, demographic data were obtained from the United States Census Bureau, American Community Survey 2017, five-year estimates, derived from 2010 US Census data, including: socioeconomic features that pertain to equity, such as: racial minority populations, areas of low income, access to vehicles, education level, populations over 64 years of age and populations under 14 years of age.

The compilation of these data layers, as previously mentioned, was weighted for a suitability analysis, which is a landscape analysis model developed by Ian McHarg, which analyzes weighted parameters as to how to map areas of importance in a geographical model. The effectiveness of analysis is highly dependent on the researcher's inputs. This process used ArcMap 10.6.1, which included the use of the following toolsets: Analysis, Geocode, Data Management, Conversion, Spatial Analysis, and Model Builder.

3.6 DATA ANALYSIS

An examination of locations with EE's concerning an area's physical features,

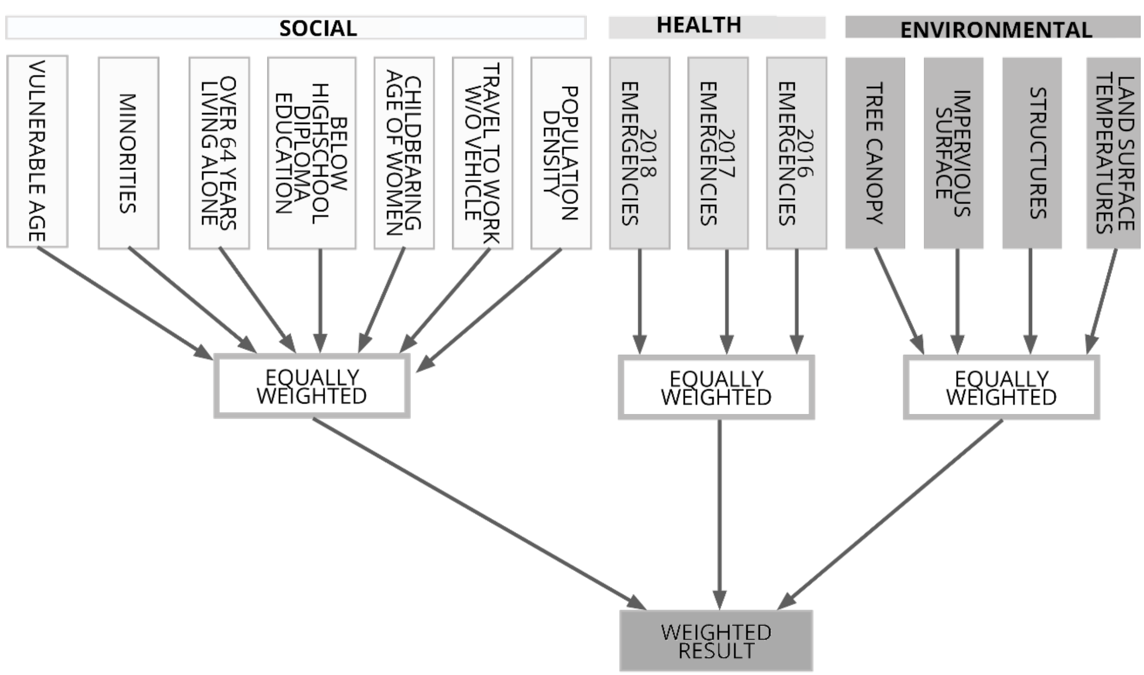


Figure 3.3 GIS Weighted Overlay for Suitability Analysis of Dallas Sites

land surface temperatures, and socioeconomically distributions are taken into consideration to fully capture the vulnerabilities associated with climate change and urban morphology. The fields were weighted equally to find a connection between health, physical, and demographic distributions (see Figure 3.3).

A model for data selection methods and suitability analysis was developed by the Climate and Health Program at the Center for Disease Control and Prevention (CDC), Building Resilience Against Climate Effects (BRACE) was a basis for this study (see Figure 3.4).

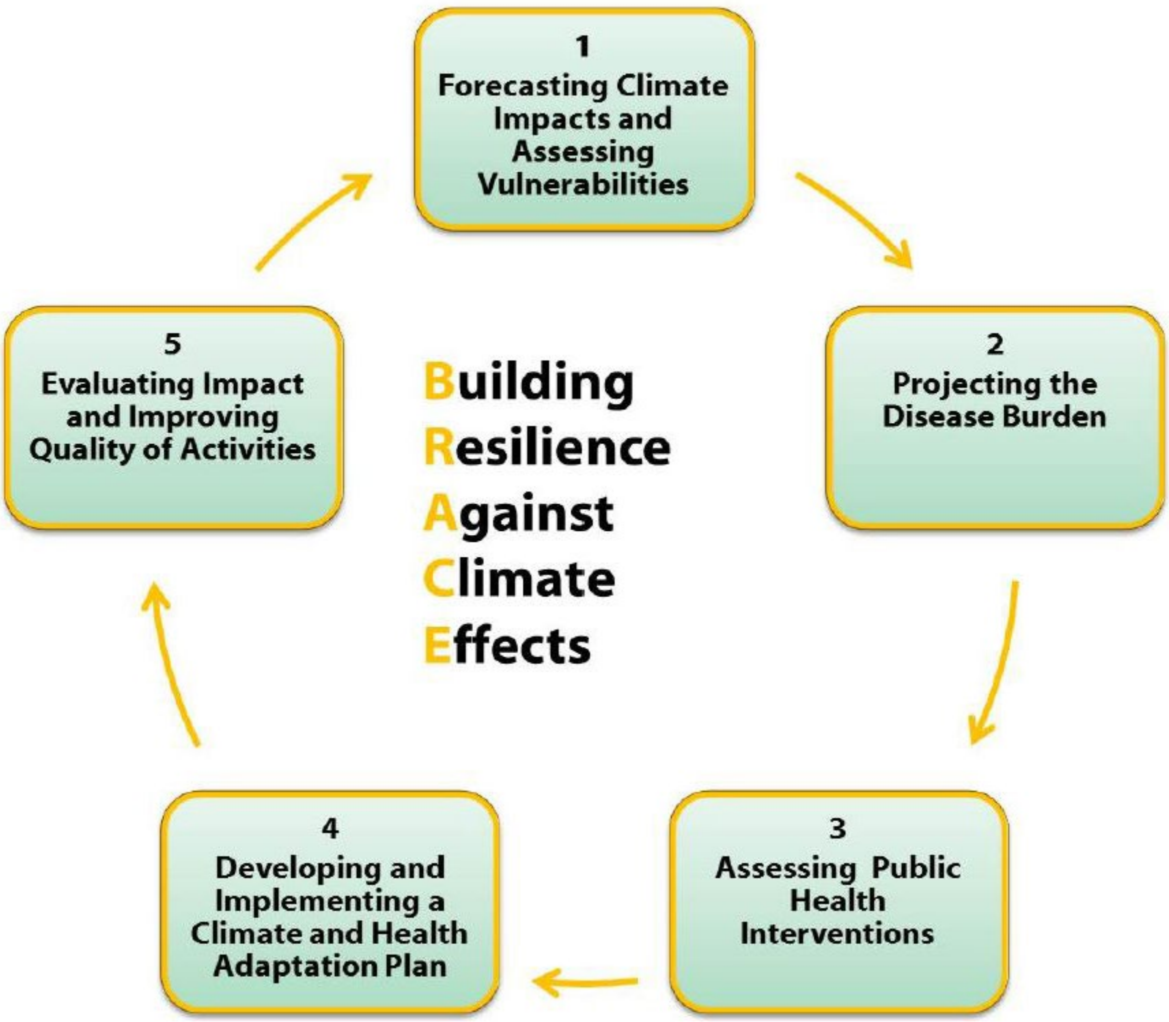


Figure 3.4 CDC BRACE Model Steps (CDC, 2019)

This model provides a framework for assessing people and places exhibiting vulnerability. The goal of the model is to implement interventions to reduce public health impacts. A systematic and evidence-based process can be customized to any area of the world where climate change may affect public health. The accumulation of data, such as climate information, environmental emergency calls, city infrastructure use, and demographics were mapped to determine focus areas to investigate further. The BRACE Model Steps include the following:

1) Forecasting Climate Impacts and Assessing Vulnerabilities
2) Projecting the Disease Burden
3) Assessing Public Health Interventions
4) Developing and Implementing a Climate Health Adaption Plan
5) Evaluating Impact and Improving Quality of Activities

3.7 BRACE MODEL: DESIGN PROCESS

The accumulation of data, such as climate information, environmental emergency calls, city infrastructure, and demographics were mapped to determine focus areas to investigate further. This process covered step (1) and step (2) of the BRACE Model (CDC). Secondly, these concentrated areas were examined carefully to assess public health interventions step (3).

The focused area underwent analysis by determining the distance of the emergency event in proximity to the fire station responders. The distance between these points was achieved using the Network Distance tool in ArcGIS. These areas, with higher response times resulted in site selection for the proposed implementation of microclimate cooling bioclimatic design interventions, step (4).

Additional criteria for site bioclimatic design intervention are:

- pedestrian pathways
- tree canopy percentage
- plantable area
- impervious surface percentage
- sun angle exposure
- building shade
- wind exposure

Finally, after the proposed bioclimatic design interventions, step (5), assessment of the vulnerability of site was determined given the amount of area possibly influenced by the use of functional landscape architecture bioclimatic design interventions (see Figure 3.5). In order to bioclimatic design areas that will have the most significant cooling effect on people during hot summertime weather, a landscape architect needs to know the relative impact of various bioclimatic design interventions (e.g., Brown, 2011).

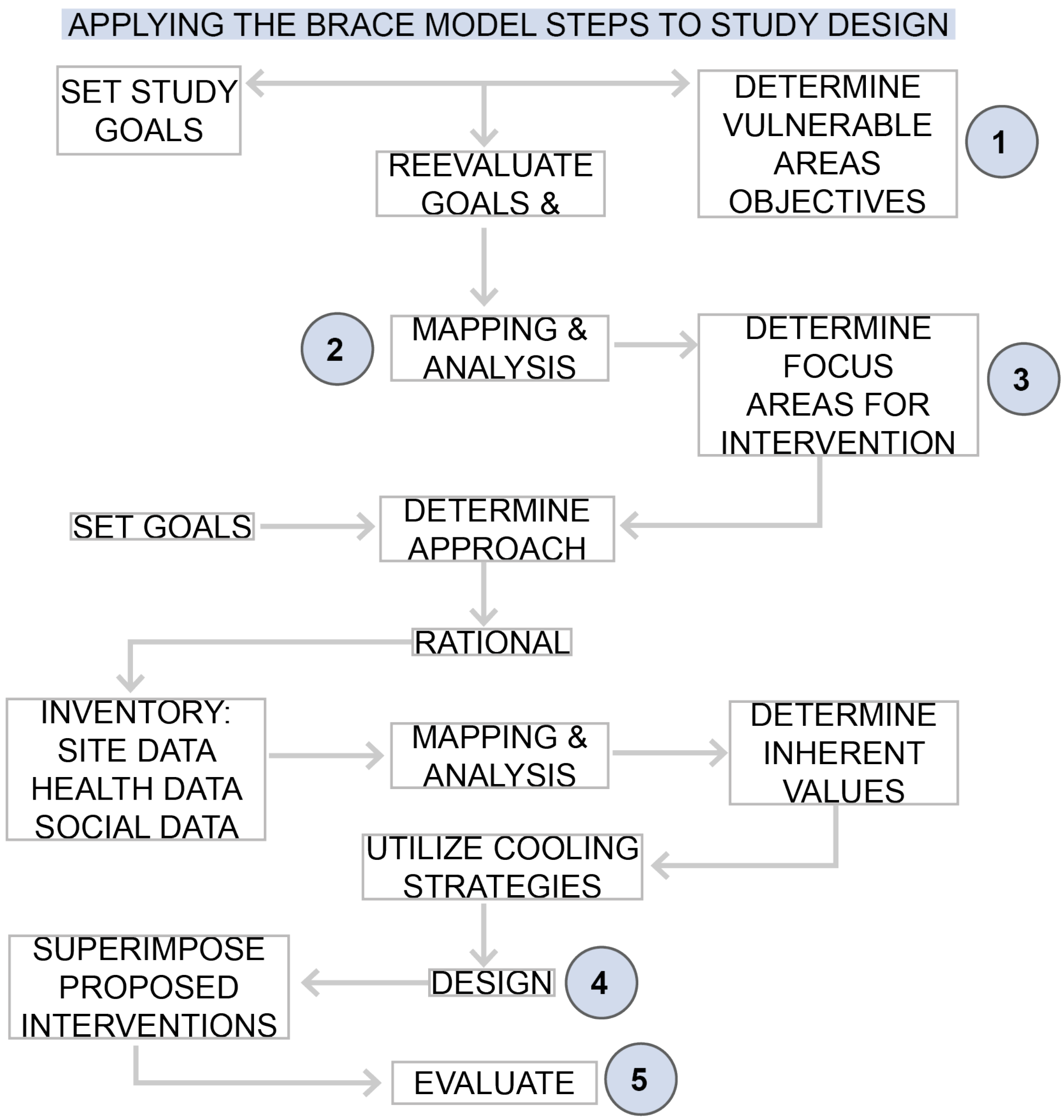


Figure 3.5 Applying BRACE Model Steps

3.8 LIMITATIONS

Quantitative research is subject to the availability of data that is accessible to the public or obtained efficiently. Some data sourced in overlays do not correlate yearly, but are estimated using five-year estimates from the American Community Survey data. However, the data is representative of collection within the last ten years, which limits the accuracy of targeted population groups to a margin of error outlined in the ACS five-year estimates. The census data was collected many years ago; therefore, it is subject to the subsequent lack of validity. Data derived for environmental emergency call data required working with a GIS Analyst in order to derive data in an appropriate period that was relevant to the period of other data retrieved. Retrieving this data is largely limited to the researchers' ability to source relevant departments of public entities in a timely fashion, or the ability to retrieve data that do not have general public gained access. Government and other official institutions are often a reliable data source, but it is subject to human error in transposing the data. Additionally, online sourced data at times lacked metadata for the exact timeframe of procurement, therefore, may require further validation when implementing site-specific interventions. For this reason, quality issues are always a possible outcome in using secondary data. This study does not include an alternative technique of data collection, such as survey or interviews.

3.9 CHAPTER SUMMARY

This chapter describes the research methods used in this study, which included the research design based on the city of Dallas, data analysis, and data acquisition. The analysis involved classification through spatial correlation of significant urban morphologies, geocoding of environmental emergencies and mapping demographic block group statistics. The evaluation was done through a weighted overlay analysis of site information along with categorical parameters and priorities, defined by the BRACE model and literature review.

Three focus areas were isolated, analyzed, to reveal opportunities for intervention using a variety of climate cooling strategies. This systematic process of inquiry also used McHarg' s suitability analysis, which ranked areas based on vulnerability to urban morphology, climate, the occurrence of EE's, and social determinants of vulnerability. This GIS graphics technique helped discern logical, spatial relationships and areas of focus. The evaluation was deductive based on the BRACE model framework.

This study used a quantitative research method approach that used numerical & mapping data. A combination of environmental, health and vulnerable population factors mapped a relationship of how climate, urban morphology, and social demographics coincide to reveal focused areas of vulnerability.

GIS data obtained from the City of Dallas, GIS website, which includes building footprints or structures, city limits, impervious surfaces, roads, and hydrology. Also,

An examination of locations with EE's concerning these physical features was taken into consideration to capture the vulnerabilities associated with climate change entirely. The fields were weighted equally to find a connection between health, physical, and demographic distributions. This model provides a framework for assessing people and places exhibiting vulnerability. The goal of the model is to implement interventions to reduce public health impacts. A systematic and evidence-based process can be customized to any area of the world where climate change may affect public health.

This process covered steps of the BRACE Model. Secondly, these concentrated areas were scrutinized to assess public health interventions. The focused area underwent analysis by determining the distance of the emergency event in proximity to the fire station responders. Proposed bioclimatic design interventions and assessment of the vulnerability of the site was determined given the amount of area, possibly influenced by the use of practical landscape architecture design interventions. This quantitative research is subject to the parameters set forth by the BRACE Model.

CHAPTER 4 ANALYSIS & FINDINGS

4.1 INTRODUCTION

Urban heat island studies of Dallas show the inner city shows marked elevations in temperature (see Figure 4.1). In the map of Dallas below (see Figure 4.2), the lighter areas are apparent and show the vast sprawl of the urban core. The greener areas mark the existing vegetation (see Figure 4.2). An urban tree canopy assessment, by the Texas Trees Foundation found that the 375 square miles of Dallas exhibited approximately

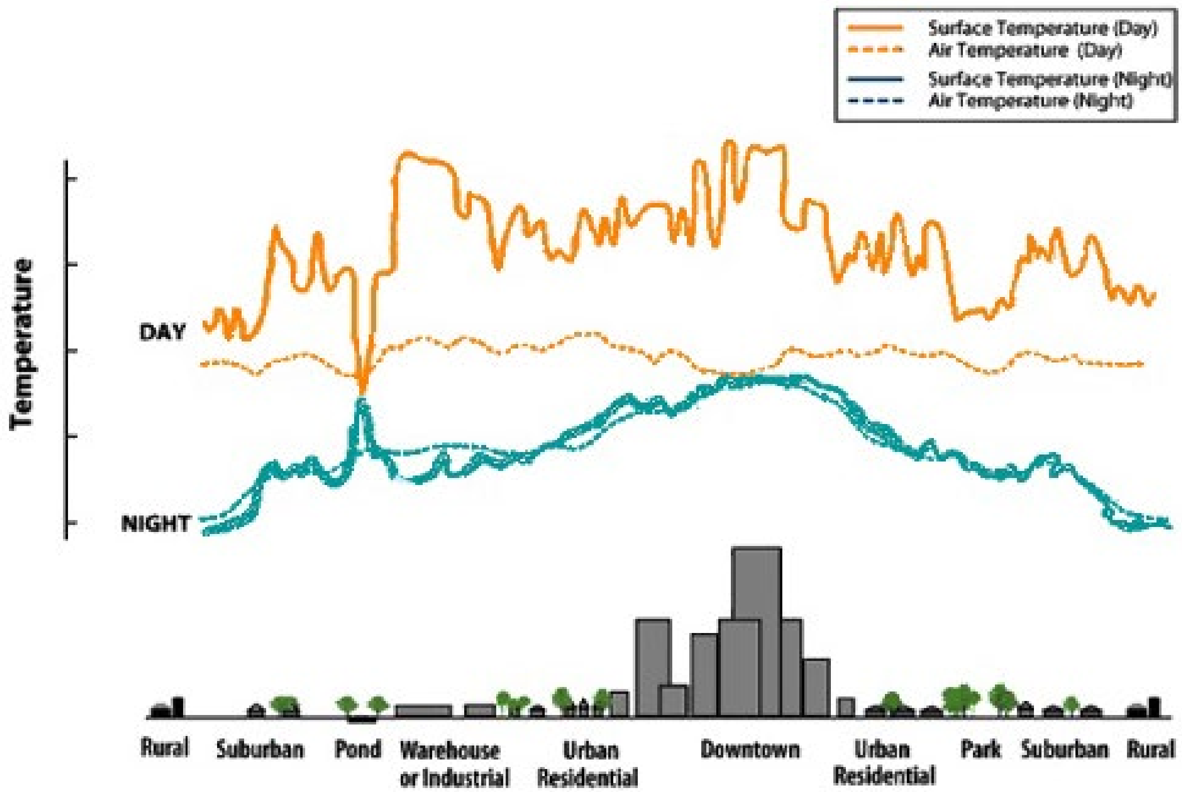


Figure 4.1 Urban Heat Island Diagram (EPA, 2008)

30% canopy cover. However, the most substantial proportion runs along the Trinity River, leaving the surrounding area with an average closer to 8-9%. To understand these physical relationships to the effect it has on the residents of Dallas, it is vital to look at the bigger picture, which includes an in-depth, look at where populations reside and where the climate is having a severe impact on the health of those residents.

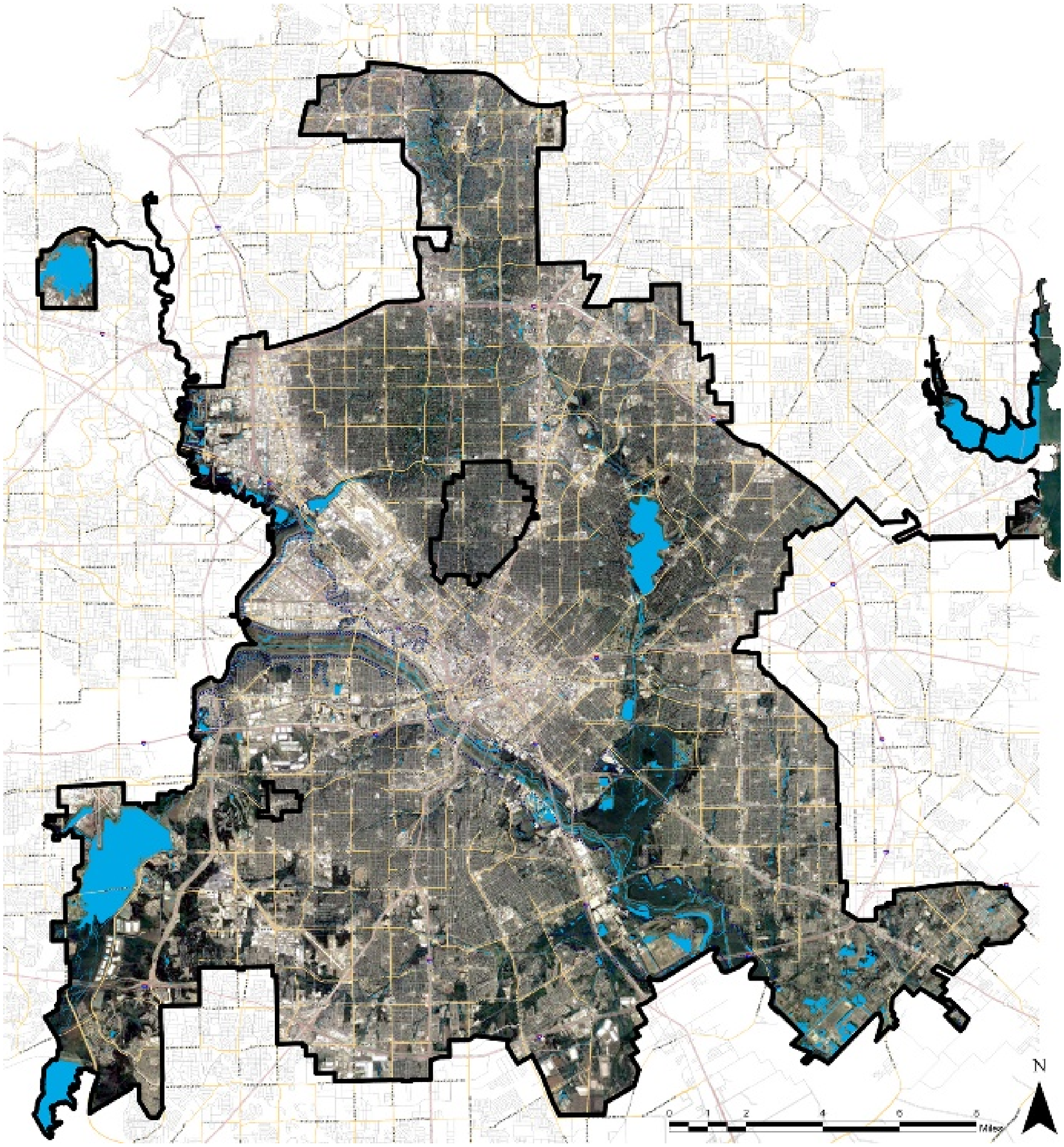


Figure 4.2 Aerial Map of Dallas

4.2.1 ENVIRONMENTAL FACTORS

The environmental factors examined include tree canopy cover, impervious surfaces, building footprints, and land surface temperatures. Together these attributes form the physical influences that can influence microclimates.

