EXPLORING THE CHARACTERISTICS OF THE

URBAN HEAT ISLAND EFFECT IN AUSTIN, TEXAS, USING URBAN

CLIMATIC DATA AND ANALYSIS

A Thesis

by

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ABSTRACT

An urban heat island is an urban area with significantly warmer temperature than its surrounding . Reinforced energy and pollution problems, changed comfort zones, and threatened endangered-population necessitate the consideration of heat island effect in planning for urban areas. Human activities, city structures, lack of vegetation and cool sinks, and non-circulated air are defined as the variables that underpin heat island phenomen by increasing inner cities' temperature. The heat island reduction can reduce the energy consumption within urban areas. The investigation of the characteristics of a heat island in a study on small-scale areas can provide more information about how to manage the increasing energy consumption in buildings.

This research explores the effect of urban development on increasing inner cities' temperature. Austin was chosen as the study area because it experienced an average of 4.7 degrees C per year increase in the land temperature from 1993 to 2011. Also, the rapid development during the past 30 years let the researcher track the changes.

Secondary data assisted the researcher to conduct this research. The research developed a methodology to estimate urban heat intensities from atmospheric weather data and utilizing regression analysis to quantify urban development relation with urban heat island effect. Degree-day is an indirect measure for calculating the urban heat by considering the differences of the environmental temperatures from the standard base temperature. The warming trends have been calculated from the yearly sums of heating degree-days (HDD), and cooling degree-days (CDD) from 1939–2010. The ultimate results show that the heat island phenomenon is significantly related with land

development only during the month of August. Also, CDD are significantly correlated to non-residential developments rather than the residential or total development. Therefore, recognizing heat mitigation strategies should be focused on non-residential sectors in order to reduce the CDD in summer. Moreover, the heat island phenomenon is not significantly dependent on the land development itself. Other issues that are associated with development may cause the significant increase in heat in Austin.

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NOMENCLATURE

C	Centigrade
CDD	Cooling Degree Days
EHW	Extreme Heat Wave
ETM+	Enhanced Thematic Mapper Plus
GIS	Geographical Information System (GIS)
HDD	Heating Degree Days
H/W	Height/Width
LST	Land Surface Temperature
LTM	Landsat Thematic Mapper
NOAA	National Oceanic and Atmospheric Administration
RS	Remote Sensing
UHI	Urban Heat Island
UHIE	Urban Heat Island Effect

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1. INTRODUCTION

1.1. Concept of Research Problem

Heat island is the most documented phenomenon of climate change (Santamouris et al. 2001). The Urban Heat Island Effect (UHIE) has an impact on increasing the ambient temperature in urban areas compared to the surrounding rural and suburban zones (Santamouris and Kolokotsa 2015). Although it is not often considered as a serious weather-related hazard, urban heat island (UHI) increases the exposure to extreme heat waves and threatens endangered-population (Santamouris 2014). In the United States the most number of deaths caused by extreme heat waves occurred between 1991-2010 (NCDC 2004).

Scholars believe that increasing urban heat emission is the result of human activities, city structures, trapped solar energy, lack of vegetation and cool sinks, non-circulated air (Oak 1982), dense urban population, and vehicle pollution (Norwine 1976, Givoni 1998). A city's development pattern is recognized as significant factor affecting urban temperature. Arrangement of built environment and land surface materials influence land surface temperature (Stone and Rodgers 2001). UHI also influences other phenomena including energy-consumption in building sectors (Akbari and Konipacki 2005, Maric et al. 2015). Increased energy consumption causes air and heat pollution (Santamouris 2014), and changes comfort zones (Johnsson 2006). The higher air temperatures in the urban area have a serious impact on the energy consumption of buildings specifically during the summer period (Santamouris et al. 2001, Mihalakakkou et al. 2004).

In recent decades, significant efforts have been made to explore the heat island effect in developing urban areas. Few empirical studies have explored the land temperature in the developing city of Austin, Texas. In the research conducted by Richardson, Austin's land surface temperature increased by an average of 4.7° C during the years 1993 to 2011 (2015). However, the research provided no information regarding the characteristics of Austin's atmospheric temperature and it's correlation with the development.

1.2. Research Purpose and Objectives

A city's development pattern is recognized as significant factor affecting urban temperature (Stone and Rodgers 2001). Richardson stated that Austin's land surface temperature increased by an average of 4.7° C during the years 1993 to 2011 (2015). The goal of this study is to better understand the relation between development and the characteristics of UHIE in the city of Austin. Studying changes of HDD and CDD in a longitudinal study is recognized as a way to study UHIE (Debbage and Shepherd 2015). Using secondary data the study will conduct a longitudinal research about the effect of development on CDD and HDD for the years 1939 to 2010. The primary research question for this study is: how does development affect the UHI characteristics in the city of Austin.