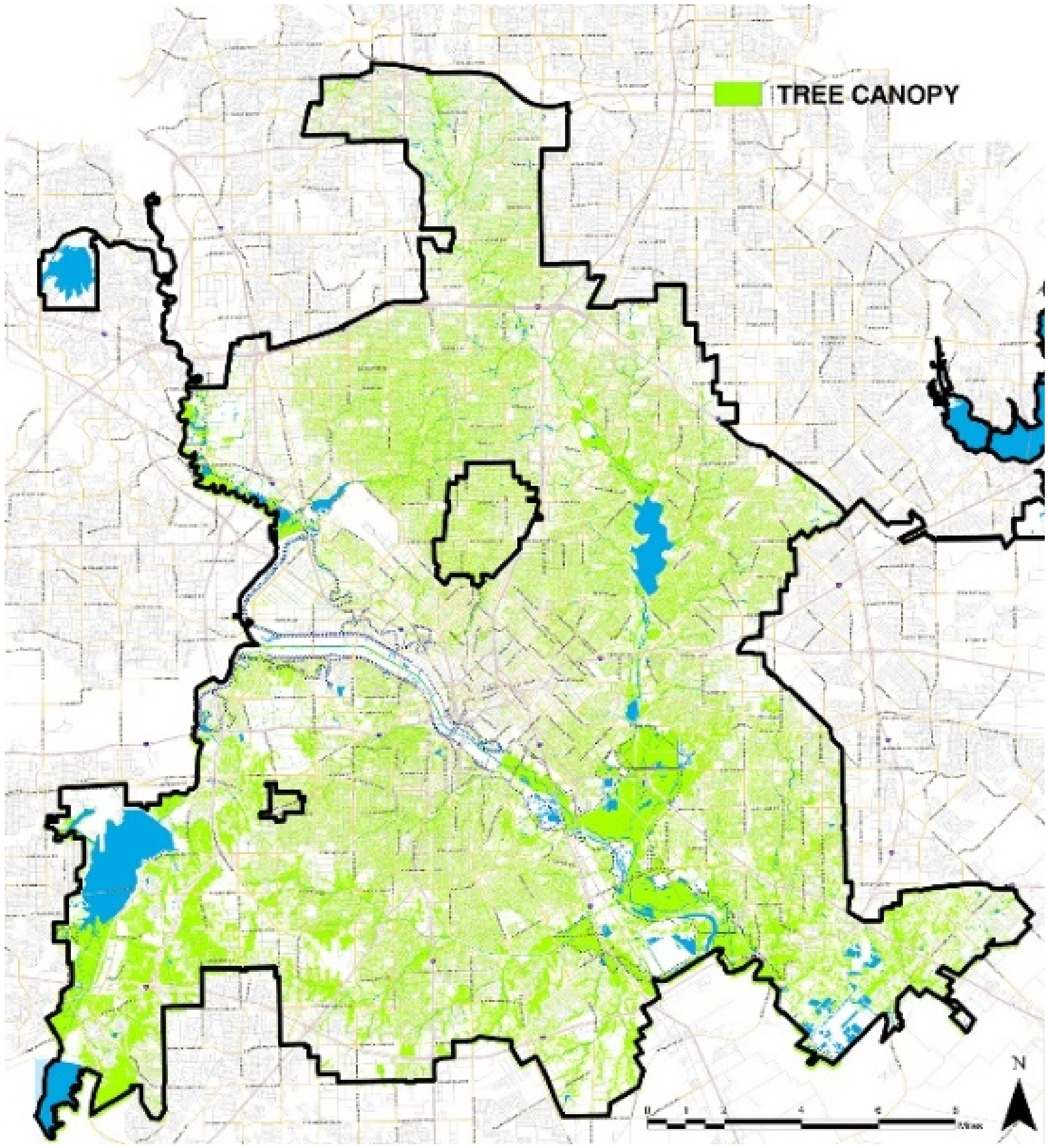


Figure 4.3 Tree Canopy of Dallas

The tree canopy cover (see Figure 4.3) was mapped and clipped by the corresponding block groups. The lack of tree canopy to block groups was ranked "most vulnerable" when the total area of the block group exhibited areas with the lowest percentage of the tree canopy.

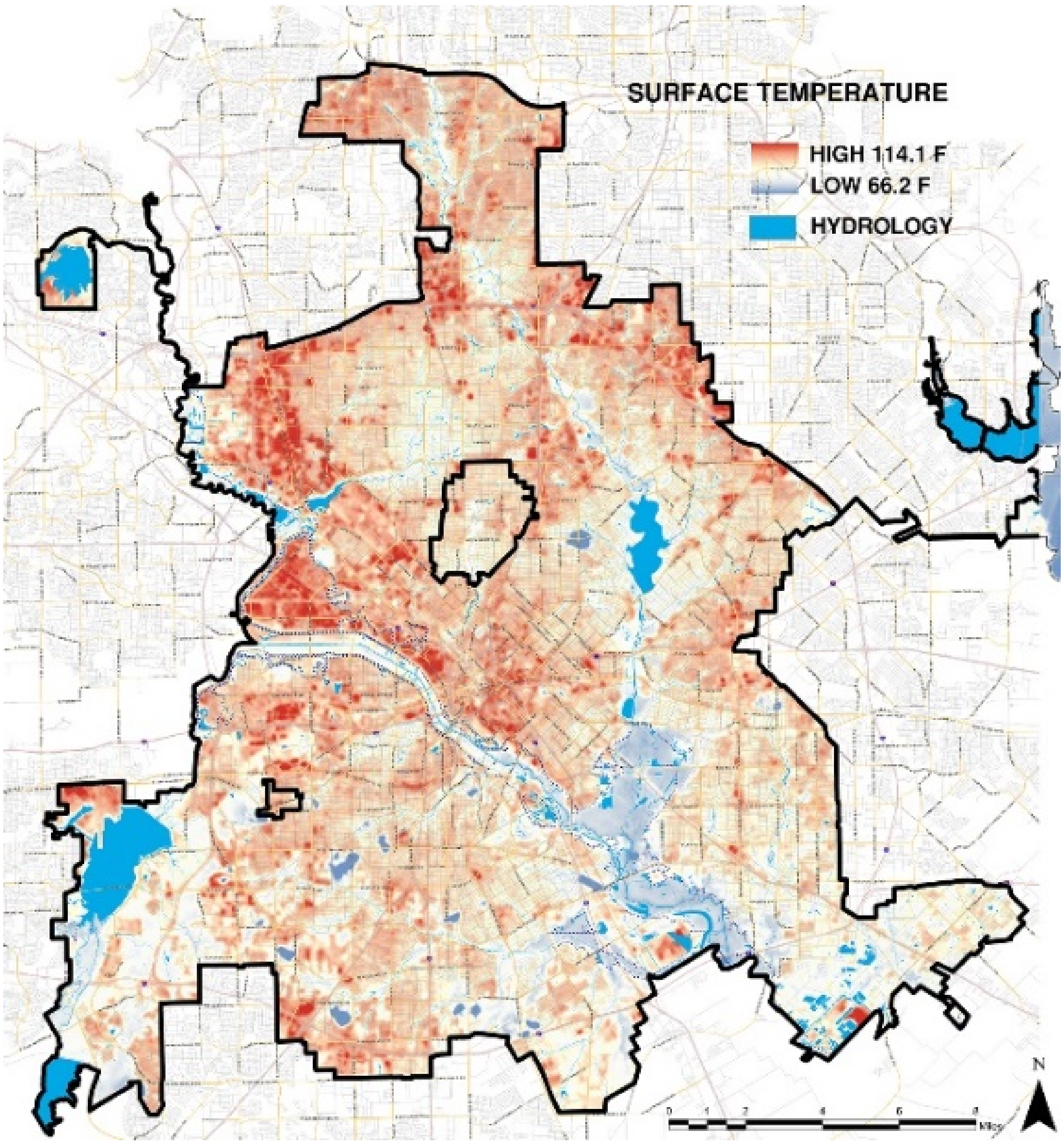


Figure 4.4 Land Surface Temperature July 22, 2017

Block groups possessing area with the highest average surface temperature were considered areas that were "most vulnerable". The low tree canopy cover and the areas with high temperatures occurred in all focus areas, vulnerable block groups. This finding was consistent with the literature review.

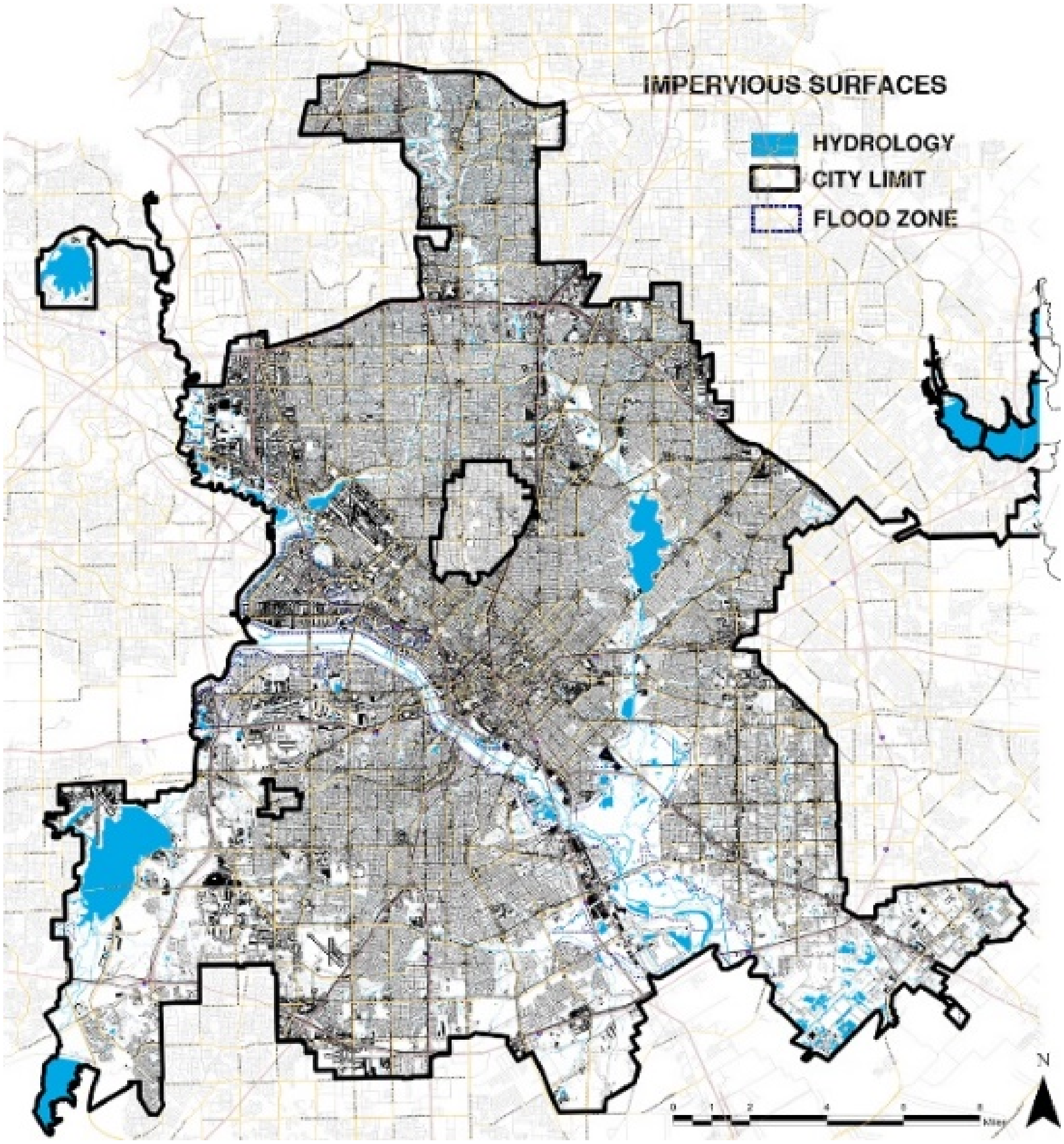


Figure 4.5 Impervious Surfaces of Dallas

Block groups with the highest amounts of impervious surfaces were considered "most vulnerable". These areas were consistent with regions of high surface temperature, and regions with the lowest tree canopy area in focus area block groups. The lack of tree canopy is consistent with areas of the high impervious surface because trees require porous soil to survive. There are limitations when planting trees among impervious surfaces because the roots require access to air, which is limited given the proximity of impervious surfaces.

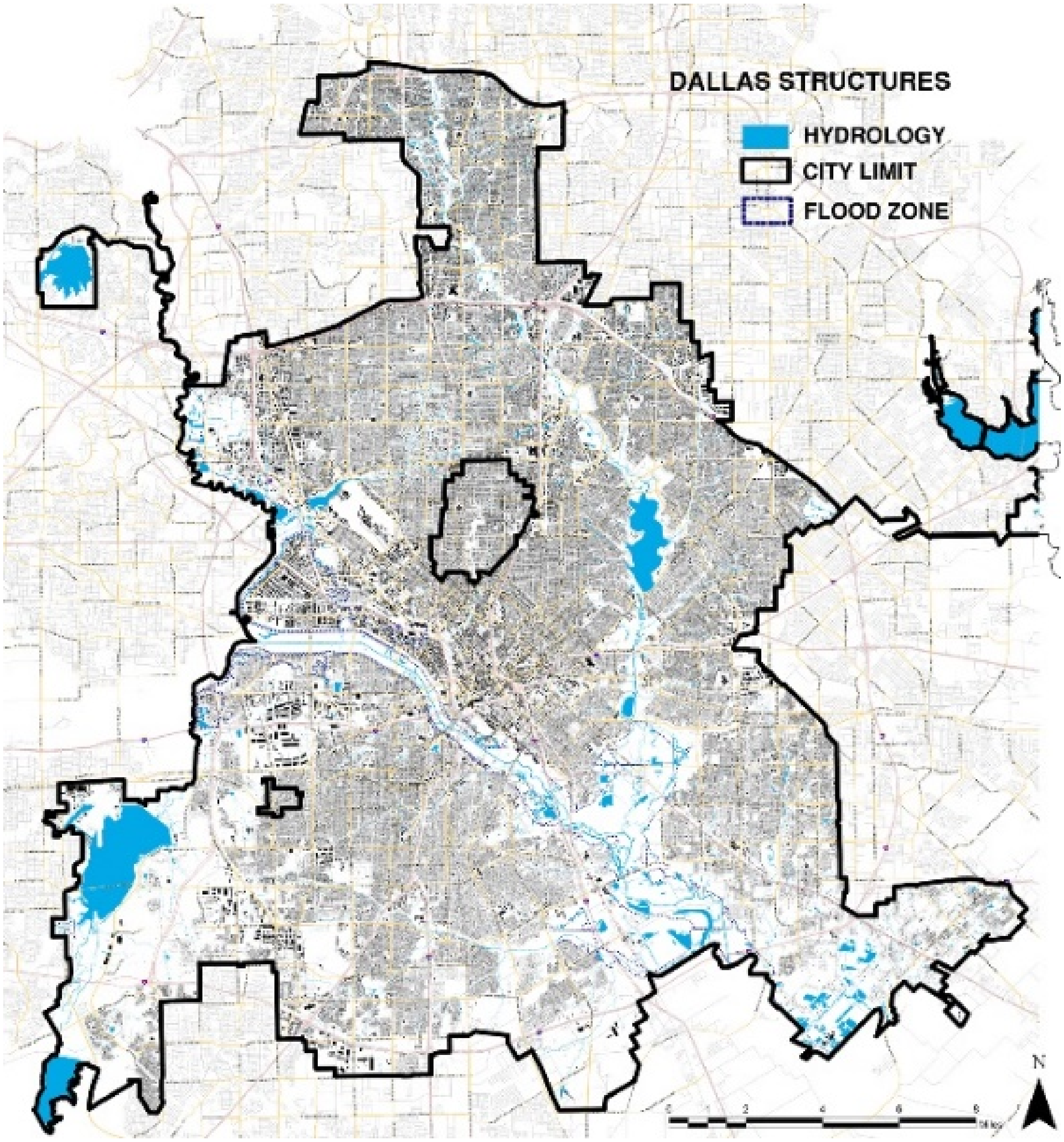


Figure 4.6 Structures (impervious) of Dallas

Block groups with areas of high building density were ranked “most vulnerable”. High density of buildings was observed in all vulnerable block group focus areas, including the previously mentioned environmental factors. Buildings with green roofs or other bioclimatic design considerations were not included in the ranking.

4.2.2 HEALTH FACTORS

Environmental Emergency calls data was obtained from the GIS Analyst at the Dallas Fire and Rescue Department. The location of these events was mapped to find where they were occurring in the city. The highest density of the EE's occurred in the urban core of the city that possessed vulnerable environmental factors. (see Figure 4.7)

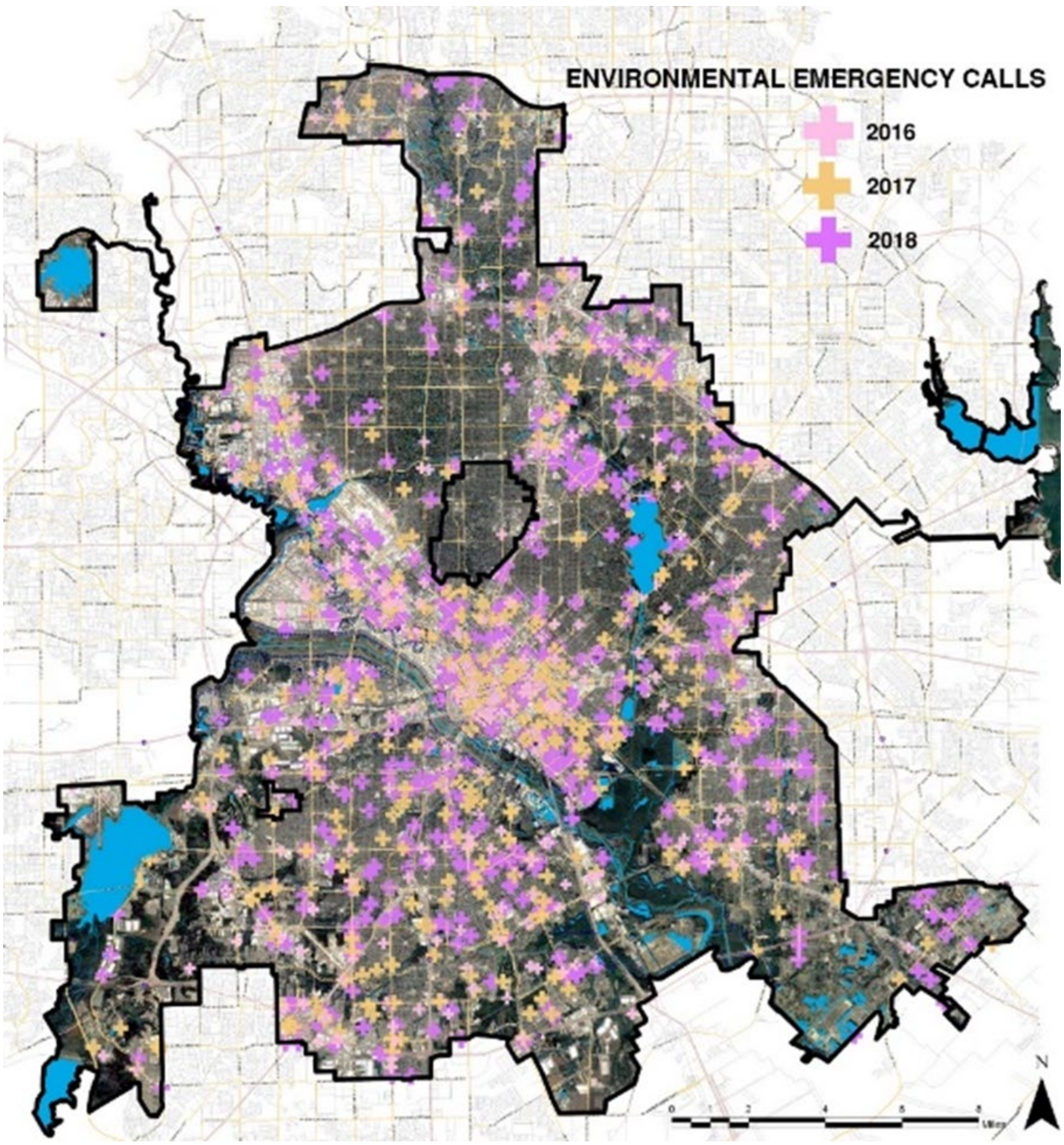


Figure 4.7 Dallas EE's 2016-2018 (Dallas Fire & Rescue)

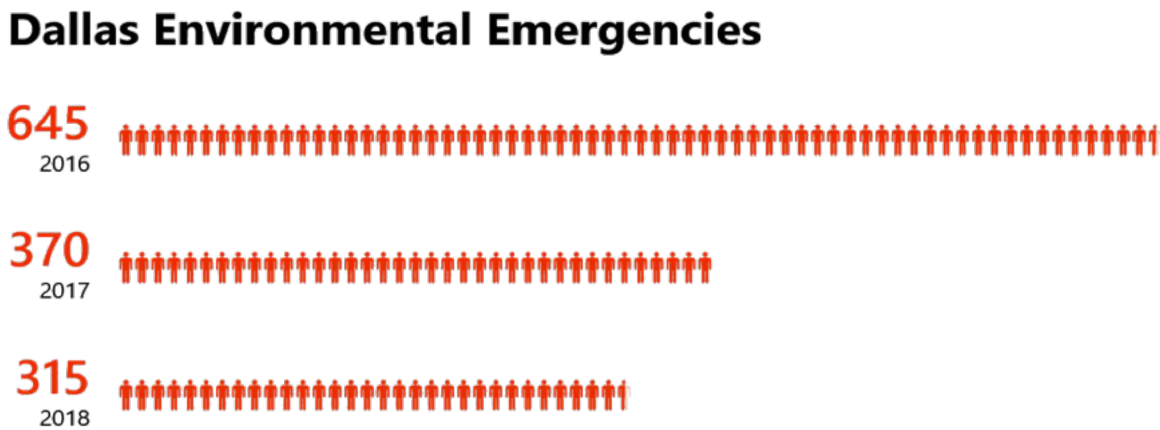


Figure 4.8 Environmental Emergencies per Year (Fire Department)

The environmental emergencies were counted by year (see Figure 4.8) which shows that 48.4% of the recorded EE's from January 13, 2016, to September 22, 2018, occurred in the year of 2016. 27.8% of the EE's took place in 2017, and 23.6% of the EE's occurred in 2018. However, at the time of data release to the researcher, the Fire & Rescue Department did not have recorded events of EE's in beyond September 22, 2018. The estimated difference based on the average totals EE's in 2016s and 2017s October, November, and December counts yield an estimated 1% of total calls missing from 2018. However, the possibility of EE's occurring, the eight days after September 22, was not included in this estimate.