The specific objectives of this study are to:

1. Investigate the significance of changes in CDD, HDD, and development in the city of Austin in 1939-2010;

2. Explore the relationship between development and CDD by employing statistical analysis, in Austin;

3. Explore the relationship between development and HDD by employing statistical analysis, in Austin;

4. Recommend strategies for policy implications and design guidelines for reducing UHIE in Austin.

2. LITERATURE REVIEW

This section provides an overview of research works focusing on UHIE. Also, an understanding of the major concept of this study is discussed in this section.

2.1. Urban Heat Island Effect

Urban heat island (UHIE) is an urban area with higher temperature than the temperature of its surroundings. It appears as an island in the pattern of isotherms on a surface map (Oke 1973). Luke Howard's study of the climate in and around London represents the scientific beginnings of investigating Heat Island Effect. He described urban heat island (UHI) when he compares his air temperature of 'rural' temperature, against those maintained by the Royal Society (the official scientific body) in the center of London. The evidence from plotting these data showed higher temperature of near-surface atmosphere in the urban area (Figure 1). Howard concluded that the Mean Temperature of the London's Climate is about 48.50° Fahrenheit, but in the denser parts of the metropolis, the heat is raised, by the effect of the population and fires, to 50.50° (Howard 1833).

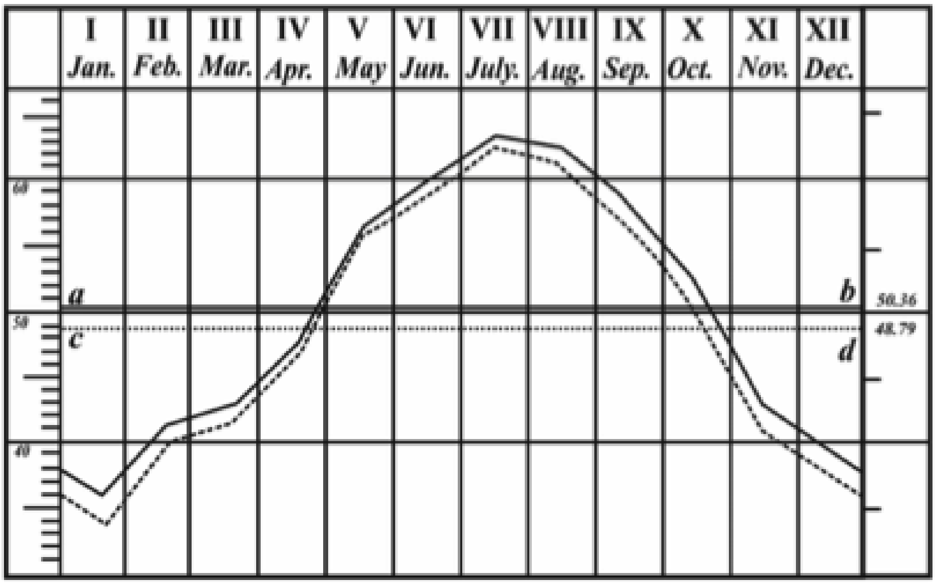


Figure 1. A Comparison Between the Air Temperature Observations by Luke Howard (1833)

Howard's attempt to explain the process responsible for the UHI was the beginning of the study of the urban effect on the atmosphere and the application of this knowledge to the better design and planning of cities. After then, there has been a stream of research attempting to evaluate the effect of a city's growth (size) over time on its heat island (Arakawa 1937, Fukui 1957, Mitchell 1961, Chandler 1964). In 1973 Oke compared many settlement sizes at the same period in time to eliminate the effect of regional climate change and suggested that industrialization and urbanization is more influential on the regional temperature than global warming (Oke 1973). He also concluded the magnitude of the UHI depends on the geometry, and size of a city (Oke 1981). Recently remotely sensed imagery has been increasingly used to investigate the effects of 2-D surface characteristics on urban temperature. In another word, suggesting that the UHI can be reasonably predicted, the research investigates correlation between urban built-up land cover and UHI (Chen et al. 2006, Katpatal et al. 2008, Amiri et al. 2009). The tight correlation between urban built-up land cover and UHI suggests that the UHI can be reasonably predicted. Therefore, using GIS data to delineate building boundaries and land uses, and LiDAR data to closely approximate the real urban infrastructure and environment in 3-D space model has allowed for the computation of a comprehensive set of 3-D urban characteristics. The integration of these various datasets represents an advance over past research, and the model was used to simulate urban temperatures under different scenarios to evaluate the impact of such scenarios to mitigate the UHI through land-use design (Chun and Guldmann 2014).

Strategies to mitigate the urban heat island effect that have been suggested in the literature can mainly be classified into three categories: modification of urban geometry, use of cool surfaces, policies and measures to increase energy efficiency.

Modification of Urban Geometry: the influence of city growth on UHIE has been studied for more than a decade (Oke 1987, Oke 1988, Oke et al. 1991, Ahmed 1994, Bourbia and Awbi 2004, Johnsson 2006). Recent studies reveal that the higher density of the city will not always result in increasing urban temperature. In dense cities shading and natural ventilation are factors that have cooling effect (Johnsson 2006, Bourbia and Boucheriba 2010, Luo et al. 2014, Bakarman and Chang 2015). Also, spatial proximity and attached buildings in urban development has the potential to mitigate UHI by reducing the heating and cooling loads in buildings (Debbage and Shepherd 2015). Results of the research on regions with different floor area ratios to investigate the optimum balance point for density along with the relationship between density and heat island effect reveals that regional temperature increases with the increase of building density when the building density is lower than 21% or higher than 33%. Also, “Regional temperature gets its lowest point at 46.3 degree Celsius when the building density is 8.26% and highest point at 50.3 degree Celsius when the building density is 45.45%. (Luo et al. 2014, p355).

Use of Cool Surfaces: the properties of surface materials influence the microclimate around buildings. The surfaces of buildings and pavements absorb solar radiation and become hot, which in turn warm the surrounding air (Akbari and Konopacki 2005). The temperature difference between urban areas and the surrounding suburban or rural areas can be as much as 5 °C (9.0 °F). Nearly 40 percent of that increase is due to the prevalence of dark roofs. The heat island effect can be counteracted slightly by using white or reflective materials to build houses, roofs, thus increasing the overall albedo of the city (Albers et al. 2015). Relative to remedying the other sources of the problem, replacing dark roofing requires the least amount of investment for the most immediate return. A cool roof made from a reflective material such as vinyl reflects at least 75 percent of the sun's rays, and emit at least 70 percent of the solar radiation otherwise absorbed by the building envelope (Rosenfeld et al. 1995).

The evaporation of water provides an important counter to this effect, and so vegetation (Akbari and Konopacki 2005, Chun and Guldmann 2014, Santamouris 2014) and water surfaces (Steeneveld et al. 2014) are vital in urban areas for creating urban cool-island. With increasing urbanization and predictions of increased frequency of heat waves under projected climate change scenarios, one strategy that has been suggested to address both adaptation and mitigation for urban areas is the increased use of green space (Akbari and Konopacki 2005, Chun and Guldmann 2014, Santamouris 2014). Evaporation of liquid water occurs at the leaf surface of vegetation lowers the local air temperature (Arnfield 2003, Johnsson 2006, Meng and Liu 2013). Akbari and Konopacki have developed summary tables (sorted by heating- and cooling-degree-days) to estimate the potential of heat-island reduction strategies (i.e., solar-reflective roofs, shade trees, reflective pavements, and urban vegetation) to reduce cooling-energy use in buildings. The tables provide estimates of savings for both direct effect (reducing heat gain through the building shell) and indirect effect (reducing the ambient air temperature). They concluded that for all building types over 75% of the total saving is from direct effects of shade trees (2005).

Moreover, cities experience relatively low evapotranspiration because of the relatively small fraction of open surface water. Water bodies form urban cooling islands to mitigate the UHI effects. The results of an investigation on the cooling intensity of urban water bodies indicated that large area intensify cooling intensity but reduce cooling efficiency and cooling effect is stronger near downtown or in densely built-up areas (Coutts et al. 2013). The results from a field survey during spring and summer for a river in Sheffield shows a mean level of daytime cooling of over 1.5 °C above the river in spring, but this was reduced in summer when the river water temperature was warmer (Hathway and Sharples 2012).

Policies and Measures to Increase Energy Efficiency: The distribution of urban buildings and structures in a city affects the formation of the urban heat island since this distribution can determine the absorption of solar energy and the formation of wind streams (Ratti et al. 2003). Optimal designs can reduce energy consumption and CO_2 emissions, which can counteract the negative effects of the heat island (Futcher et al. 2013). The optimization of urban design/planning in relation with the energy consumption of buildings allows savings of up to 30% (Gago et al. 2013).

The EPA has recognized the states role in mitigating heat island effect by requiring all states to set forth a State Implementation Plan (SIP). SIP requires a state to plan an approach on how to carry out their goal of reducing greenhouse emissions by a targeted date. The plan has main strategies to reduce greenhouse gases such as regulations, having monetary incentives, and voluntary actions (EPA 2017). The Seattle Green Factor is a multifaceted system for urban landscaping in Washington State. The plan has seen much success in the mitigation of urban heat islands. The program focuses on areas that are prone to high pollution, such as business districts. There are strict guidelines for any new construction that exceeds roughly 20 parking spaces, and this platform helps developers physically see their levels of pollution while trying different methods of construction to figure out the most effective course of action. Seattle has correspondingly produced a score sheet for cities to use in their city planning (Seattle 2017). The Emerging and Voluntary Measures Policy allows a state to add unconventional forms of heat island mitigation. These measures are not implemented into law, but they do make it possible for certain parties to voluntarily become more efficient by following the most successful forms of mitigation (EPA 2017).