Based on the data EE's occurring each month, 1,044 or 78% environmental EE's recorded occurred in June (249 EE's), July (526 EE's), and August (269 EE's) (see Figure 4.9) where maximum monthly temperatures were at their highest, with the highest maximum monthly temperature recorded to be 112°F in July of 2018. However, out of the recorded temperature months, July of 2016 exhibited the maximum high temperature at 100°F (see Figure 4.10), when 18%, the highest EE count recorded per month, over the three years.

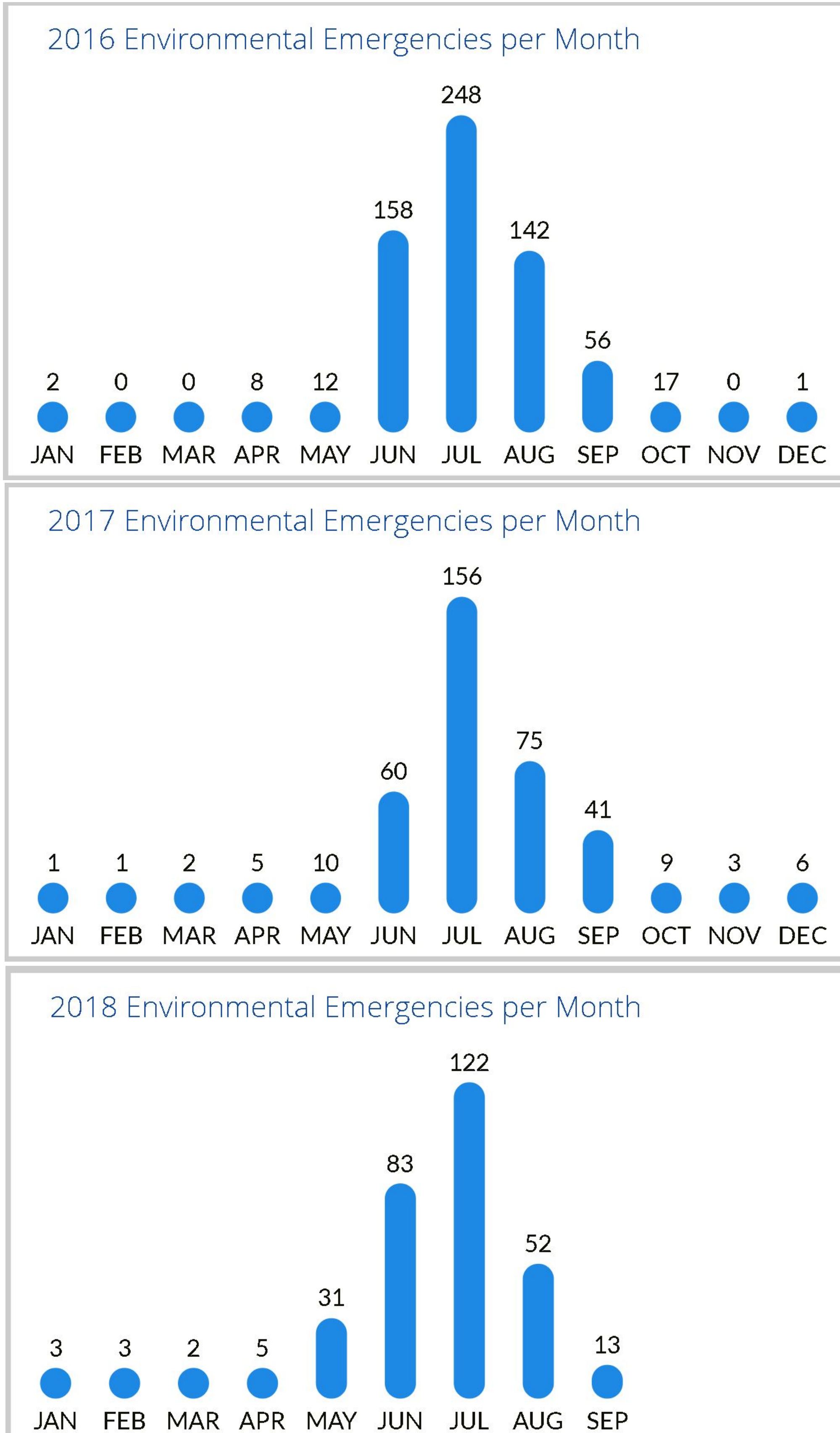


Figure 4.9 Environmental Emergencies per Month (Fire & Rescue Department)

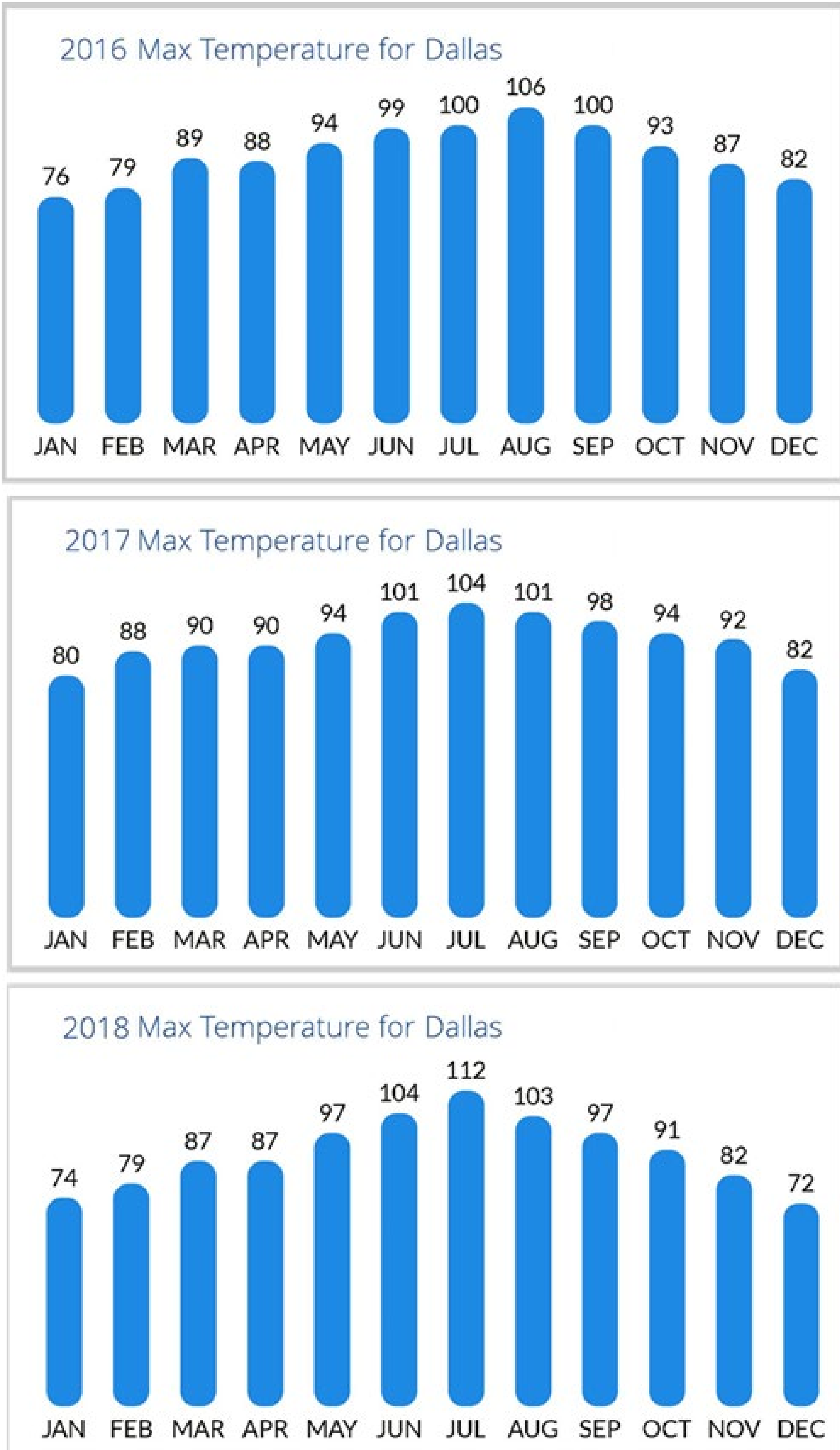


Figure 4.10 Maximum Temperatures per Month (NWS).

The average high temperature of Dallas, based on weather date from the National Weather Service, was 97° F, (see figure 4.11) with a minimum daily temperature of 76°F and an average daily temperature of 87°F. The average emergency call occurred at 3 pm. This time and beforehand must be considered when implementing shade. This temperature is well above the comfort level of an adult, but can have more compounding effects on children and older populations among many other social health factors and demographics. On average, the average temperature of 2016-2018 had a 4-degree higher departure from the normal average temperature based on the thirty-year normal temperature for this region.

AVERAGES OF TIME & CLIMATE FACTORS FOR ENVIRONMENTAL EMERGENCIES

ALL YEARS	HOUR	MAX	MIN	AVG	DEP	CDD	PCPN: WTR	WIND: SPD	MAX	2 MIN DIR	PK: SPD	WND DR
	15	**97**	**76**	**87**	**4**	**22**	**0.066**	**10**	**20**	**167**	**26**	**167**
2016	HOUR	MAX	MIN	AVG	DEP	CDD	PCPN: WTR	WIND: SPD	MAX	2 MIN DIR	PK: SPD	WND DR
	15	97	77	87	4	22	0.068	10	19	180	25	181
2017	HOUR	MAX	MIN	AVG	DEP	CDD	PCPN: WTR	WIND: SPD	MAX	2 MIN DIR	PK: SPD	WND DR
	15	95	76	86	3	21	0.117	10	20	157	26	159
2018	HOUR	MAX	MIN	AVG	DEP	CDD	PCPN: WTR	WIND: SPD	MAX	2 MIN DIR	PK: SPD	WND DR
	15	98	76	87	4	22	0.012	11	21	163	27	160
Year	Average Hour of Emergency	The **highest** temperature for the day (F).	The **lowest** temperature for the day(F)	The **average** temperature for the day(F)	**Departure** from normal. The difference between the average temperature for the day and the 30 year normal temperature for this date.	A **cooling degree day** is a measurement designed to quantify the demand for energy needed to cool a building. **Degrees above 65** in which buildings need to be cooled.	Total **precipitation** for the day to the nearest hundredth of an inch.	**Average** Wind Speed for the Day	**Maximum** 2-min-average wind speed during the Day	**Average Wind Direction** for the Day (360 degree compass)	**Peak** Wind Speed	**Direction** that **peak** wind came from (360 degree compass)

Figure 4.11 Averages of Time & Climate Factors of EE's (NWS & Dallas Fire & Rescue)

4.2.3 VULNERABLE POPULATION FACTORS

Vulnerable populations "include patients who are racial or ethnic minorities, children, elderly, socioeconomically disadvantaged, underinsured or those with certain medical conditions", National Center for Biotechnology (NCBI, Waisel, 2013). The vulnerable population layers examined in GIS included the following block group comparisons:

- Populations with Less than a High School Diploma Education
- Groups Below the Poverty Line
- Childbearing Female, Age Group 15-44 yrs. old (defined by the CDC)
- Minority Group Populations
- Travel to Work, Without a Car (Travel on foot, public transportation, etc.)
- Over the Age of 64 Living Alone
- Vulnerable Age, Under 14 & Over 64 years
- Population Density (higher density requires more health resources)

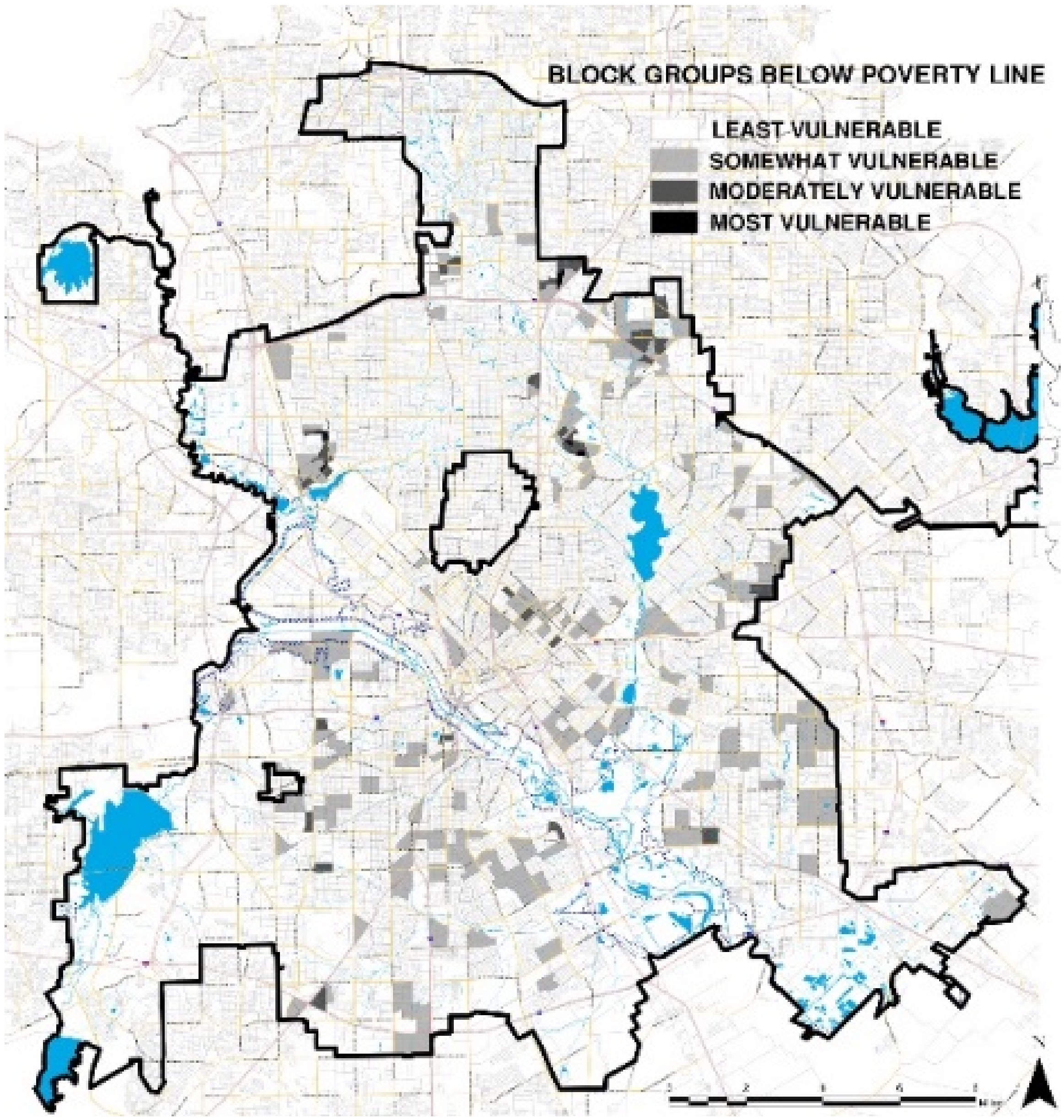


Figure 4.12 Below the Poverty Line

Demographic block groups that exhibited a high percentage of populations living below the poverty line were ranked "most vulnerable" (see Figure 4.11). The neighborhoods' regions of Dallas with these populations were Northwest Dallas, Far North Dallas, Vickery Meadow, Lochwood, Balch Springs, Oak Cliff, Wynnewood North, Redbird, Casa View, Deep Ellum, Redbird, and West Dallas. The locations of these block groups were also found near crossing significant highways.

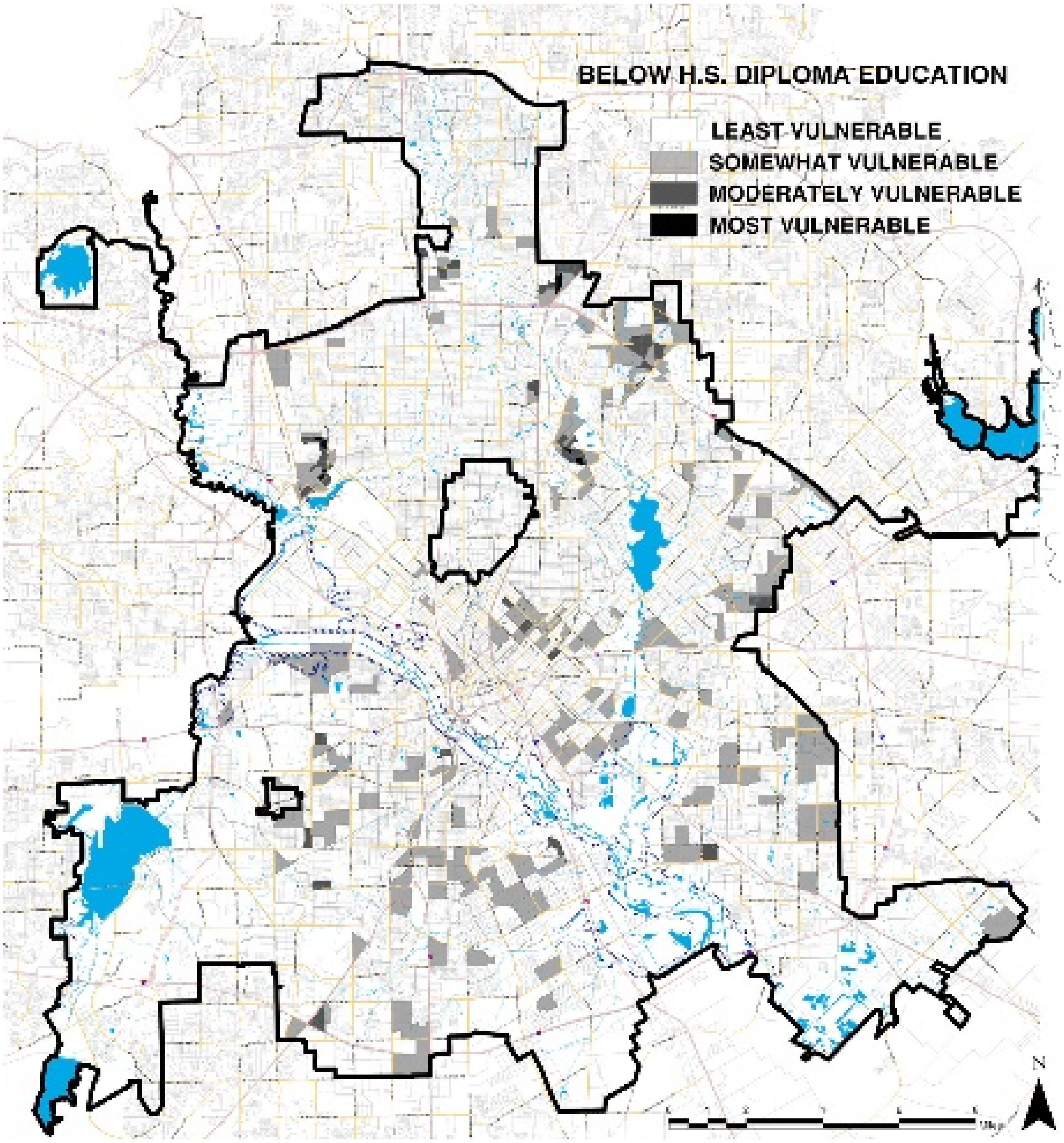


Figure 4.13 below H.S. Diploma Education

Demographic block groups that exhibited a high percentage of the population with an education level less than a high school diploma were ranked “most vulnerable” (see Figure 4.12). The neighborhoods’ regions of these areas were similar to populations below the poverty line. These populations were in Northwest Dallas, Far North Dallas, Vickery Meadow, Lochwood, Balch Springs, Oak Cliff, Wynnewood North, Redbird, Casa View, Deep Ellum, Redbird, and West Dallas.

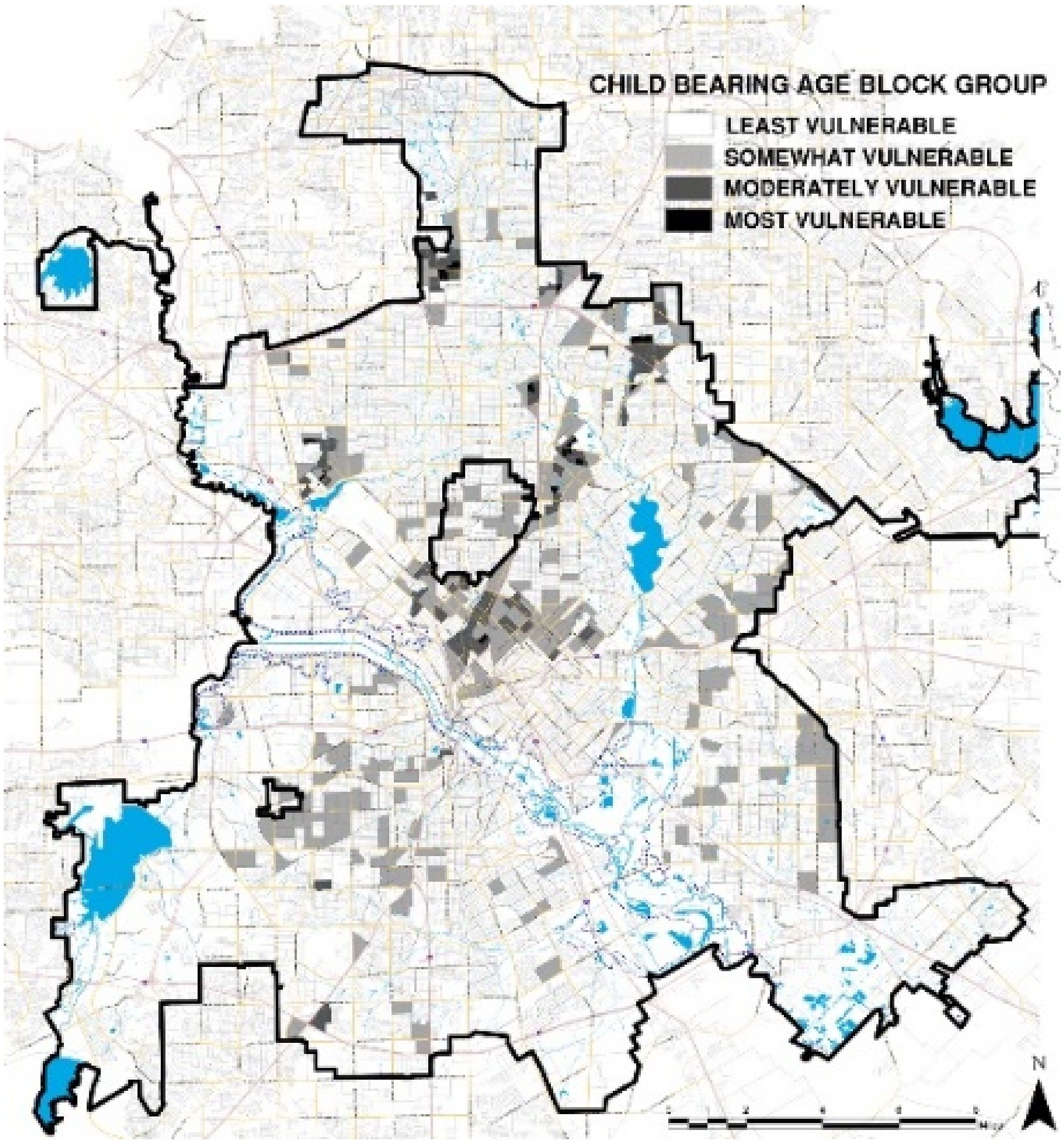


Figure 4.14 Childbearing Age

Demographic block groups that exhibited a high percentage of populations of women of childbearing age were ranked "most vulnerable" (see Figure 4.13). The neighborhoods' regions of Dallas with these populations were North East Dallas, Lake Highlands, Casa View, Balch Springs, Old East Dallas, Highland Park, Knox/Henderson, Oaklawn, Uptown, Cockrell Hill, Oak Cliff, Northwest Dallas, and Bluffview.