Creating incentives is another way to reduce the effects of climate change in states' communities by reducing greenhouse gases through investments in clean technologies. A plan in Sacramento Municipal Utility District (SMUD) and the Sacramento Tree Foundation have been implemented to provide the city of Sacramento shade trees for free. The program allows citizens to receive trees from four to seven feet tall. They also give them fertilizer, and delivery, all at no cost. They encourage citizens to plant their trees to benefit their home by reducing air conditioning costs. As a result, more than 450,000 shade trees have been planted in the Sacramento area (SMUD 2017). The Eco-Roof Incentive Program, in Canada, grants throughout Toronto for installing green and cool roofs on residential and commercial buildings. This will reduce usage of energy and lower greenhouse gas emissions (Toronto 2017). Moreover, community-based approach like Bundled Measures Policy authorizes different factions within the state to collaborate on mitigation projects and generates co-benefits for both parties (EPA 2017).

In a local level, a variety of local governments have implemented tree and landscape ordinances, which will help communities by providing shade during summer. Tree protection is an ordinance that does not allow someone to prune or remove trees without a city permit. An example in the City of Glendale, California (City of Glendale 2017), City of Berkeley, California (City of Berkeley 2017), and City of Austin (City of Austin 2017).

2.2. Summary and the Gaps in the Literature

Although urban warming has been put in to numerous investigations, no developed comprehensive programs have been recognized to mitigate the effects of heat islands. While it has been established that compact and condense form of development tend to be more advantageous to reducing heat gain (Norwine 1976, Givoni 1998); extensive and sprawl patterns of urbanism have been debated due to higher level of radiant heat that they produce (Oke 1987, Bourbia and Awbi 2004, Luo et al. 2014). The literature is largely silent on the issue of whether one pattern of urban development is thermally more negative than another. One factor affects urban temperature is local climate because of variation in surface temperature (Johnsson 2006, Corburn 2009, Bakarman and Chang 2015). Also, research conducted in different climates revealed the fact that surface urban heat island intensity is a dependent of seasons and time of the day (Bourbia and Awbi 2004).

Therefore, to suggest land-use policies and urban design guideline a case study research is needed for every growing city. City of Austin is a rapidly growing city during last 30 years. The city has experienced a 4.7° C increase in temperature during the years 1993 to 2011 (Richardson 2015). However, there is no literature investigating the characteristic of UHIE in Austin. Such inaction necessitates the need for further research on the relation of UHIE characteristics and development. Hence, the further research can investigate the potential of development strategies and adopting policies to mitigate UHI in Austin.

3. RESEARCH FRAMEWORK AND METHODOLOGY

The following sub-section explains key variables and the description of measurement strategies used in this study to determine the characteristics of UHIE and urban development. This chapter also outlines and discusses the research methodology including the identification of study area (sample frame) and time frame, and clarification of data analysis methods used in this research.

3.1. Dependent Variable: CDD and HDD

An Urbanized area recognized as UHI when it's temperature is higher than the surrounding rural areas. The larger magnitude of UHI means higher temperature and as a result increasing cooling and heating demands in building sectors. Degree-day is a quantitative index demonstrated to reflect demand for energy to heat or cool houses and businesses. The objective of this study is to explore the effect of development on the CDD and HDD as the indicators of UHI. Thus, the dependent variable for this study is CDD and HDD.

Measurement and Data: There are two ways to measure the urban temperature, surface temperature and atmospheric temperature. The surface measurement method is collecting the temperature data by taking the advantage of airborne or satellite thermal infrared remote sensing. The surface urban heat island lets researchers study UHIE on a regional scale (Yuan and Bauer 2007). On the other hand, atmospheric measurement strategy has the air temperature data collected by using the weather station networks.

The latter measurement strategy permits researchers to investigate the UHIE at the local level. There are still ongoing debates about whether to select ground temperature or air temperature when measuring urban temperature (Stone and Rodgers 2001). Since the objective of this study is to focus on city scale the latter strategy is applied. Thus, this study uses atmospheric measurements in analyzing the characteristics of the Urban Heat Island Effect in Austin.