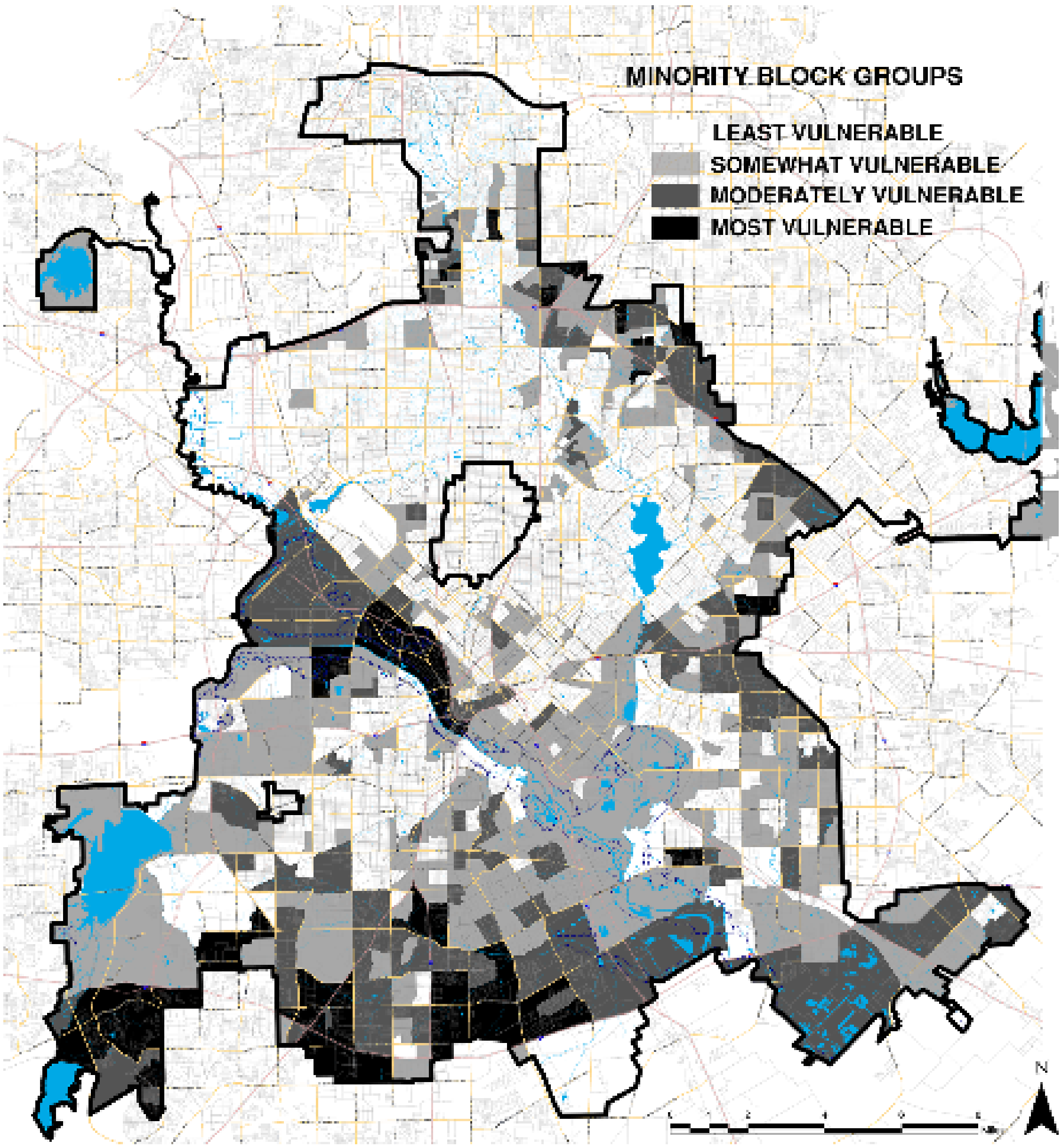
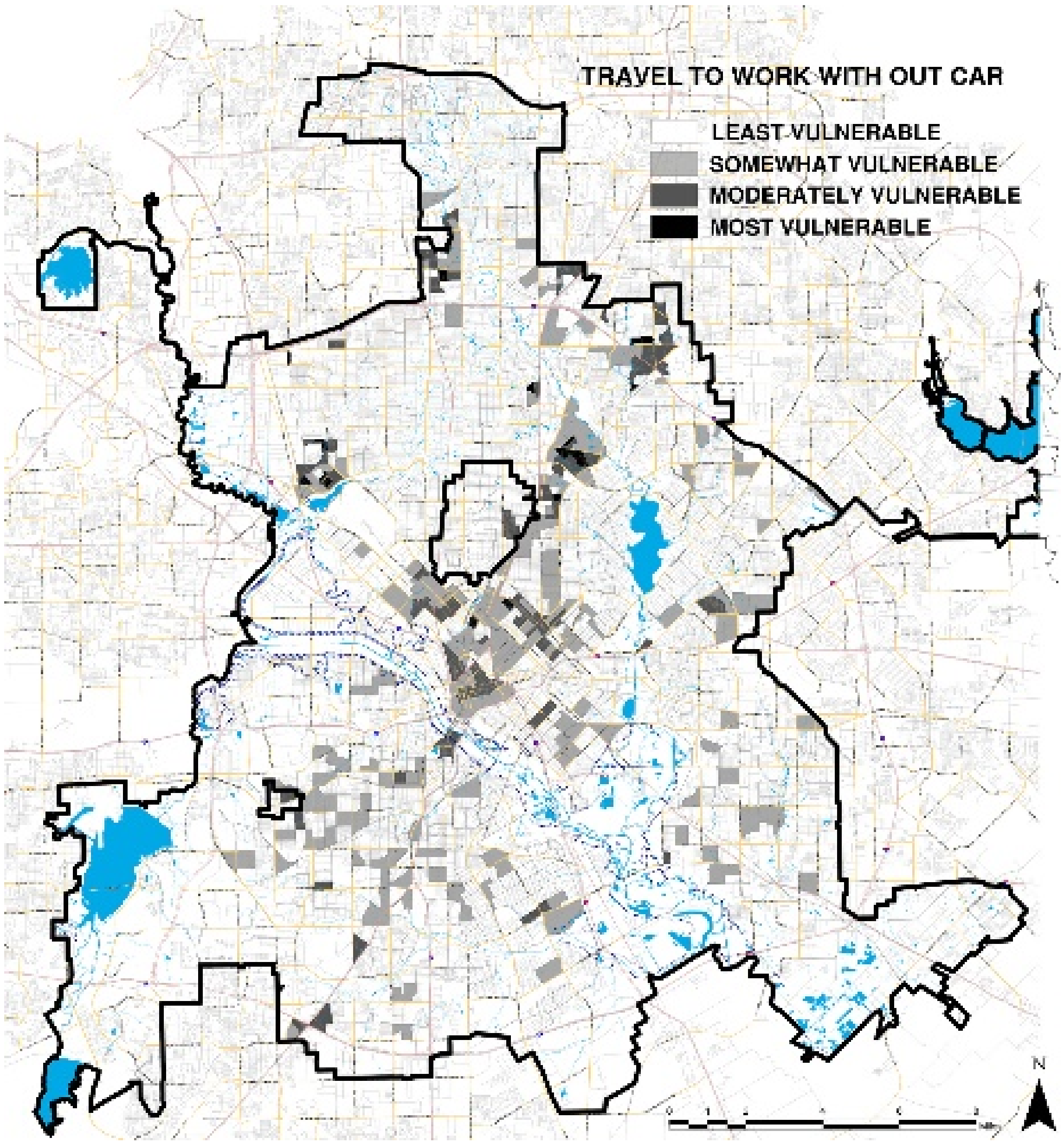


Figure 4.15 Minorities per Block Group

Demographic block groups that exhibited a high percentage of population of minorities were ranked "most vulnerable" (see Figure 4.14). The neighborhoods' regions of Dallas with these populations were DeSoto, Cedar Hill, Duncanville, Lancaster, Hutchins, North Dallas, Lake Highlands, Highland Meadow Casa View, Casa Linda, Seagoville, West Dallas, Northwest Dallas, and Far North Dallas. A large block group exists where Stemmons Freeway meets John Carpenter Freeway, and along areas between Loop 12 and Ronald Reagan Highway. There seems to be the highest prevalence of "most vulnerable" minority block groups compared to other demographic data.



4.16 Travel to Work without a Car

Demographic block groups that exhibited a high percentage of populations who travel to work without the use of a car were ranked "most vulnerable" (see Figure 4.15). The neighborhoods' regions of Dallas with these populations were Bishop Arts District, Wynnewood North, Downtown Dallas, Deep Ellum, Oaklawn, Turtle Creek, Vickery

Meadow, Northeast Dallas, Lower Greenville, South Dallas, Old East Dallas, Towne Crossing, North Dallas, and Far North Dallas. These areas appear to be more centralized with less occurrence happening near the city limits with a few exceptions.

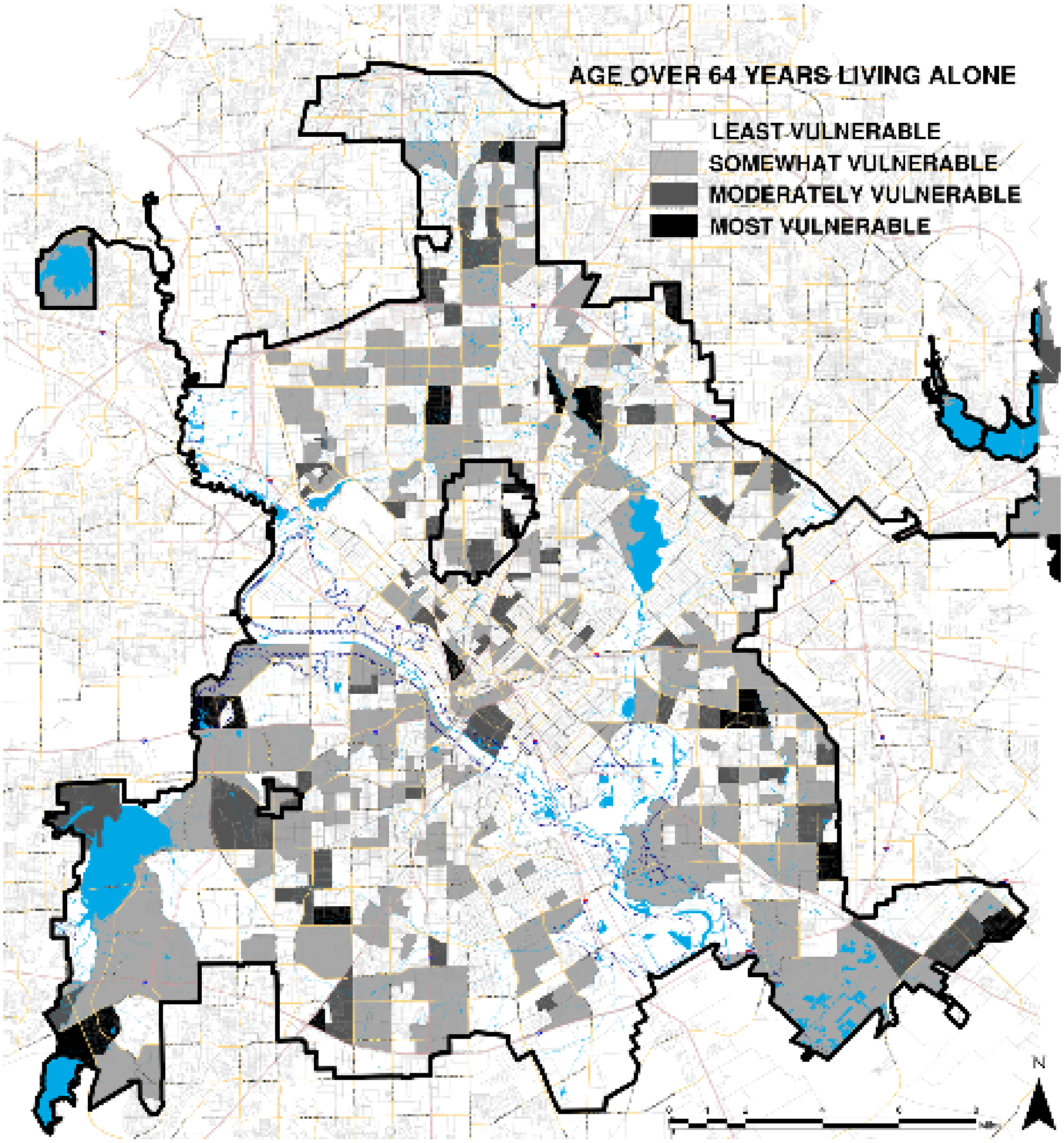


Figure 4.17 Age Over 64 yrs. Living Alone

Demographic block groups that exhibited a high percentage of populations of Adults over the age of 64 years living alone were ranked "most vulnerable" (see Figure 4.16). The neighborhoods' regions of Dallas with these populations were Vickery

Meadow, Preston Hollow, Highland Park, Cedars, Uptown, West Dallas, Duncanville, Far North Dallas, Balch Springs, and Pleasant Grove.

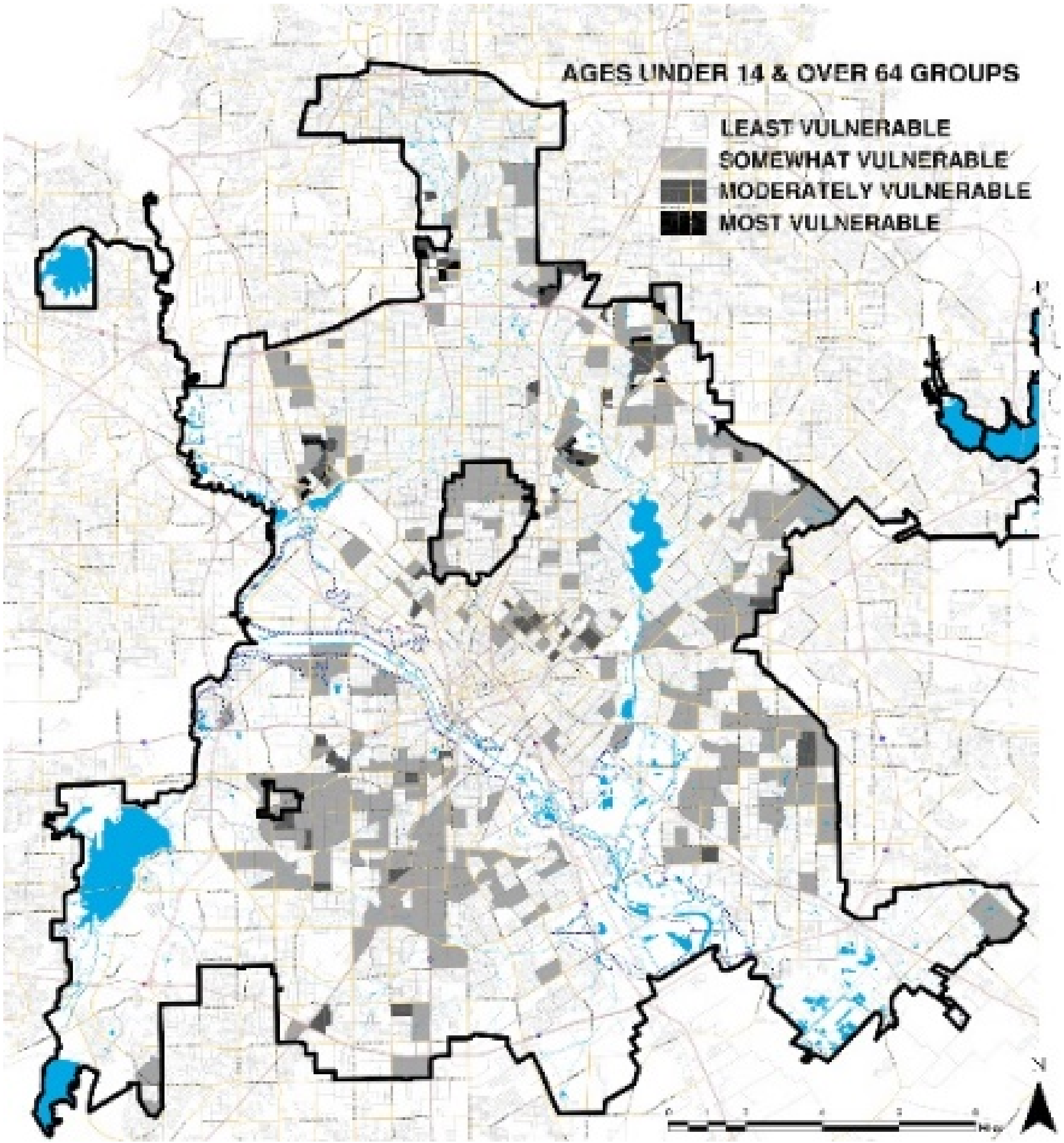
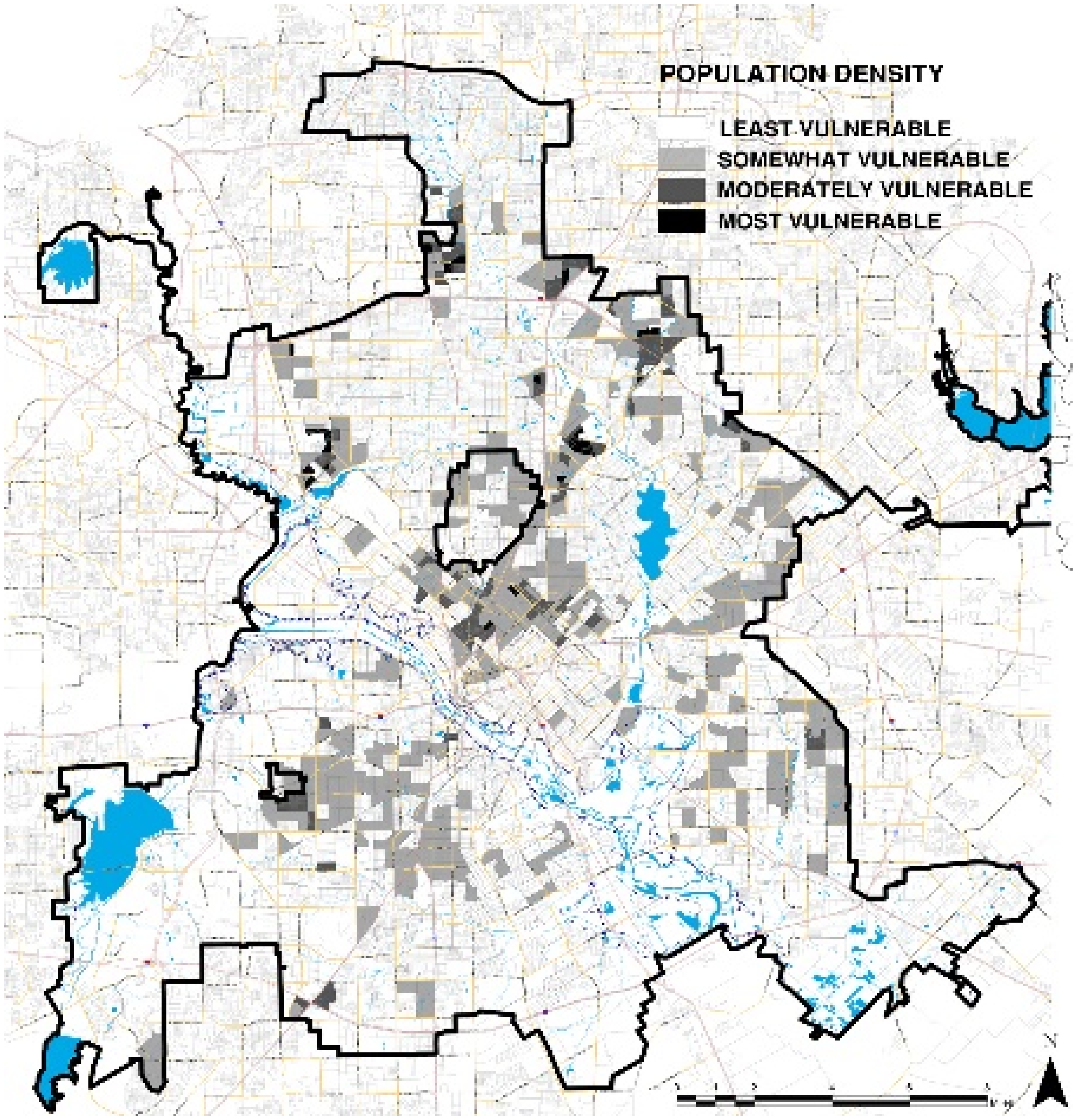


Figure 4.18 Under 14 & Over 64 yrs.

Demographic block groups that exhibited a high percentage of populations of children under the age of 14 years and adults over the age of 64 years were ranked "most vulnerable" (see Figure 4.17). The neighborhood regions of Dallas with these populations were Vickery Meadow, University Park, Lower Greenville, Old East Dallas, Casa View, Cockrell Hill, Oakcliff, Balch Springs, and Pleasant Grove. The smaller block groups in these regions were considered more vulnerable.



. Figure 4.19 Population Density

Demographic block groups that exhibited a high percentage of population density were ranked “most vulnerable” (see Figure 4.18). The neighborhood regions of Dallas with these populations were Far North Dallas, North Dallas, North Lake Highlands, Highland Meadow, Casa View, Balch Springs, Cockrell Hill, Wolf Creek, Oakcliff, Uptown, Downtown, Oaklawn, Turtle Creek, Old East Dallas, Deep Ellum, and Bryan Place. Population density lies centrally.