Former studies on the topic of UHIE have used the mean temperature, daily maximum temperature, and daily minimum temperature to investigate the differences in atmospheric temperature. Also, this measurement has been applied to examine the degree and magnitude of UHIE. Furthermore, the characteristic of UHIE measured through more innovative strategies including, Cooling Degree Days and Heating Degree Days. CDD and HDD are specifically applied when the objective of the study is to estimate energy used in building sectors (Theophilou and Serghides 2015). Degree-days are a tool to detect the heating or cooling demand to keep the indoor temperature of a building in the thermal comfort zone (Stathopoulou et al. 2006). Degree day is a quantitative index and reflects demand for energy to heat or cool buildings. This index is derived from daily temperature observations at weather stations. The degree days can be easily measured yearly or monthly through accumulated daily data. A mean daily temperature (average of the daily maximum and minimum temperatures) of 65°F is the base for both heating and cooling degree day computations. Heating degree days are summations of negative differences between the mean daily temperature and the 65°F base; cooling degree days are summations of positive differences from the same base

(NOAA 2016). This benefit of degree days makes it possible to capture trend of changes in urban temperature at the city level by comparing the number of heating degree-days and cooling degree-days in an urbanized area when the purpose is to conduct a longitudinal study. This study analyses the possible trends in local climate as the result of the land development by conducting a longitudinal study. Hence, this study conducted an analysis of the meteorological measurements to determine the possible trends in CDD and HDD to identify the magnitude of the Urban Heat Island Effect resulting from land development.

Previous studies of meteorological studies on heat island effect were conducted by using various fixed and mobile weather stations (Tselepidaki et al. 1994, Christenson et al. 2006, Theophilou and Serghides 2015). This study used secondary data recorded by fixed standard weather stations recognized by NOAA to analyze atmospheric temperature. The reasons to choose this source of data for this study are as follows: first, it has weather station recorded the data since 1939 and makes a longitudinal analysis possible. Second, it has been said that for the accuracy of results it is better to use one source to gather the data from (Stone and Rodgers 2001). Also, this service allows users to extract the weather temperature trends by providing locations (national, regional, statewide, and cities) and times of interest.

3.2. Independent Variable: Urban Development

The independent variable in the study is urban development. As discussed in the literature review, previous studies have attempted to investigate the relationship between urban components including development and temperature (Norwine 1976, Oke 1987, Givoni 1998, Bourbia and Awbi 2004, Johnsson 2006, Lue et al. 2014, Bakarman and Chang 2015). Urban heat islands are the result of numerous variables. The main reason can be defined as the alteration of land surfaces by urban development, which contains materials that effectively retain heat. Construction of building of structures eliminates vegetation from the landscape, and blocks surface heat. Research shows that the increase in impervious surfaces in the cities increases heat island effect (Arnold and Gibbons 1996, Yuan and Bauer 2007).

Therefore, development is a factor expected to affect UHI. Based on the different energy demand, and management strategies in residential building types comparing with non-residential ones, development can have different relation with CDD and HDD, based on the building type (Theophilou and Serghides 2015). As a result, in this study the category of development refers to area of the parcels developed in a year, and will be analyzed in categories of residential development, and non-residential development. Analyzing the categorized development provides an alternative method for studying of relation of type of development and intensity of UHI.

Measurement and Data: The secondary data of tax appraisal is used to get the record of yearly measurements of development during the year 1938-2010. All data were organized, managed, and analyzed using ArcGIS. Yearly measurements of development are studied around the station that covered the years of interest.