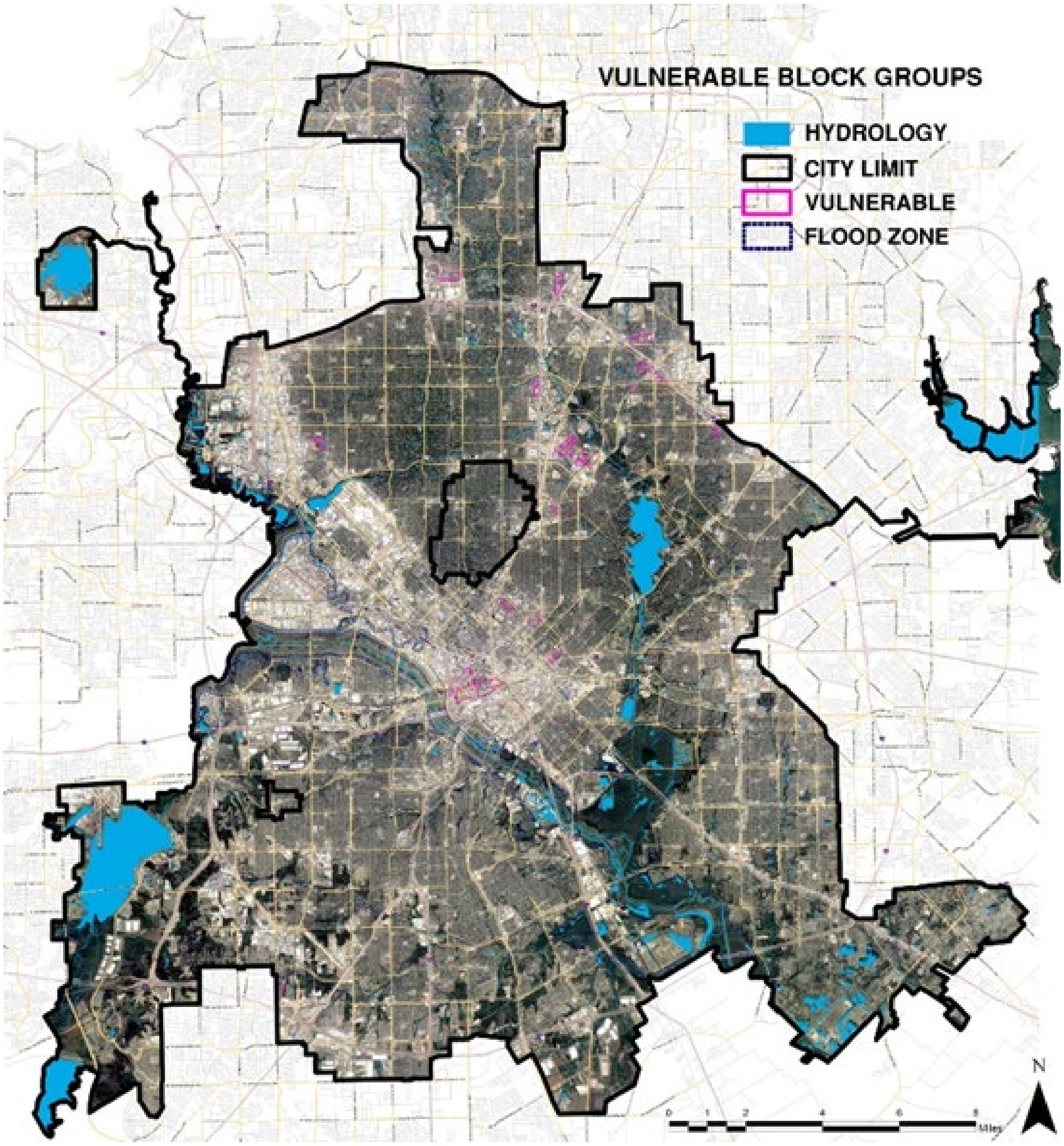


Figure 4.20 Vulnerable Block Groups Based on Weighted Overlay

4.2.4 WEIGHTED OVERLAY OF VULNERABLE BLOCK GROUPS

Combining the layers from environmental, health, and demographic data, resulted in twenty-one block groups that possess qualities that suggest higher vulnerability (see Figure 4.19). The result is an assessment of people and place vulnerability, and may be used to focus on areas in need of an intervention to reduce any burdens that may be impacted by the urban morphology. Findings show these areas, as a result of the weighted overlay:

- Occur near major roadways and highways
- Exhibit high occurrences of EE's based on their block group area
- Has the highest degree of social determinants of health, but vary based on the individual block group and can exhibit one to eight of the factors explored
- Environmental vulnerability rank highly among the four factors explored

4.3 FOCUSING IN FURTHER ON ADAPTIVE CAPACITY

In Step (3) of the BRACE model, it is necessary to assess how Dallas' existing systems can help these populations cope with the effects of climate change. As the population grows and temperatures warm, it will be necessary for the city to accommodate for possibly higher incidence rates. One way to measure and assess the existing systems is to take the fifty-seven fire stations of Dallas into consideration. These emergency responders become closer in proximity at the dense urban core. Three areas were chosen based on their proximity and travel time to responding to fire station dispatch. All areas of incidents were appropriate distances from the corresponding fire station. However, the following areas were chosen based on the further distance from the responding fire stations of the twenty-one most vulnerable block groups based on results from the ArcMap network Analysis tool (see Figure 4.20;. Figure 4.21; Figure 4.22 ;.)

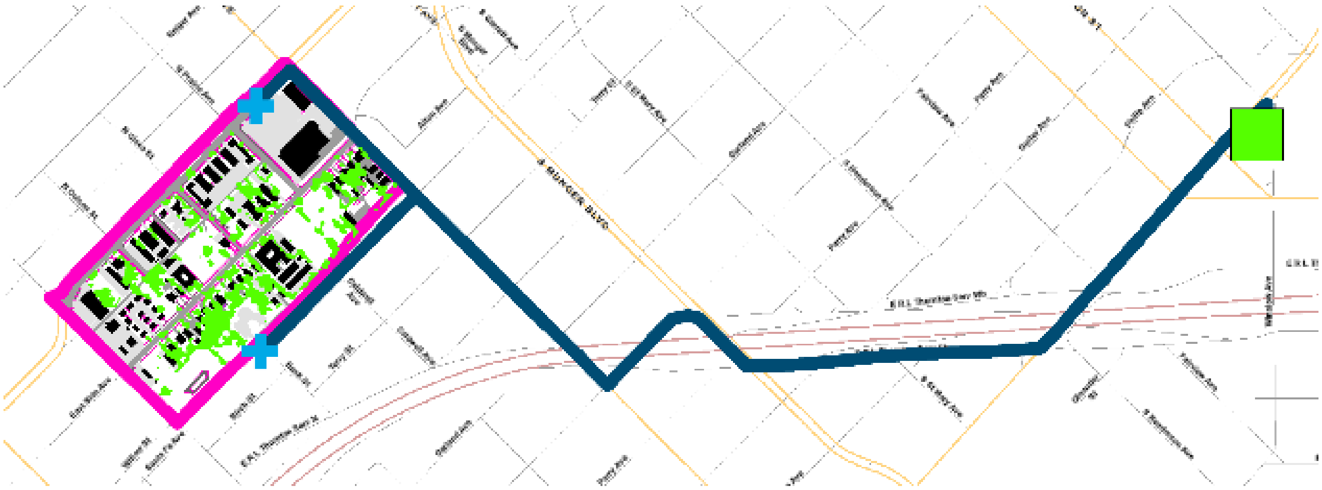


Figure 4.21 Old East Dallas Network Analysis of Fire Department Proximity

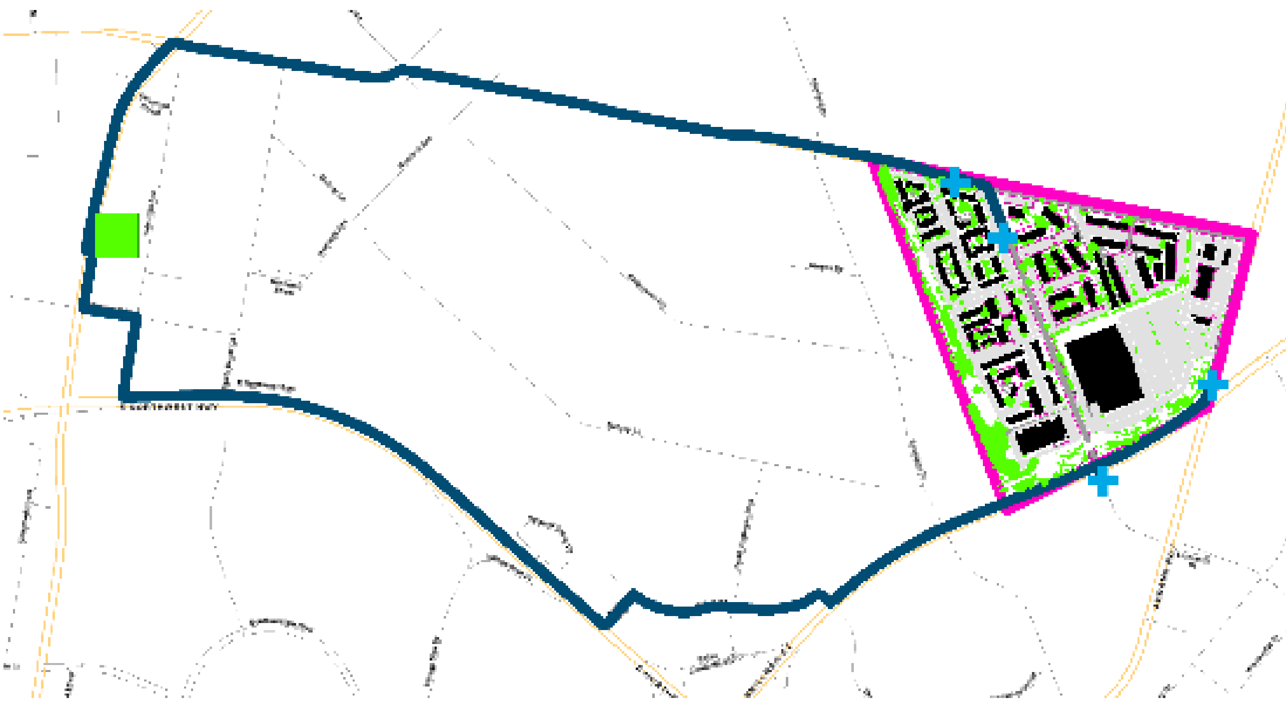


Figure 4.22 Vickery Meadow Network Analysis of Fire Department Proximity

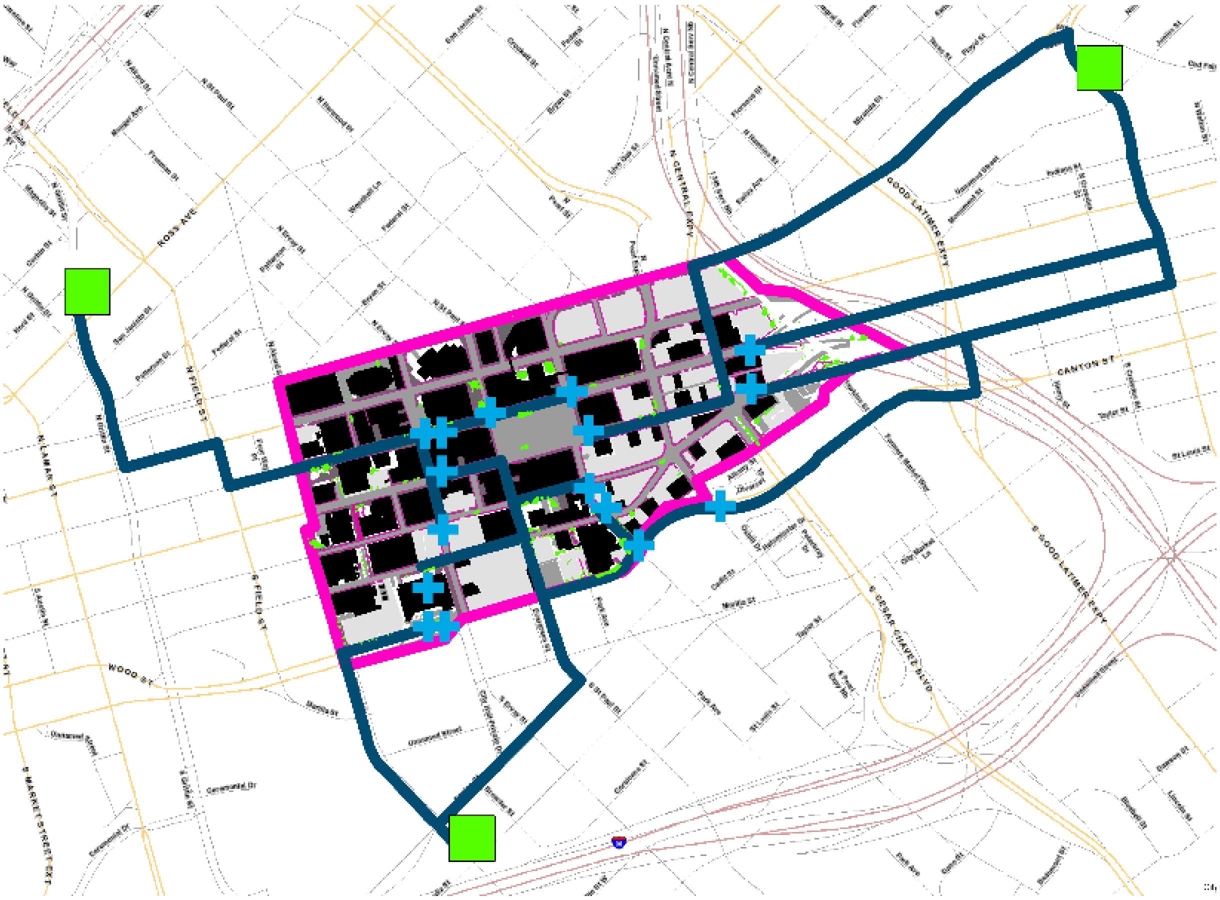


Figure 4.23 Downtown Dallas Network Analysis of Fire Department Proximity

4.4 AREAS OF FOCUS INTRODUCTION

Step (4) of the BRACE model involves developing and implementing a climate, health, and adaptation plan. The fourth step can be illustrated with bioclimatic design tools LA's use daily in the landscape. However, the implementation should be strategic and requires an in-depth look of the neighborhoods at a smaller scale.

In order to implement the proper design interventions, the focus areas need to be studied considering several parameters — all of the naturally occurring site conditions. The ultimate goal of the site analysis was to determine how to implement the appropriate cooling strategies.

4.4.1 FOCUS AREA DISTRICT INVENTORY

This inventory is a vital process in the practice of landscape architecture. The influences of the climate are necessary to implement climate-cooling designs. Site inventory gives practitioners a snapshot of the existing conditions. The existing environmental and urban morphology was assessed on a smaller, more detailed scale, for example, identifying land-use patterns, tree canopy, plantable area, building shade, wind patterns, and surface temperature.

Figure 4.24 Land use of Downtown Dallas

Figure 4.25 Land use of Old East Dallas

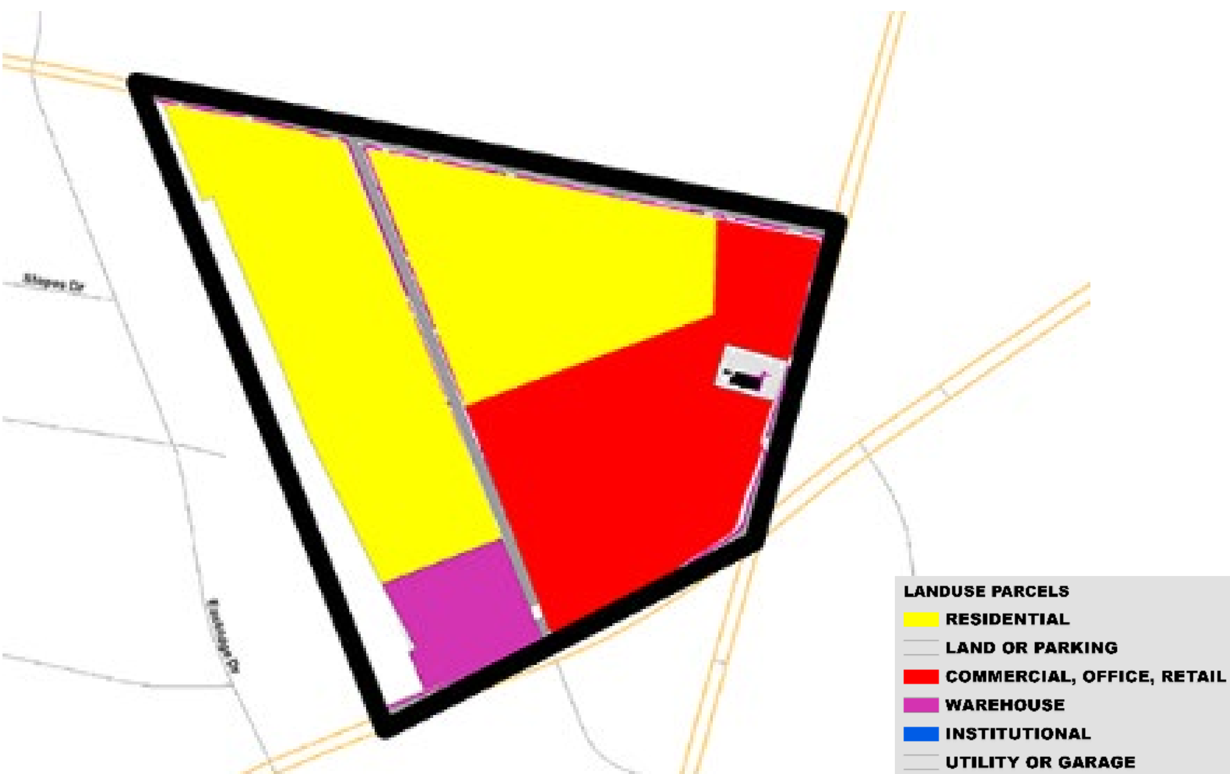


Figure 4.26 Land use of Vickery Meadow

Land use helps planners and designers understand the uses of environmental morphology. In Downtown Dallas, the area consists of a majority of commercial and institutional uses with a large area designated for parking. There are a few residential areas (see Figure 4.23). The land use of the Old East consists of residential and commercial uses. (see Figure 4.24). Vickery Meadow (see Figure 4.25) consists of a majority of residential uses with a large commercial area in the southeast corner as well as a large storage facility to the south. This observation leads to the conclusion that Downtown Dallas land uses are urban and offer more institutional options for the public.

A focused lens explores the environmental morphology of the following area of site inventory. The EE's were mapped in order to see the relationship to tree canopy, impervious surfaces, and buildings. Downtown exhibits very little tree canopy and high impervious surfaces and building density (see Figure 4.26)

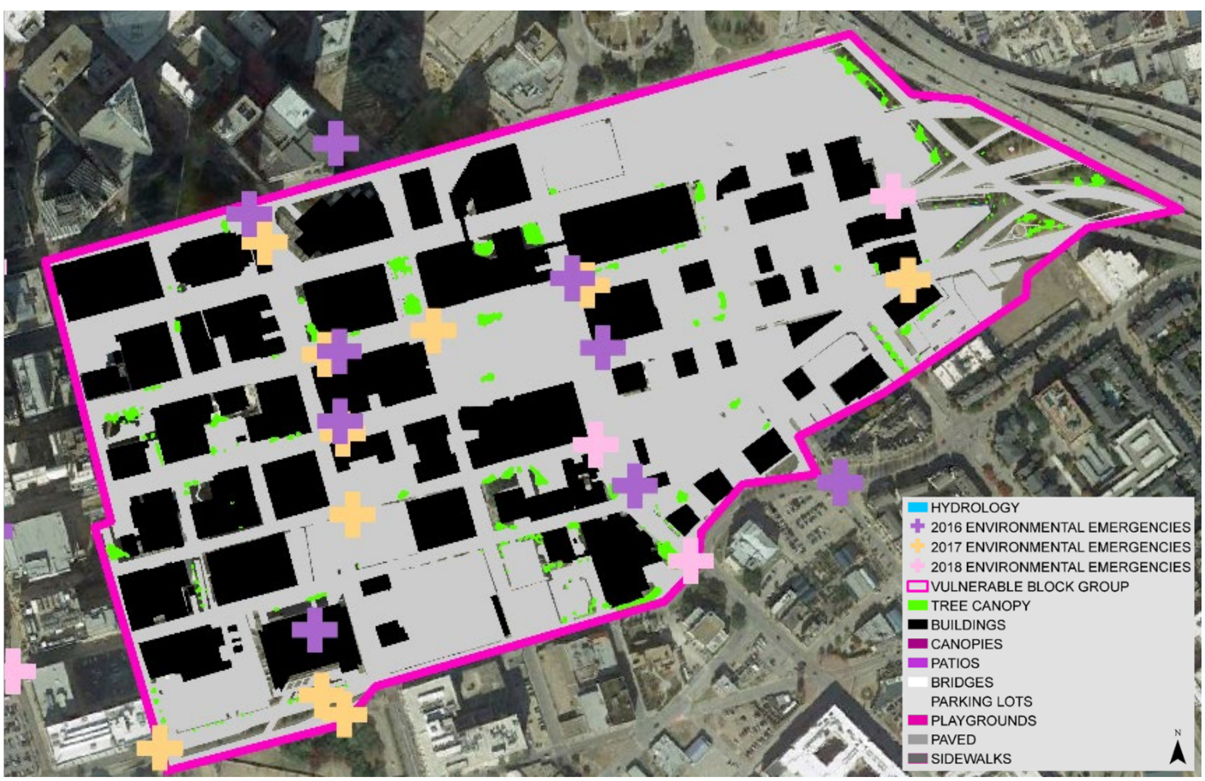


Figure 4.27 Downtown Physical Morphology

Figure 4.28 Old East Dallas Physical Morphology

Old East Dallas has fewer emergency events compared to Downtown (see Figure 4.27). However, many impervious surfaces exist towards the west and northwestern portions of the block group, which can raise surface temperatures, especially during the summer.

Vickery Meadow environmental morphology shows a vast area of impervious surface with very little tree canopy towards the eastern side of the block group. This area has EE's that occur along the major corridors which may suggest that there is a high heat present caused by exposed impervious surfaces in the summer that may affect pedestrians (see Figure 4.28).

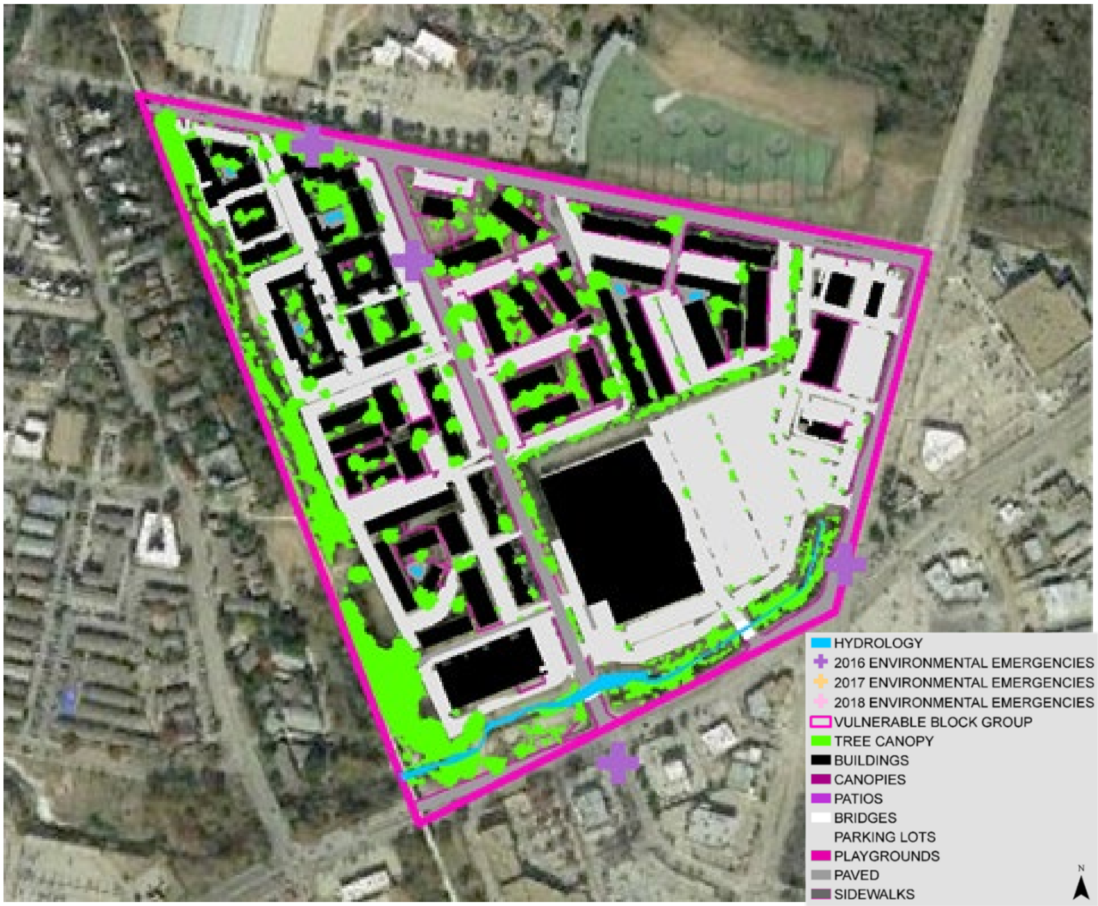


Figure 4.29 Vickery Meadow Physical Morphology

Based on a closer look showing the physical morphology maps above, square footage, tree canopy, structures and impervious surfaces were calculated in order to gain an idea of the extent of the plantable area that exist ((see Figure 4.29). The largest area,

SITE	BLOCK GROUPS AREA	BLOCK GROUPS AREA %	TREE CANOPY AREA %	STRUCTURES AREA %	IMPERVIOUS %	COMBINED T+S+I %	IMPERVIOUS + BUILDINGS %	EXPOSED AREA %	PLANTABLE/ PLANTED %
OLD EAST DALLAS	1,678,492	17%	17%	17%	43%	77%	60%	23%	40%
VICKERY MEADOWS	3,113,245	31%	15%	23%	44%	83%	67%	17%	33%
DOWNTOWN	5,118,753	52%	2%	32%	60%	94%	92%	6%	8%
TOTAL	9,910,491 SQ FT	**100%**	**9%**	**27%**	**52%**	**88%**	**79%**	**12%**	**21%**

Figure 4.30 Site percentages, Old East Dallas & Vickery Meadow

Downtown has the least amount of tree canopy at 2% and only 8% plantable area. Old East Dallas and Vickery Meadow had a higher area available for planting yet low tree canopy area of 17%. The percentage is higher than the average tree canopy in Dallas neighborhoods, typically 8-10%. However, this area has a higher vulnerability index in combination with a higher occurrence density compared to other block groups in addition to the high index of other environmental factors that influence microclimates.

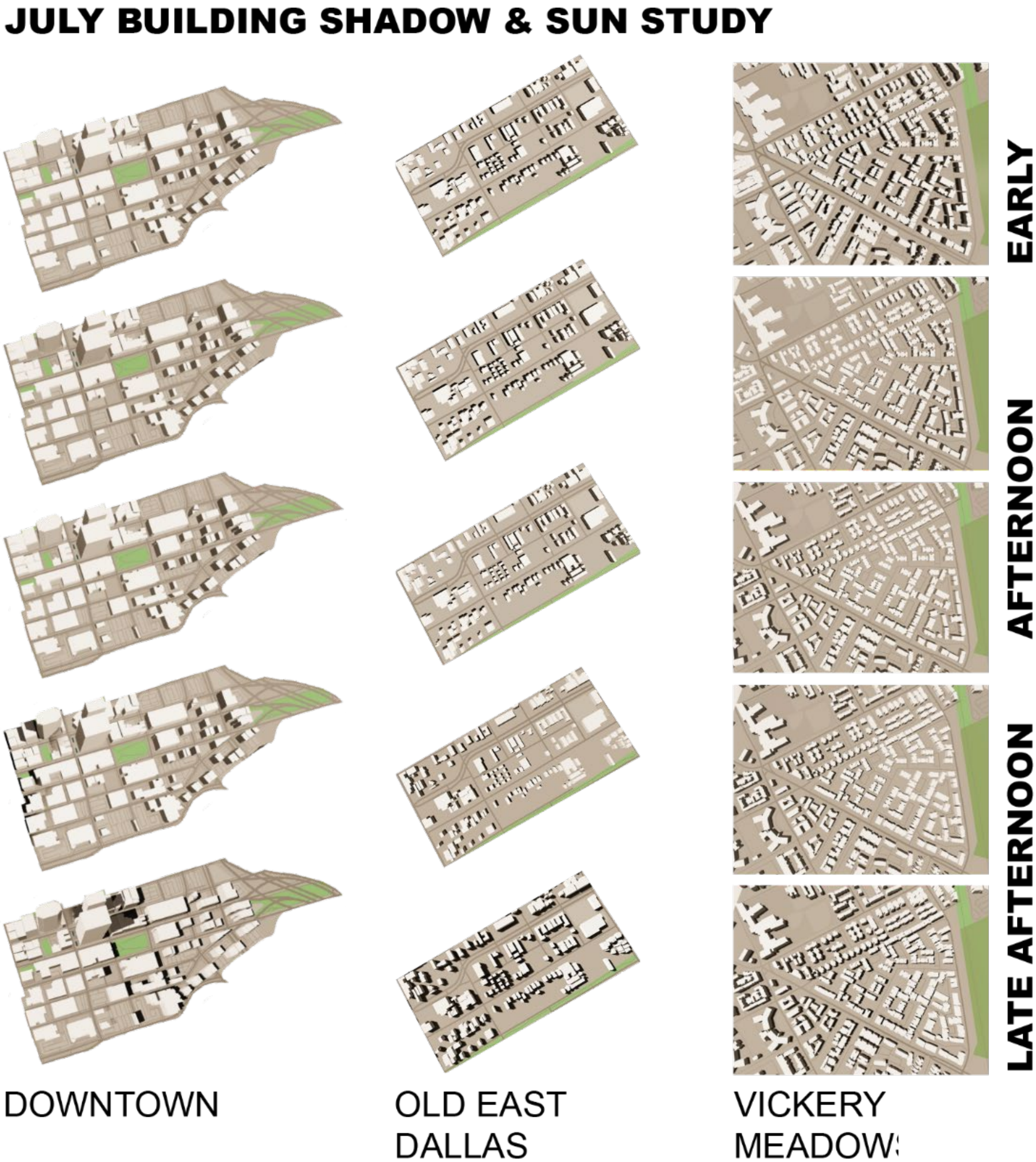


Figure 4.31 Shade Study of Focus Areas

A shade study was analyzed in order to understand the effect of building height and shade throughout the day among the focus areas. (see Figure 4.30). This process provides an understanding of where areas are exposed to solar radiation at the hottest parts of the day such as the afternoon to late evening. An analysis of the reported times of EE's on average was p.m. Therefore, sun exposure during this time and beforehand should be taken into consideration.

The study of wind patterns during the warmest times of the year and the most prevalent months of environmental emergency calls were studied to find the direction of the prevailing winds. The months vary as to the direction of the prevailing winds (see Figure 4.31)

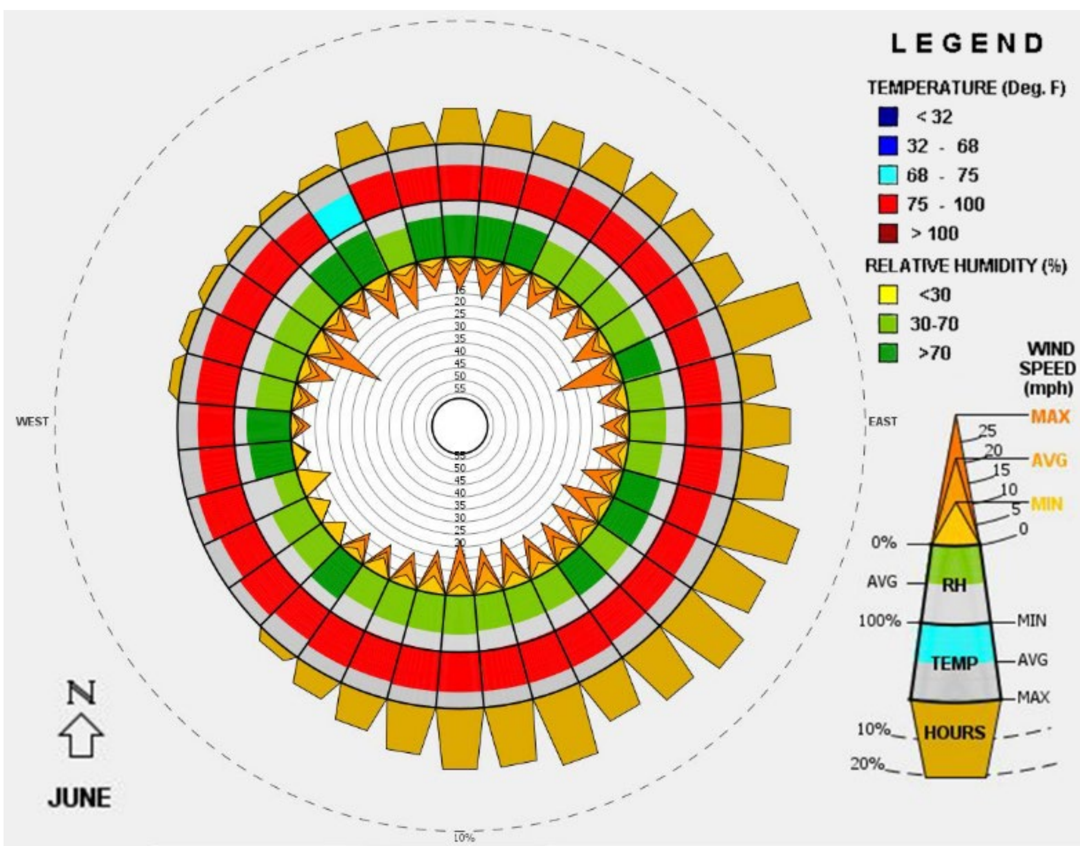


Figure 4.32 Wind Rose for June (Dallas Love Field Airport)

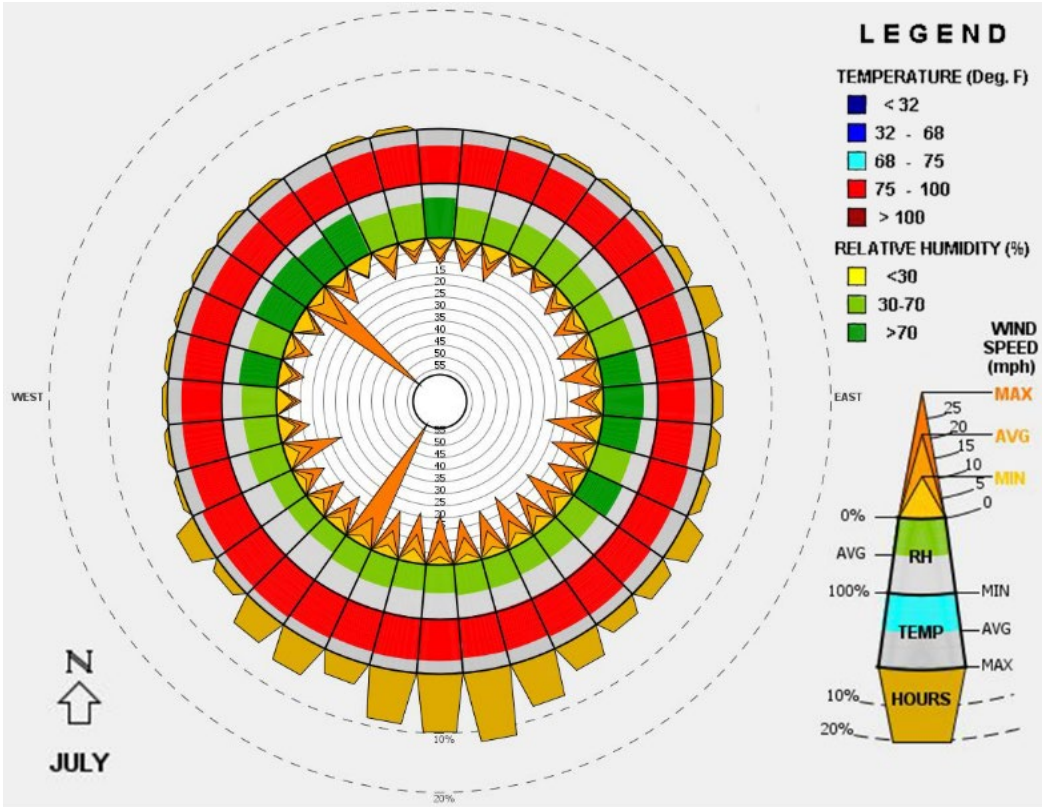


Figure 4.33 Wind Rose for July (Dallas Love Field Airport)

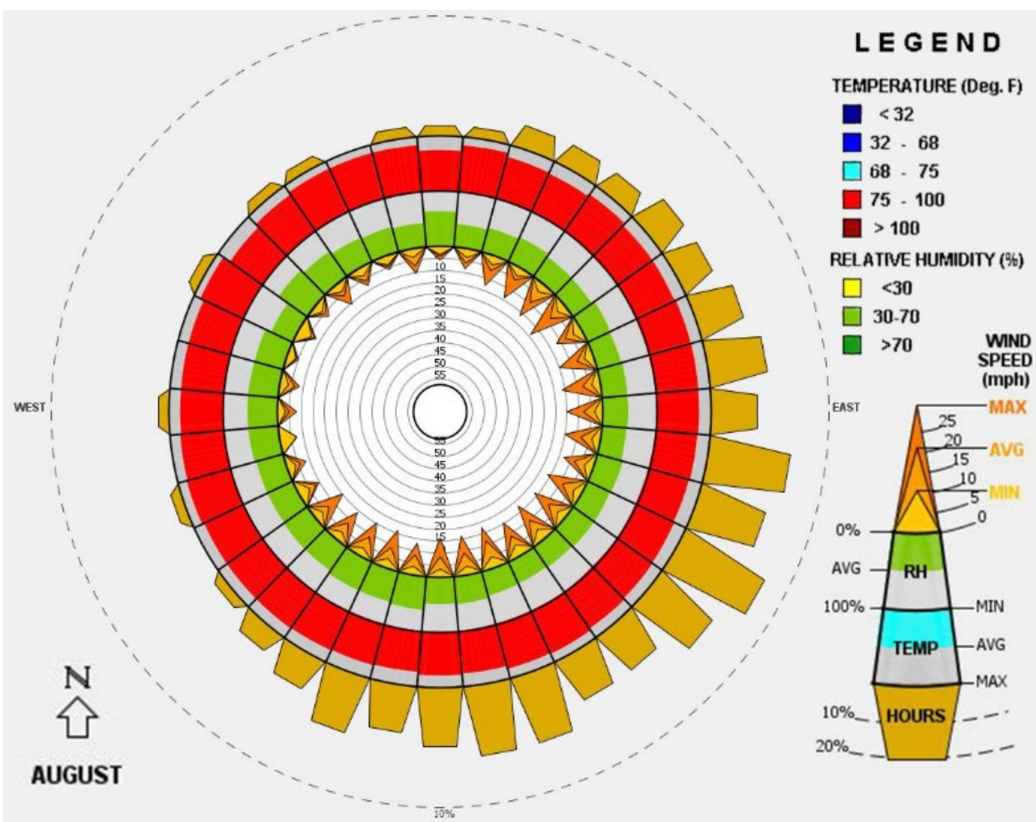


Figure 4.34 Wind Rose for August (Dallas Love Field Airport)

The prevailing winds shift throughout the course of the three summer months, which show predominantly warm, humid winds from the northeastern to the southeastern direction in June. In July, the wind originates mostly from the south. This month also exhibits maximum wind speeds for long periods and relative humidity between 30 to more than 70%. August prevailing wind some in short gusts and originate predominantly for the southeast. The study of the wind roses will help to decide which areas; water features of vegetation that can cool the air via evapotranspiration should be strategically placed.

Surface temperatures studied on a closer level can reveal which areas of the block groups become the warmest and therefore require cooling strategies such as shade from structures or trees to reduce solar radiation exposure.

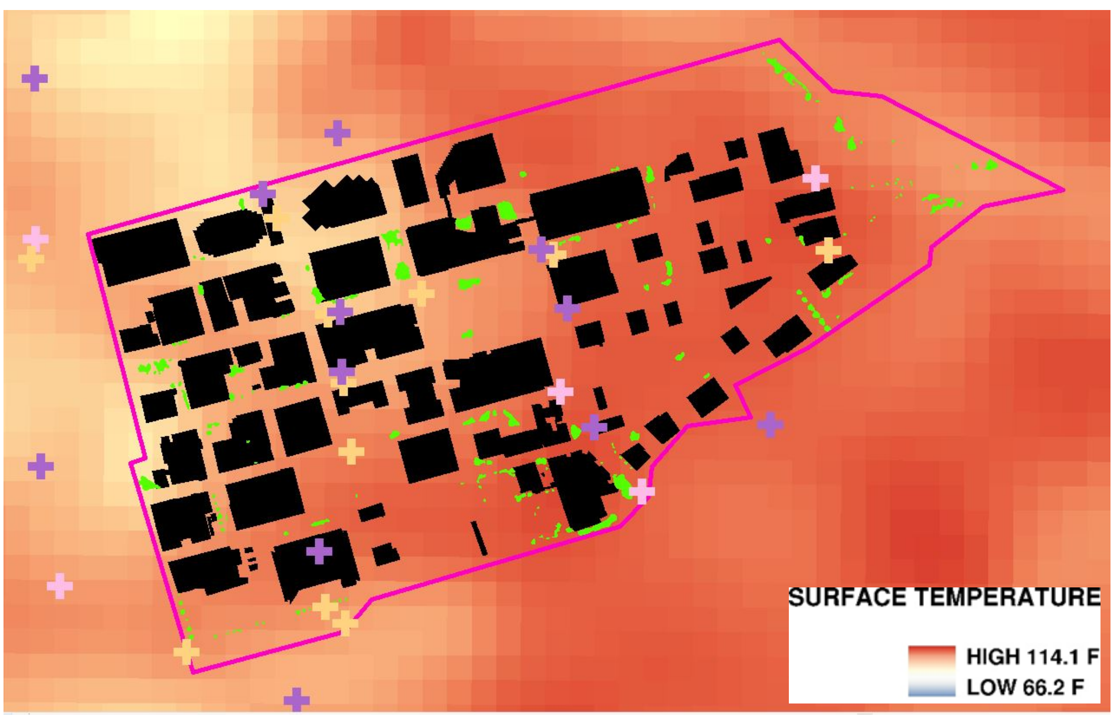


Figure 4.35 Surface Temperatures on July 22, 2017, Downtown

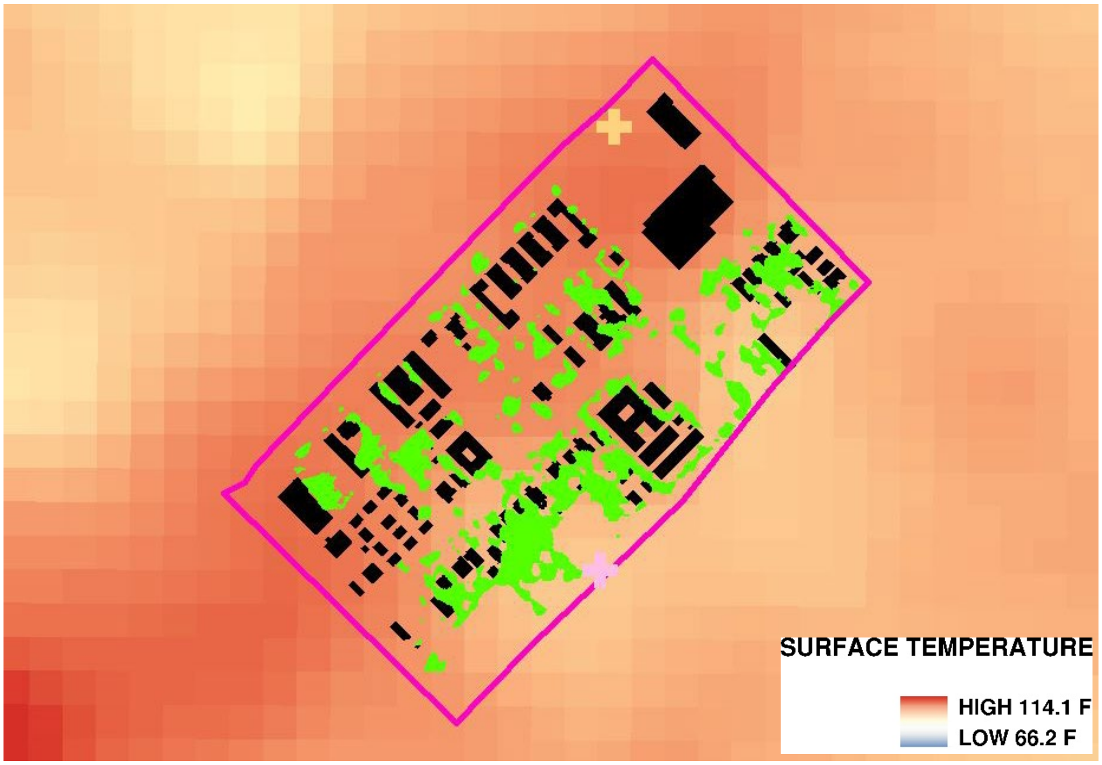


Figure 4.36 Surface Temperatures on July 22, 2017, Old East Dallas

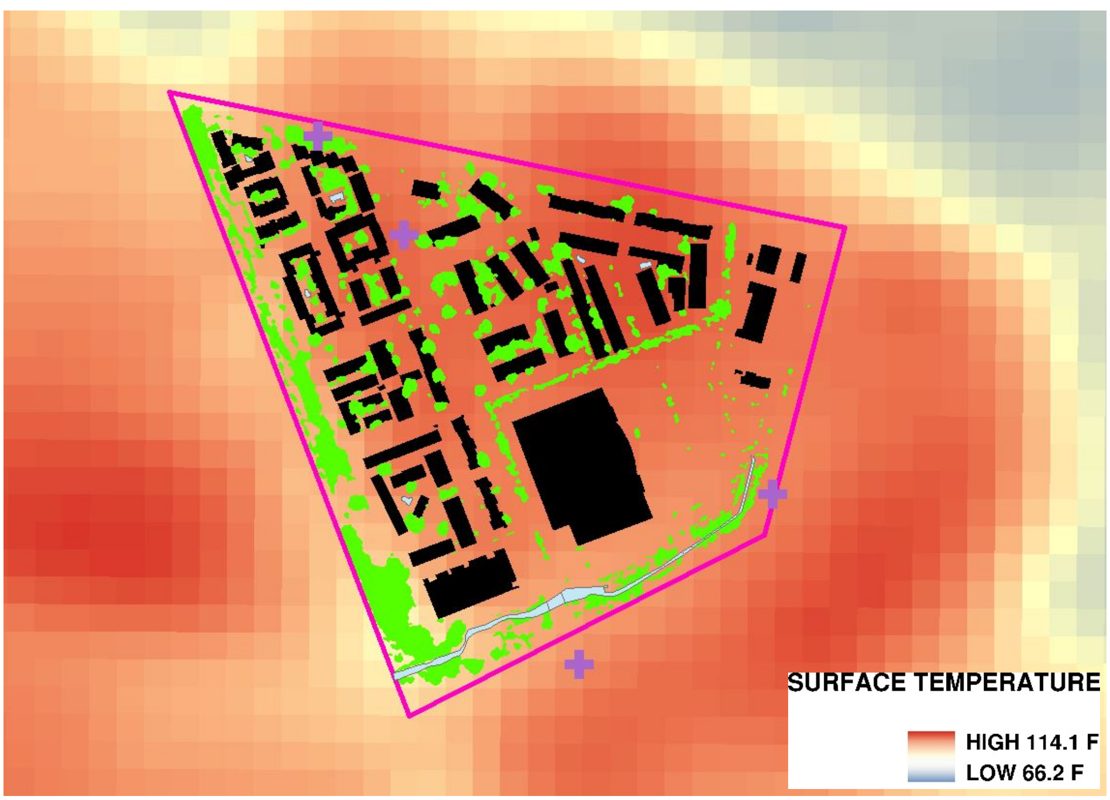


Figure 4.37 Surface Temperatures on July 22, 2017, Vickery Meadow

The surface temperatures reveal areas with tree canopy or building shade downtown have lower surface temperatures than exposed impervious surfaces (see Figures 4.34, Figure 4.35, and Figure 4.36). These areas should be of the highest priority when attempting to reduce the microclimate of the block group focus areas. EE's appear to occur in the area of high and lowered surface temperature. However, this assumption is based on surface temperatures from July 22, 2017, when the maximum temperature of 104°F, compared to 2016 and 2018, which were 100°F and 114°F, respectively. Surface temperatures are often higher than air temperatures because of sustained radiation absorption based on surface qualities.