3.3. Study Area (Spatial Sample Frame)

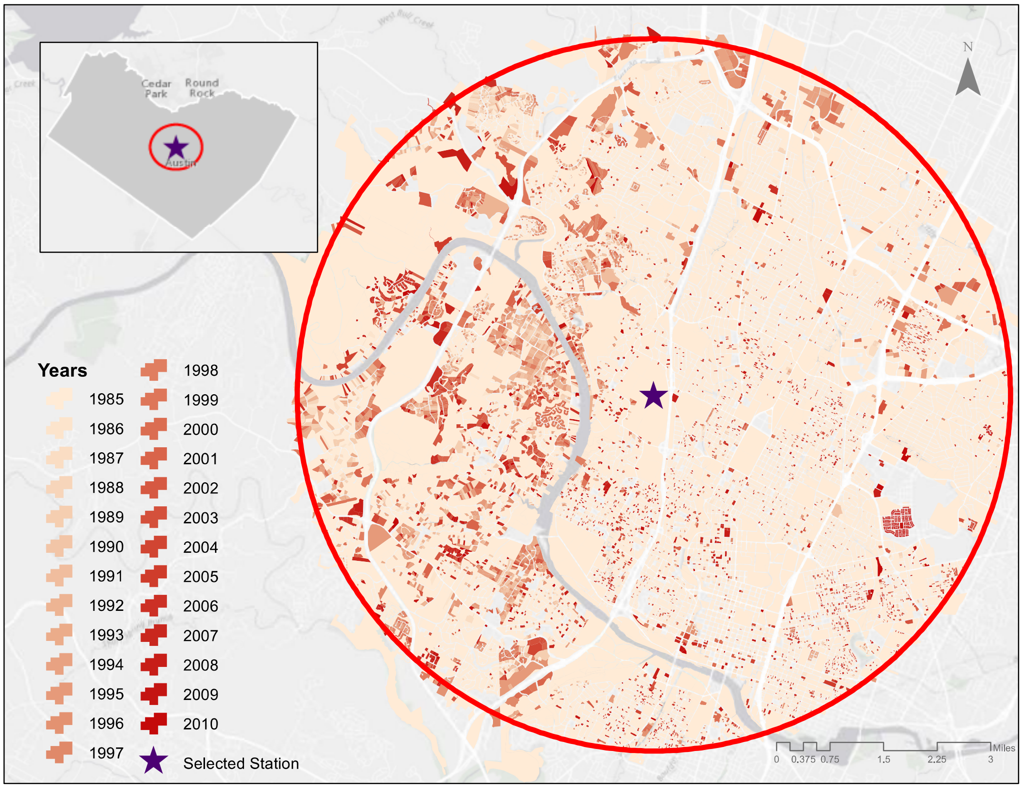
Austin is located in Travis County, Texas (Figure 2). Based on the information provided by United States Census Bureau, Austin population was growing with the average rate of 3.37 in 1939 to 2010. The maximum increase rate in the population is for year1998 with 8.1% and the minimum is for year 1990 with -0.2% (US Census Bureau and the City of Austin). Over the last 30 years, Austin is one of the fastest growing cities in the United States, since Central Texas has become a desirable place to live (Richardson 2015).

Figure 2. Study Area

Increasing population is logically correlated to an increase of urban development, more people residing in a city with the more demand on land to be transformed to houses and other supporting uses. Given the rapid population growth and development of Austin, UHI is expected to be an issue in the region (Figure 3).

In the research done by Richardson in 2015, the average surface temperatures for each year were calculated as well as the temperature difference between 1993 and 2011. Results of the former study in Austin show that the average surface temperature for Austin increased by 4.7 degrees C between 1993 to 2011, and the city is experiencing the UHI phenomenon. Average temperatures and temperature difference are presented for the years 1993 to 2011, in the maps. Based on the maps, land surface temperatures increased by an average of 4.7 degrees C between 1993 to 2011. The research also showed that the majority of Austin's metropolitan area displays an average surface temperature of 31 degrees C or higher in 2011. Results also display the areas with the largest temperature changes are located in the southern part of the city (Richardson 2015).

However, former research provided no information regarding the correlation of UHIE in Austin and the development. Therefore, the Austin area is considered a case study to be explored in regard with the characteristics of atmospheric temperature during the rapid development years.



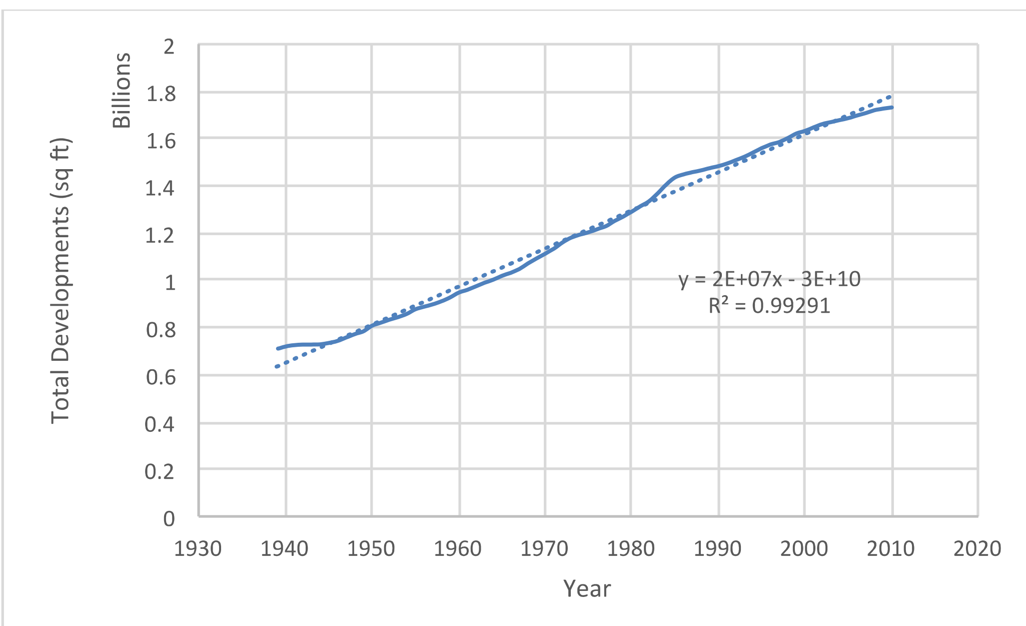


Figure 3. Development 1939-2010

The atmospheric temperature is collected from different types of monitoring techniques including data provided through standard and non-standard fixed weather stations, and mobile traverses. Since the use of standard fixed meteorological stations provides an advantage of the availability of the measurements for long periods of time, the weather station locations play an important role in sampling strategies and selecting the focused study area in Austin.