4.4.2 AREAS OF FOCUS SUMMARY

Step (4) of the BRACE model involves developing and implementing a climate, health, and adaptation plan. The step can be illustrated with bioclimatic design tools LA's use daily in the landscape. A more in-depth look into the neighborhoods at a smaller scale provided feedback in order to implement the proper design interventions.

In Downtown Dallas, the area consists of a majority of commercial and institutional uses with a large area designated for parking. The EE's were mapped in order to see the relationship to tree canopy, impervious surfaces, and buildings. Old East Dallas has fewer emergency events compared to Downtown, but many impervious surfaces exist towards the west and northwestern portions of the block group, which can raise surface temperatures, especially during the summer. Vickery Meadow environmental morphology shows a vast area of impervious surface with very little tree canopy towards the eastern side of the block group. The largest area, Downtown had the least amount of tree canopy while the other two block groups had a more significant surface area for tree planting or other microclimatic cooling strategies, such as pools and water features.

A shade study was analyzed in order to understand the effect of building height and shade throughout the day among the focus areas. An analysis of the reported times of EE's on average was p.m. Therefore, sun exposure during this time and beforehand should be taken into consideration.

The study of wind patterns during the warmest times of the year and the most prevalent months of environmental emergency calls were studied to find the direction of the prevailing winds in order to find critical areas for intervention.

The surface temperatures revealed areas with tree canopy or building shade downtown have lower surface temperatures than exposed impervious surfaces. These areas should be of the highest priority when attempting to reduce the microclimate of the block group focus areas. Surface temperatures are often higher than air temperatures because of sustained radiation absorption based on surface qualities.

A closer inventory and analysis is vital to strategic and practical approaches to cooling microclimates in areas where social health determinants and environmental emergencies occur.

4.5 BIOCLIMATIC DESIGN APPROACH & CONCEPT

After analyzing the three focus areas, based on their proximity to fire stations, as well as their environmental, health, physical morphology, and demographics, based on exhibiting characteristics, different approaches to cooling bioclimatic design strategies were selected. Overall, many of the goals remained the same. A chart outlining the literature review organizes these goals and approaches to cooling microclimate strategies (see Figure 4.37).

COOLING STRATEGIES FROM THE LITERATURE REVIEW

DESIGN INTERVENTION	PRIORITY AREAS	VEGETATION	TREES	SUN ORIENTATION	VENTILATION & HUMIDITY	PAVING & LANDSCAPE STRUCTURES	BUILDINGS
GOALS	*REDUCE HEAT IN AREAS WHERE HUMANS ARE EXPOSED*	*LESSEN RADIANT HEAT & IRRIGATION NEEDS*	*REDUCE SOLAR RADIATION*	*REDUCE SURFACE TEMPERATURE*	*INCREASE WIND CIRCULATION TO WISP PERSPIRATION*	*REDUCE TERRESTRIAL RADIATION*	*REDUCE ABSORBED RADIATION*
	HIGH ACTIVITY AREAS	PLANTS TO SHADE WALLS TO LESSEN RADIANT HEAT	DROUGHT TOLERANT OR INDIGENOUS SPECIES	IMPLEMENT TREES ON STREETS WITH S & W FACING EXPOSURE	LOW ENERGY FANS	REPLACE DARK PAVEMENT WITH LIGHT COLOR, USED LIGHT COLORED STONES	SHADE SAILS AND OVERHANGS
	PEDESTRIAN PATHS STREETS & PARKING LOTS	PLANTS WITH LOW WATER NEED	CONCENTRATE ON TREES WITH HIGH LEAF AREA INDEX OR TREES WITH DENSE & BROAD CANOPY STRUCTURE	REALIGNMENT OF ROWS OF PARKING FOR TO BE PLANTED IN AN E TO W ORIENTATION	PLANT TREES IN WIND PATHS	AVOID DARK COLORED SHADE STRUCTURES	REFLECTIVE ROOFING MATERIAL
	PUBLIC SPACES	COMBO OF TURF & TREES FOR MAXIMUM COOLING & DECREASED IRRIGATION	STRUCTURAL SOIL FOR TREES IN DENSE AREAS TO MAXIMIZE GROWTH	IMPLEMENT TREES WITH SUN EXPOSURE AT 12PM AND THEREAFTER	LIMB UP EXISTING TREES TO INCREASE CIRCULATION	70% OPACITY FOR SHADE MESH	WHITE ROOF OR GREEN ROOF

Figure 4.38 Cooling Strategies Chart

General goals for cooling strategies:

- Reduce heat in areas with where humans are exposed, in public areas or areas of high activity
- Lessen radiant heat & irrigation needs with the use of vegetation
- Reduce solar radiation with the use of shade trees
- Reduce the surface temperature of sun exposure
- Increase wind circulation to aid in cooling
- Reduce absorbed radiation from buildings with the use of vegetation, green, white & reflective roofing

Specific Cooling Strategies derived from the Literature Review and citations:

- In order to bioclimatically design parks that will have the most significant cooling effect on people during hot summertime weather, a landscape architect needs to know the relative impact of various bioclimatic design interventions (e.g., Brown, 2011).
- There are thus many ways to influence the cooling of cities and all people, who 'shape' the cities, be they architects, urban planners, public designers or landscape architects. They need to bear in mind that careful, evidence-based microclimate bioclimatic design (Brown and Corry, 2011) can mitigate the dangerous effects of heat waves, providing environments that are not only safe but are also thermally comfortable (Brown et al., 2015).
- Vegetative characteristics, Sun Angle Exposure, Ground surface type, temperature, and humidity can influence year-round type and amount of physical activity (Ciucci et al., 2011; Vanos, 2015).

- Urban planners and designers should focus on developing ‘shaded green space’ in urban parks, not simply ‘green space’ (Vanos et al., 2012).
- Many cities and coalitions of cities, supported by national and international organizations, such as the US Environmental Protection Agency and the International Council for Local Environmental Initiatives, have initiated programs for heat island mitigation using three key strategies:
- Increasing vegetation cover in public spaces
- Adopting standards for reflective roofing and paving materials
- Lowering anthropogenic emissions

Trees &Vegetation

Increasing vegetation cover in public spaces, portable vegetative platforms using plant materials to shade walls can lessen radiant heat, as well as, using plant materials or shade structures can reduce solar radiation. Treed parks also result in cooling from evapotranspiration with moisture available, which also increases the relative humidity.

- Trees that possess the qualities of having a dense, broad canopy structure (Sanusi et al., 2017).
- The combination of shade trees and grass is found to be the most effective combination to reduce the thermal stress of a human in hot climates (Shashua-Bar, Pearlmutter & Erell, 2011).
- Tree plantings are used to fight desertification, so we can expect that they will also work in urban environments (Pasternak & Schlissel, 2001).
- In the parks of other cities, the species should also fit the local climate, and indigenous species should be used to provide other ecosystem services (Boone-Heinonen et al., 2010; Spronken-Smith & Oke, 1998).

- Concentrating species with high leaf area index (and thus shading potential) in urban parks can significantly improve the thermal comfort experienced during warm, summertime conditions (de Abreu-Harbich, Chaves & Brandstetter, 2018).
- Places that were less densely settled with some open space and more abundant vegetation were environments that are more comfortable in the summertime (Harlan et al., 2006).

Sun Orientation

- Consideration of sun angle during programmed features on a landscape reduces solar radiation. There are ample avenues to take when modifying a microclimate based on the season for increased activity, where factors such as sun orientation.
- Other landscape objects (oriented to maximize shade at the hottest time of the day) are examples that also reduce overall shortwave radiation, and hence surface temperature (Santamouris, 2013; Vanos 2015).
- Implementing deciduous trees, especially on pedestrian paths with south and west facing exposure (Graham et al., 2017)
- Hardscape (streets & parking lots) or building facing south and west exposure (Graham et al., 2017)
- Realignment of rows of parking to allow trees to be planted in an east-west orientation (Graham et al., 2017)

Ventilation & Humidity

- With considerations to wind circulation and ventilation, in urban areas, with low green space, it is recommended to plant the trees in the wind paths to enhance the cooling effects.

•Using low energy, mechanical ways to cool outdoor environments and pruning lower tree branches to allow more wind to flow through an outdoor space also helps to cool a space (Brown, 2010).

• Increasing wind circulation to cool landscapes in the summer is the ultimate goal.

• In regions that are more humid the presence of a strong wind often dominates over the effect of high humidity, which results in heat loss via evaporative cooling and a lower energy budget (Brown et al., 2015).

• Natural ventilation and passive cooling could reduce the use of mechanical systems (Schiano-Phan, Weber, & Santamouris, 2015).

Buildings & Structures

• Adopting standards for, overhangs, pavilions, replacement of roofing materials with green roofs, white roofs, or reflective roofing can reduce air conditioning & terrestrial radiation.

• Shade sails increased school students' use of the newly shaded areas; shaded spaces result in non-direct radiation, which is safer for outdoor use/activity for more extended periods (Vanos 2015).

Paving & Landscape Structures

• Albedo considerations, such as avoiding the use of dark pavement to reduce terrestrial radiation (Brown, 2010)

• Replacement of existing dark-colored asphalt pavements with light-colored concrete pavements, using light colored stones or avoiding dark furniture or shade structures are imperative (Brown, 2010).

The remaining step before applying cooling strategies is to consider how people in these block groups interact with their environment by taking a final inventory of areas where activities are focused such as parks, pedestrian pathways, trails, and bike routes. Additionally, the identification of public transportation stops can show where people may spend more time exposed to solar radiation. With consideration of these factors, the areas differed significantly in terms of their typologies; the following (see Figure 4.38, Figure 4.39) were examined:

FOCUS NEIGHBORHOOD ATTRIBUTES

KEY: ● high; • med-high; ◒ medium; ○ low

	Surface Temperature	Building Density	Lack of Tree Canopy	Impervious Surfaces	Environmental Emergencies 2018	Environmental Emergencies 2017	Environmental Emergencies 2016	Travel to Work w/o a Car	Women of Childbearing Age	Education Below HS Diploma	Minorities	Age over 64 yrs. Living Alone	Under 14 & Over 64 yrs.	Population Density	Parks	Asphalt	Pedestrian Walkways	Bustops	Rail Stations	Bike Routes	Trails
Downtown	●	●	●	●	•	●	●	•	◒	○	○	◒	○	●	●	○	●	●	•	●	◒
Old East Dallas	•	•	•	●	●	•	●	•	•	•	•	•	•	•	○	○	•	●	○	○	◒
Vickery Meadow	●	•	●	●	○	○	●	•	◒	◒	◒	●	•	●	○	○	•	●	○	○	●

Figure 4.39 Focus Neighborhood Vulnerability Attributes

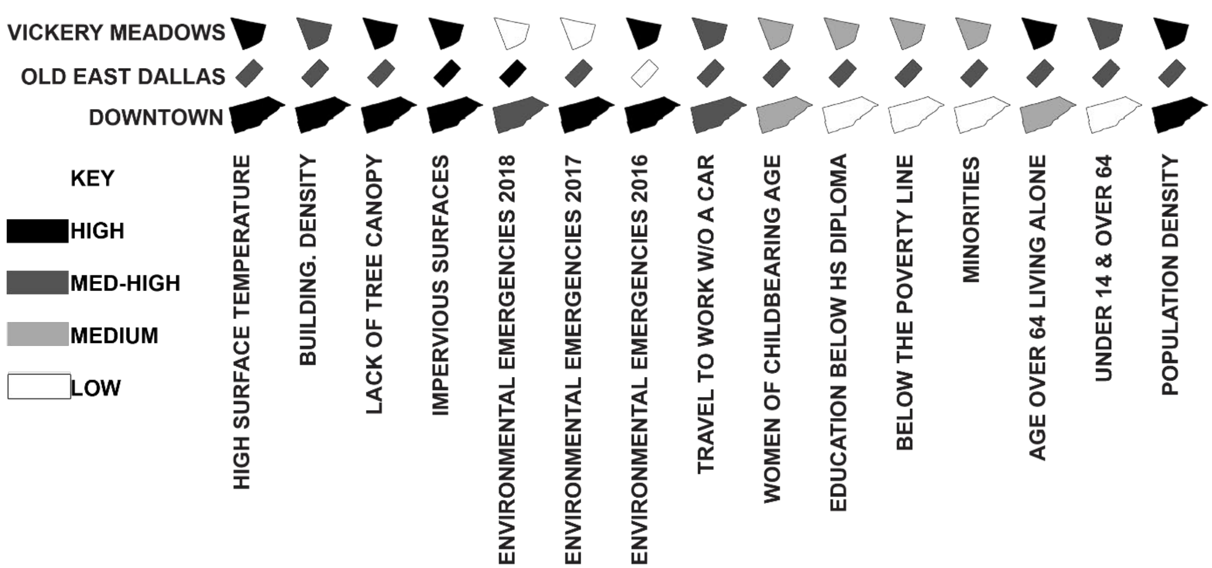


Figure 4.40 Focus Block Group Weighted Analysis Vulnerability Attributes

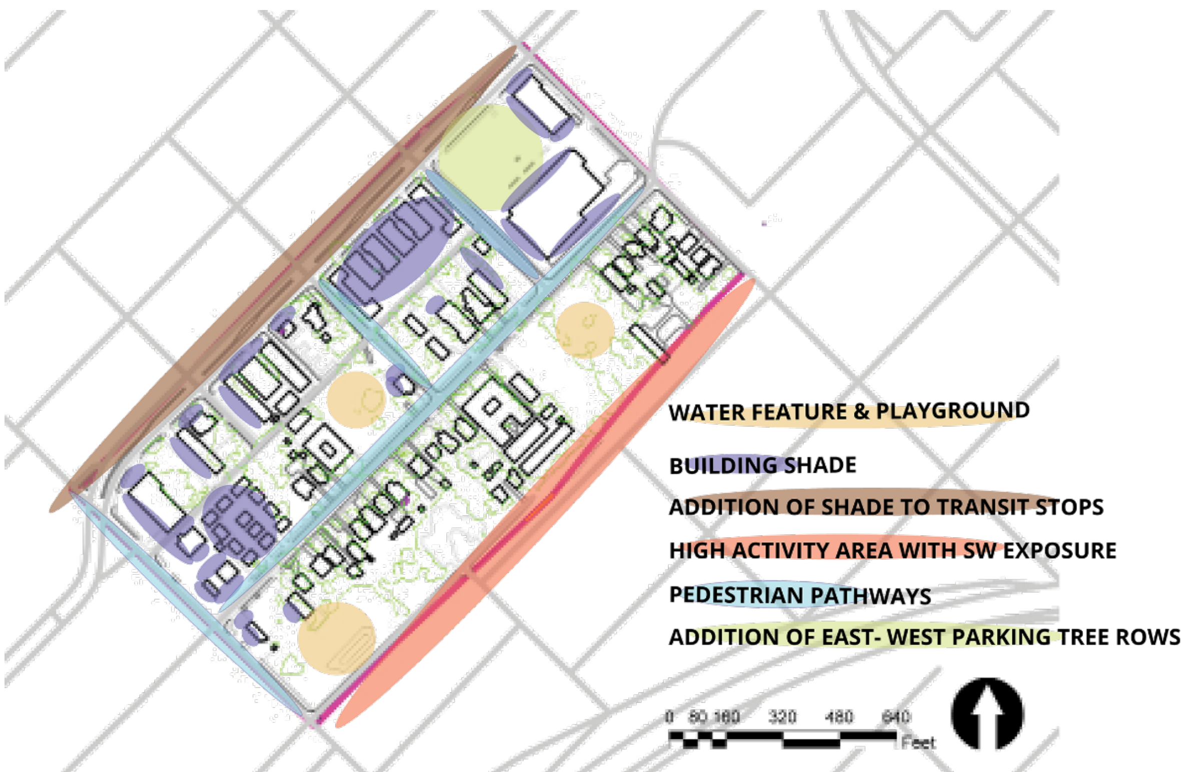
4.5.1. DESIGN CONSIDERATIONS FOR DOWNTOWN DALLAS

Downtown, a dense urban area, exhibited very little plantable space and the lowest tree canopy coverage of 2%. The large area of parking space benefitted from the realignment of parking rows with trees running east to west (see Figure 4.40). New shade structures with dense vine cover will give more shading opportunities in areas that will not support large shade trees and near the many transit stops. With consideration of the many bike routes downtown, the shaded intersection would benefit these populations, as well as pedestrians, as they wait to cross the intersections. Due to the high percentage of buildings, green walls can be implemented to reduce radiant heat. These changes are imperative as this area possess the most substantial amount of emergency calls (19 EE'S) among the other two block groups,

Figure 4.41 Site Specific Diagram of Downtown

4.5.2 DESIGN CONSIDERATIONS FOR OLD EAST DALLAS

Old East Dallas' areas have medium density multifamily housing with a large plantable area and but has a lower tree canopy percentage of 17%. There is the largest population of people based on the social-demographic vulnerabilities assessed. This area also has many who travel to work by other means than by car. Several bus stops run along the north side of the block group. Trees that can provide shade at the transit stops would be ideal. The area also has a higher density due to the many apartment structures. According to parcel group data, some of the homes do not possess central air conditioning, which makes trees along the south, southwest, west and northwest sides of buildings imperative (see Figure 4.41). There are also many children under 14 years, which makes shaded playground areas a priority. This area has had two EE's in 2017 and



2018.

Figure 4.42 Site Specific Diagram of Old East Dallas

4.5.3 DESIGN CONSIDERATIONS FOR VICKERY MEADOW

Vickery Meadow is also highly dense with a high older population living alone, as well as a sizeable vulnerable age population. The plantable area is smaller and has more structures in the area compared to Old East Dallas. Due to the high building density in this area, vegetation on south and west facing walls can limit the solar radiation absorbed and radiated. The effect of evapotranspiration of the leaves converts heat into latent heat through evaporation by preventing the absorption of short-wave radiation through shading (Bielaz Sclar, 2013; Kleerekoper et al., 2012). This area has several bus stops located throughout centrally. There is the highest area of trails on the west side of the site that can benefit from trees and shade structures due to the likelihood of physical activity in this area (see Figure 4.42). In addition, there is a vast expanse of parking lots in a commercial area. Parking lots could benefit from trees located in an east to west where an environmental emergency has occurred. Several pedestrian pathways could benefit from trees exhibit a large canopy structure. This area could benefit from a shady communal

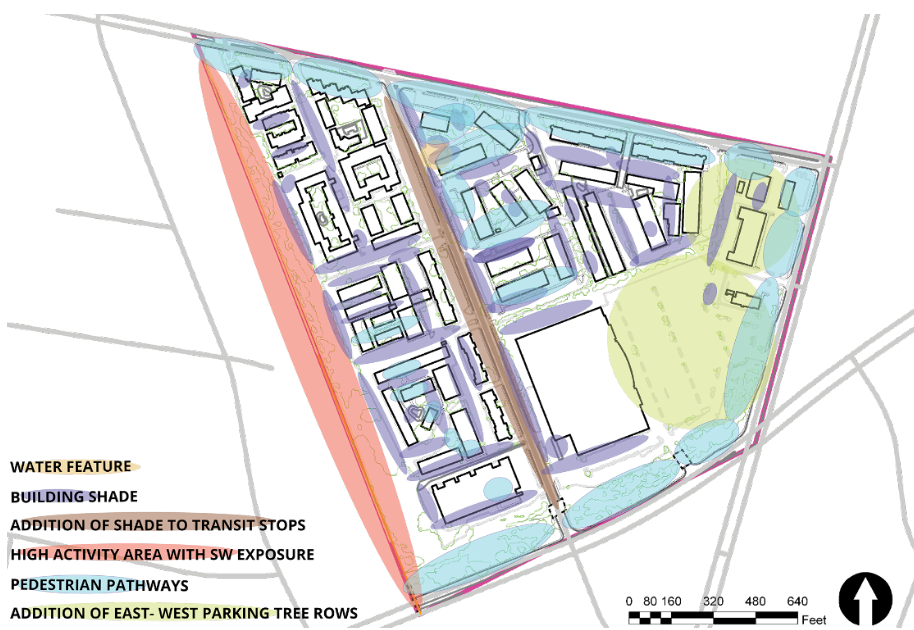


Figure 4.43 Site Specific Diagram of Vickery Meadow

space with perhaps a water feature to help connect people in the neighborhood.

4.6 FOCUS AREA BIOCLIMATIC DESIGN

The culmination of the extensive focused analysis pointed to areas of redesign for each block group. The overall goals were to implement shade by route of tree canopy or shade structure in pedestrian pathways, high activity areas, building with high solar radiation exposure, transit stops, and parking lots. Additionally, vegetated walls were implemented solely for Downtown given its lack of plantable space. The incorporation of water features aid in cooling and serve as a connection node for residents and visitors.

4.6.1 DOWNTOWN DALLAS COOLING BIOCLIMATIC DESIGN

The downtown designed consisted of seven large parking lots where surface temperatures were high. These large parking lots have parking rows aligned east to west for cars and the people who drive them some relief. Smaller parking lots were treated with a shade tree planting every seven spaces to create a sense of greenery in the parking lots with the added benefits of shade (see Figure 4.43).

The multitude of bus stops and transit stations were shaded as well as passengers often have to wait outside, which can otherwise potentially be detrimental during the winter months. In addition, trees were added to the perimeters of already existing park infrastructure to heighten the cooling benefits of vegetative evapotranspiration.

In order to have a significant impact on the thermal comfort of the population Downtown, the block group's area of 5,118,753 sq. ft. exhibited only 2% tree canopy cover, the lowest percentage of the three block groups studied. The redesign added and an additional 774 trees which would potentially increase the canopy coverage by 14.9% (with average canopy size of 20 feet in diameter, small for a shade tree perhaps younger shade tree that is capable of providing additional shade as it matures. The majority of these trees were added to the vast parking lot areas on the eastern side of the block group.

Realignment of parking rows east to west and the addition of shade trees would require removal of an existing impervious cover, which currently covers 60% of the block group.

The buildings of downtown Dallas span over 30% of the block group, which in combination with impervious surfaces comes to a 92%, an impervious area almost more extensive than the other two block groups combined. Due to the lack of available surface for planting, it was essential to consider additional vegetation along the south & west sides of buildings (See Figure 4.). Some options such green walls or rows of tall columnar trees in portable vegetative platforms can help mitigate some of the radiant heat absorbed by building structures.

On the southeastern side of Downtown, there was an opportunity to implement an urban forest in a lot, where there is an aging parking lot in poor condition to place trees in the prevailing summer wind paths balance the heat from the nearby highway.

These cooling strategies for Downtown could potentially improve the heat stress of downtown based on a study in Toronto that has shown, that even a marginal increase in the tree canopy cover from <5% to >5% could reduce heat-related ambulance calls by approximately 80% (Graham et al., 2016).

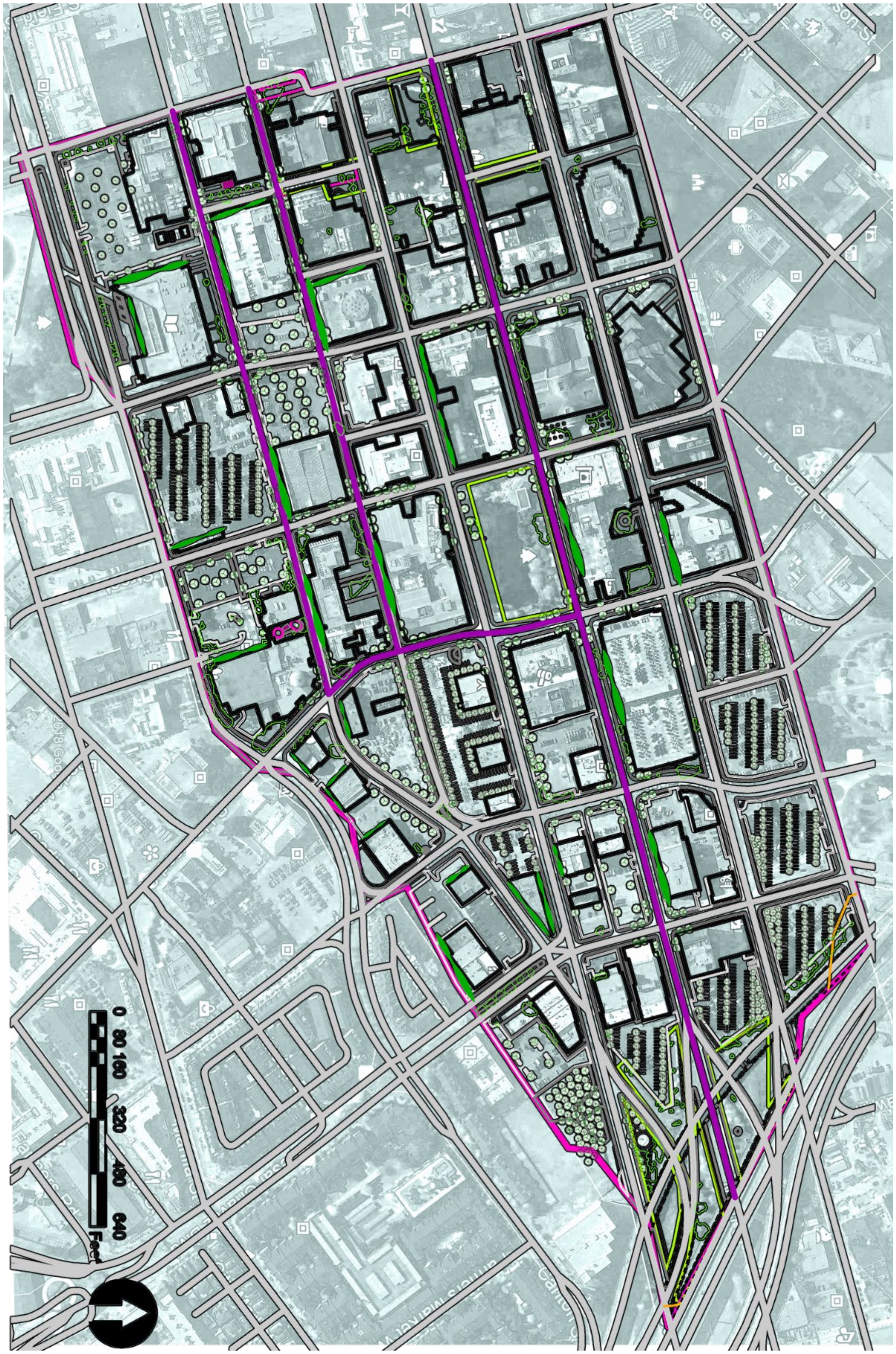


Figure 4.44 Bioclimatic Design of Downtown

4.6.2 OLD EAST DALLAS COOLING BIOCLIMATIC DESIGN

Old East Dallas is an area with consistent high to medium-high vulnerability in terms of every factor considered in the weighted analyses except one exception was in 2016, where EE's were not recorded to occur in this block group. Based on this information, it was essential to think of additional infrastructure, such as; the addition of shaded parks, as well as a community swimming pool, which would be an effective heat mitigation measure, and would increase the health and comfort of residents (see Figure 4.44).

Additionally, it was imperative to incorporate strategic tree plantings along the west facing facades of builds, as some homes based on parcel data lack central air conditioning. The southern portion of this block group features a trail where rows of trees were implemented where the physical activity takes place. This area had a combined impervious area (including building structures) of 60%, and a tree canopy covered 17%. An additional 383 trees were incorporated into the redesign, which raises the potential tree canopy area to 39%, hitting benchmark for tree cover, between 30-40%, which is shown to be effective in cooling the surrounding environment (Texas Trees Found, 2019).

The consideration of social determinants of vulnerability should be considered in urban design to find areas where cooling design strategies can have the most effective and potentially improve the health of people that reside in these areas. Environmental factors and the implementation of infrastructure that can provide cooling destinations or safe outdoor areas where children can play can become a useful tool for mitigating a warming climate.

Figure 4.45 Bioclimatic design of Old East Dallas

4.6.3 VICKERY MEADOW COOLING BIOCLIMATIC DESIGN

Vickery Meadow is about twice the size of Old East Dallas and showed differing demographics possessing predominantly more people over the age of 64 living alone and young children. Additionally, the majority of EE's occurred in 2016 and possessed high environmental factor vulnerability.

This area has a broken tree line along the west side and a trail running due west of it. The cooling strategies provided shade for this area and focused on the realignment of parking rows in a large commercial parking lot towards the east (see figure 4.45). Mitigation of heat by planting in this vast expanse of impervious area will aid in cooling and provide additional evaporative cooling with exposure to warm, humid easterly winds in the summer. Additionally, trees were added to the pedestrian corridor where bus stops exist as this are depends has an increased population who travels to work without the means of a car.

The redesign incorporated 612 trees, increasing the tree canopy by 19.4%, raising the block groups total to 34.4%, and like Old East Dallas has enough plantable area to accommodate this. The addition of a water feature surrounded by trees on the western side can provide an area of heat refuge in one of the few more open and once treeless space that allows residents to connect. Additionally, an allee of trees was added along a previously existing impromptu worn path that connects the neighborhood to the trail.

The addition of shade trees cannot only effectively cool the environment, but also provides potential ecological services by continuing and connecting vegetation from the neighborhood to the adjacent mostly forested area on the eastern side.

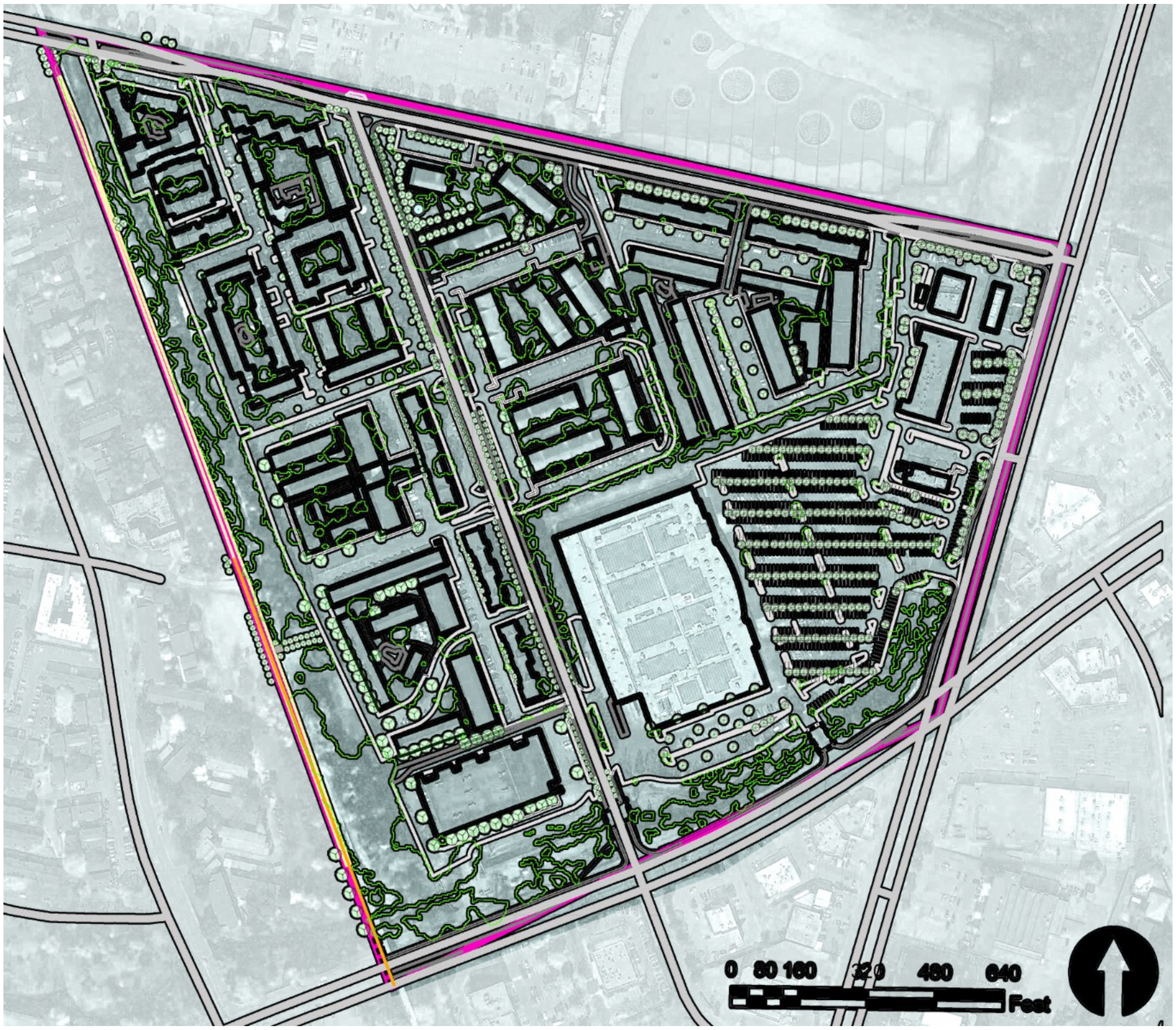


Figure 4.46 Bioclimatic design of Vickery Meadow

4.7 BIOCLIMATIC DESIGN SUMMARY

After the proposed bioclimatic design intervention, an assessment of the vulnerability of the site resulted given the amount of area, possibly influenced by the use of capable landscape architecture design interventions. In order to bioclimatically design areas that will have the most significant cooling effect on people during hot summertime weather, a landscape architect must know the relative impact of various design interventions (e.g., Brown, 2011).

CHAPTER 5 CONCLUSION

5.1 INTRODUCTION

Relevance to climate change adaptation in Dallas, Texas was the primary goal of this study. Use of the BRACE model has offered a clarification of existing constraints to resilient climate design. This data was mapped to give practitioners the ability to identify and assess heat stress vulnerability to prevent Environmental Emergencies (EE's) in vulnerable block groups by implementing lacking landscape features such as tree canopy, vegetation, portable vegetative platforms, shade structures, or other means of cooling the urban landscape. The BRACE model has provided the framework for the assessment, projection, analysis, and evaluation of microclimates in urban areas. This helps practitioners and researchers to understand climates effects on human health, by employing a systematic, evidence-based process to customize a response to local circumstances. With this framework with the aid of GIS mapping techniques to examine 962 block groups, 21 vulnerable areas were identified, which included a thorough analysis of three focus areas of Dallas, where bioclimatic interventions were suggested that could be implemented to affect the health of Dallas residents significantly.

Research topics of how heat and city morphology relate to health provide essential information about the complicated relationship between the urban landscape, ambient temperature, and human health, all of which should take consideration within the context of public design conversations. This potential benefit provided LA's go along with the paramount concern of practice, which is the focus on the health, safety, and welfare of the public illustrates the value of evidence-based research. Relationships between variables used a descriptive GIS mapping model and a weighted analysis to generate new knowledge of the locations and characteristics thereof, which affect human heat stress in the city of Dallas.

5.2 RESEARCH QUESTIONS REVISITED

1. How can landscape architects apply the BRACE Model in the site inventory process?

Landscape Architects can use the BRACE model to analyze and evaluate areas for site selection. The parameters are flexible and can be adjusted to find different outcomes depending on the goal of the site analysis. This study is an example of how health, environmental and social factors can be overlaid to determine crucial areas for site interventions. The avenues for exploration are far-reaching. Landscape Architects can work with municipal GIS services in order to source and evaluate information.

2. What conclusions can be drawn from the use of the BRACE Model in a Study of Dallas?

Dallas is a large area to study, and the BRACE Model helps to pinpoint areas of relevance. The availability of data for the city of Dallas was critical in providing a thorough analysis of many factors. The use of environmental emergency call data was one way to evaluate health indicators in this study; however, other health information is available, that can measure the impact on heat stress in Dallas. By working with local organizations, a more detailed tree canopy data was used compared to USGS land cover data set. Additionally, the role of the city of Dallas Fire and Rescue GIS Analysts was critical in locating the data for environmental emergencies. It is essential to work with local organizations in order to find the most relevant data. It is also crucial to use GIS to perform a weighted overlay analysis to determine the importance of deferent parameters of focus. It is also important to source primary data in the event that local organizations can aid in the analysis process. Primary data is ideal to capture the most relevant spatial and temporal data as conditions of environmental morphology and localities of where people are, the types of people who exists in areas varies over time.

3. What is the prevalence of vulnerable block groups where microclimates are warmer than the surrounding area in Dallas, Texas?

Twenty-one highly vulnerable block group areas in Dallas were identified based on the weighted overlay analysis. This research shows some parallels between the EE's and Urban Morphology, which occur in most areas that have the qualities of raised surface temperatures, increased impervious surfaces, and lack of tree canopy. However, it is vital that interventions are made in areas that consist of vulnerable populations in order to affect the health positively in those areas in an attempt to mitigate the effects of climate change and accommodation of expected population growth or population density.

4. How do microclimates affect the occurrence of environmental emergency calls occurring in Dallas, Texas?

The study has found the highest density of environmental emergencies in the urban core where the physical morphology exhibits the most significant amount of impervious surfaces and lack of tree canopy. Microclimates are seldom considered. The common universal measurement of air temperature is not a reliable measure of a microclimate on human comfort because factors such as radiant heat have a larger impact on heat stress. Many factors such as surface temperatures, shade, wind patterns, and tree canopy, among others, must be taken into consideration in order to gain a more informed view on the microclimate state of specific areas where people live, work, and play.

5. What is the relevance to lack of tree coverage and surface temperatures among other analysis factors in the study Dallas?

The focus area studied in downtown exhibited the lowest tree canopy of 2% and high surface temperatures due to the existing combined impervious surfaces of 92% and subsequently had the highest incidences of EE's compared to the other two focus areas. All three focus areas exhibited a lowered surface temperature proximity to tree coverage.

6. What types of populations reside in areas with a high occurrence of environmental emergency calls?

The population of the focus areas examined had a variety of demographic factors. The Downtown community had a higher population of educated, higher income, older, non- minority and less young children but had the highest amount of EE's. Nonetheless, this area had other social determinants of vulnerability such as a high population of people traveling to work without the means of a car and a high population of women of childbearing age. The other two focus areas had high to medium-high occurrences of lower income, less educational achievement, minorities, old and young populations. The similarities of the three focus areas where some of the highest occurrences of environment and urban morphological contributors to warmer microclimates, such as more impervious surfaces, building density, lack of tree canopy and high surface temperatures. All areas had a high population density, a population that used other means of travel than a car to work and had women of childbearing age.

5.3 SUMMARY FINDINGS

Significant patterns were found which indicated vulnerable areas where opportunities for site interventions were the highest. The BRACE model and research design offered insight on how the analyze a multitude of factors in the process of site selection in order to aim towards specific health and climate related goals. Careful consideration of landscape elements can create cooling microclimates that ultimately can benefit the health of the vulnerable regions, and this is ultimately the goal of the final step of the BRACE model. Environmental, health and demographic considerations are imperative to the bioclimatic design of our urban areas and landscapes. From the analysis and bioclimatic design, ideally, the benchmark for creating a cooling microclimate on a neighborhood scale requires 30-40% tree canopy coverage (Texas Trees Foundation, 2019). Two out of the three block groups examined have the potential for this type of cooling intervention. However, downtown Dallas exhibits the lowest tree canopy coverage and less area for trees to be planted into the ground without removing some of the existing impervious surfaces. Heat-related emergency calls in Toronto were negatively correlated to tree canopy cover and positively related to hardscape cover. The Toronto study suggests that even a marginal increase in the existing tree canopy of more than 5% could reduce heat-related ambulance calls by approximately 80%. Efforts to redesign with Downtown Dallas could aim for this goal as a starting point. One solution would be to implement rows of trees with structural soil in parking lots that would allow trees to reach their full canopy size. Additional avenues would be to implement vegetation such as vines and tall columnar tree forms in large portable vegetative platforms to cover exposed surfaces of buildings. This critical in order to trap less radiant heat exacerbated by the urban heat island effect, where tall buildings trap and store much of the solar radiation extending warm temperatures of the city far into the late evening. Additionally, when it comes to all the block groups', all could benefit from interventions to add shade to public transportation corridors where many are exposed to the direct heat of the summer sun as well as the addition of shading by way of trees or landscape shading structures.

Based on the differing typologies of each study area, it is important to have an understanding of the people who live there and the ways they interact with the environment. This helps to identify interventions and their location of implementation.

Some of the smaller areas had fewer emergency calls compared to the urban areas of Downtown yet still have the ability to affect climate-related emergencies calls. With, it gives an indication of areas to focus on site intervention but there are a number of other factors on can consider identifying health related vulnerable areas.

5.4 RELEVANCE TO THE PRACTICE OF LANDSCAPE ARCHITECTURE

This study is highly relevant to LA's, planners, and architects alike. All of these professions hold a vital role in adapting ways for cities to densify without having such a significant impact of the health of residents as it currently stands. Greener infrastructure is necessary to help mitigate the effects of climate change. Strategic planting of trees along pathways and among urban infrastructure should take precedence as the preferred alternative to shading as it has the most significant effect on the temperature of small or large spaces as well as benefitting the air quality and health of the people and our environment. This study was an assessment of health vulnerability to climate change based on urban factors that LA's are capable of influencing and is highly relevant due to the prevalence of environmental health issues. The review of cooling strategies from the literature is one way to make cities more resilient to climate change by influencing the health of the people in Dallas. The emergency call data is proof that Dallas is exceptionally vulnerable to the implication of its urban morphology. LA's should consider many factors and especially socio-demographic factors in order to find value in the bioclimatic design of democratic, cooling microclimate landscapes.

5.5 DISCUSSION

The identification of the relationships to human heat-related emergencies may help LA's and planners alike understand and develop bioclimatic design strategies to maintain healthy and livable communities, as well as, help educators & students of the practice of landscape architecture, architecture and planning recognize the need for enhanced tools and technologies to identify potential heat problem areas in warmer climate cities. The phenomenon described in this review also raises a broader theoretical point, one not confined to the issues of a warming climate; but how an entity with the power to change it is capable of monitoring and measuring it—through modeling or on the ground or in the air—shapes not only how we think about warm climates and the effects but also cultural perceptions about health and safety in ways that do not necessarily align with the best available scientific information. Our "ways of seeing" these climate problems are shaped by scientific, technical, and legal practices that grant them a scientific authority that, in turn, shapes—and, in the case of microclimate, limits—our regulatory response and public understanding of the health and safety risks we actually face by not acknowledging climate change on a nationally supported platform (Carlson, 2018; Boyd, 2010).

5.6 FUTURE RESEARCH OPPORTUNITIES

The main avenue for the opportunity of the subject of EE's on heat stress lies in the reevaluation of data as the next Census comes available and more data on EE's is acquired. Further investigation into the remaining eighteen block groups could potentially offer additional insight. However, due to the time limited timeframe of this study, this investigation to be continued.

Overall, in terms of health indicators, the occurrence of emergencies seems to be decreasing, but this can be the result of complex factors such as the cyclical trends of climate. An idea of the types of people these emergencies impact would offer more insight to creating design interventions, for example, if it is perhaps a transient population or if these people are in fields such as construction, who are exposed to outdoor environments on a more frequent basis. Ideally, a closer study of the microclimates by way of urban weather stations in warm areas would be one way to evaluate the conditions and quantify the heat extremities in Dallas, in the future.

In addition, Dallas has recently adopted a new tree policy for developers that require that more trees be incorporated into the landscape and the implications this leads to would be an essential study of how a policy may influence warm climates. A closer look at the programs that exist to mitigate Urban Heat Islands or evaluating programs that implement neighborhood greening would be a valuable contribution to determine which strategies have the most impact on health and climate change.

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