Since the study relies on secondary data from the meteorological stations the sampling population is considered as a total of five standard fixed weather stations located in Travis County, Austin, which are operated during different period of time (Figure 4). With this regard the other important factors in sampling is to select area covered by a weather station that is being operated during the years in which the study is performing.

This study analyses the temperature data of Austin during 1939-2010. Former studies showed that the average surface temperature for Austin increased by 4.7 degrees C between 1993 to 2011 (Richardson 2015). The Camp Mabry weather station with the latitude of 30.28, and longitude of -97.36 is the center of the sample study area (Figure 4). The weather station is covering the area located in inner city area. Study area includes a 5-mile radius circle around the weather station. The radius of the buffer around the weather station is 5 miles, since it is a reasonable distance that it's atmospheric data can be captured by a weather station (NOAA 2016).

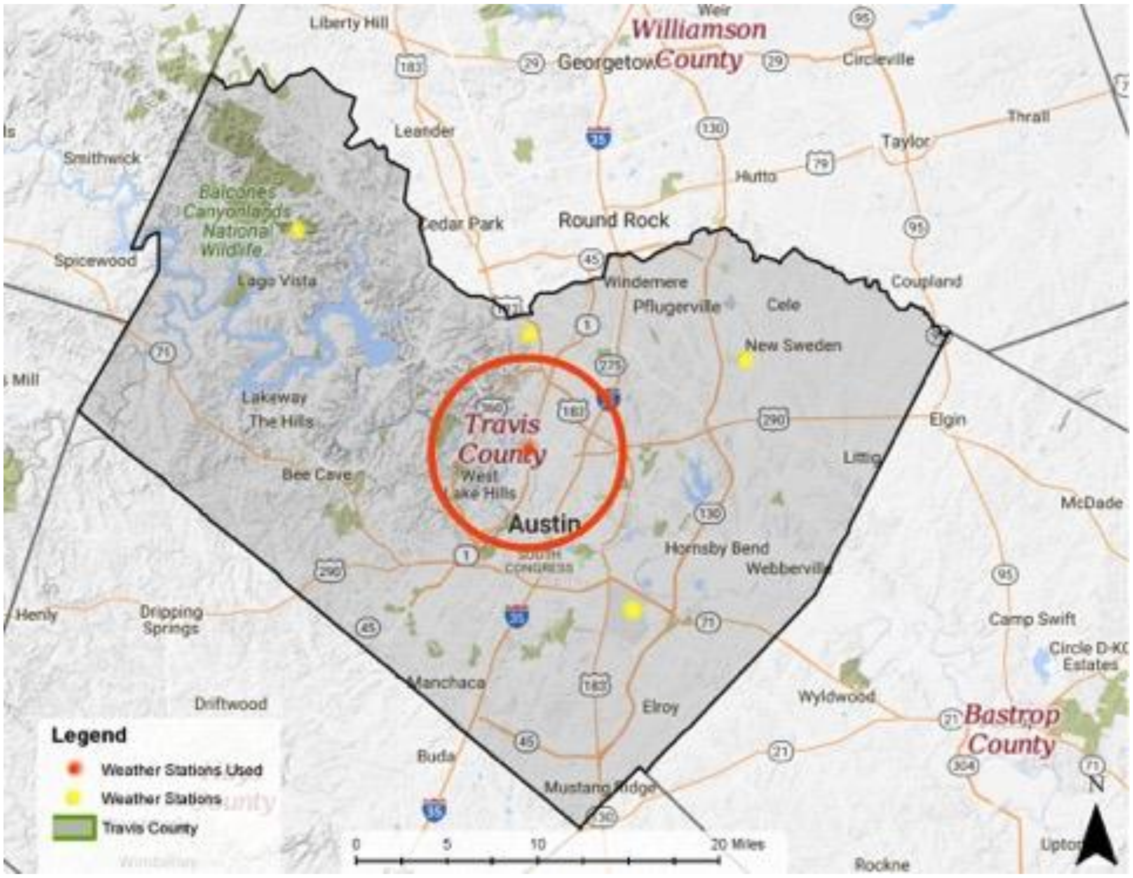


Figure 4. Weather Stations

3.4. Data Analysis

This research examines the relationship between physical development of an urban area and CDD and HDD in Travis County, Austin, Texas. If a relationship exists it is though to be a direct relationship where the increase in development positively impact the CDD, and negatively impacts the HDD. Thus, the hypothesis is:

Hypothesis 1: There is no relationship between physical environment and CDD?

Hypothesis 2: There is no relationship between physical environment and HDD?

The unit of analysis is years. The development data is obtained from Travis County Tax Assessor's Office reflecting the first year of property development and the property type. Data from 1939 to 2010 were classified and processed by ArchGIS. Also, the yearly measurements of meteorological data applied in this study. The summery of data for yearly measurements for each month have been recorded in the Camp Mabry Station: Austin City Center as shown in Table 1 and Table 2, and Figure 5 and Figure 6. The minimum, maximum, average, and median of CDD for every month calculated and reflected in Table 1. Also the same table provided for HDD in order to detect the months are experiencing CDD and HDD to study (Table 2).

Table 1, and Figure 5 reflects that months of Jun, July and August are experiencing the highest average for CDD so this study will focus on those months for the analysis of CDD. Also, Based on Table 2 and Figure 6 months of December, January, and February are going to be focused for the study of HDD. The trend and the statistical significance of the trend for CDD/HDD and development are shown in the Figure 7 to 9 using R square method.

Table 1. CDD Summary

Measure	CDDJan	CDDFeb	CDDMar	CDDApr	CDDMay	CDDJun
Min	0	0	3	44	178	381
Max	54	79	156	326	483	672
Average	8.5	15.5	55.0	153.5	331.5	500.9
Median	5	10	46	151	329	495
StdDeviation	10.57	17.64	36.84	57.74	65.98	59.46
Measure	CDDJul	CDDAug	CDDSep	CDDOct	CDDNov	CDDDec
Min	470	503	223	60	4	0
Max	759	747	582	348	123	41
Average	606.5	615.9	432.7	204.3	48.8	11.1
Median	608	614	434	210	44	8
StdDeviation	55.59	58.11	64.63	59.57	29.83	10.37

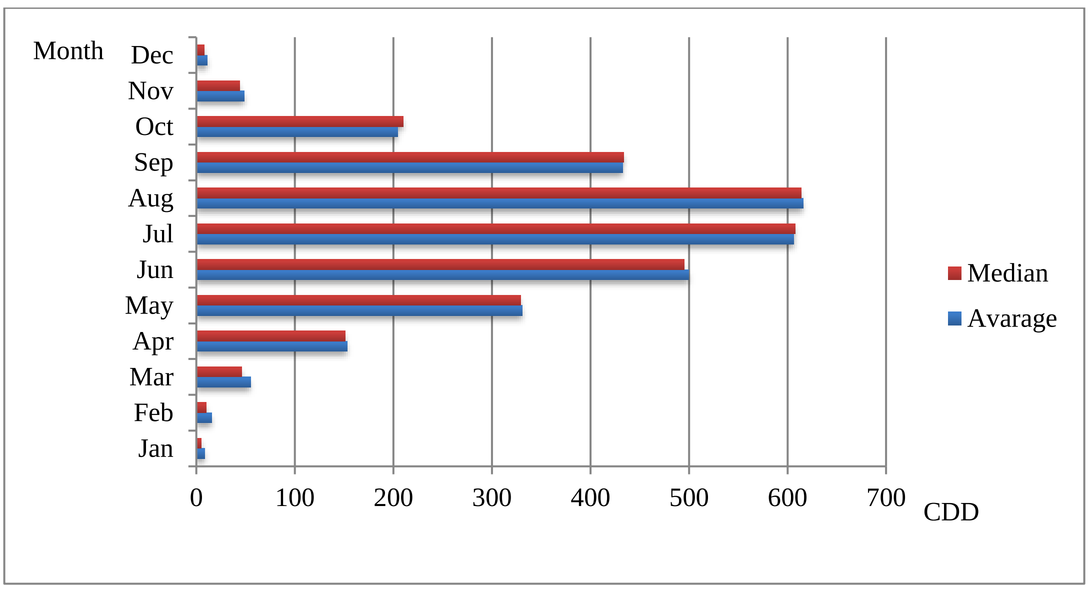


Figure 5. Average CDD

Table 2. HDD Summary

Measure	HDDJan	HDDFeb	HDDMar	HDDApr	HDDMay	HDDJun
Min	210	130	32	0	0	0
Max	794	567	373	132	25	0
Average	473.2	328.2	185.1	43.9	2.9	0.0
Median	460	321	176	37	0	0
StdDeviation	126.52	99.58	79.30	31.04	5.25	0.00
Measure	HDDJul	HDDAug	HDDSep	HDDOct	HDDNov	HDDDec
Min	0	0	0	0	81	232
Max	0	0	18	173	408	728
Average	0	0	1.8	33.1	208.1	402.3
Median	0	0	0	29	203	380
StdDeviation	0	0	3.80	27.90	76.10	94.98

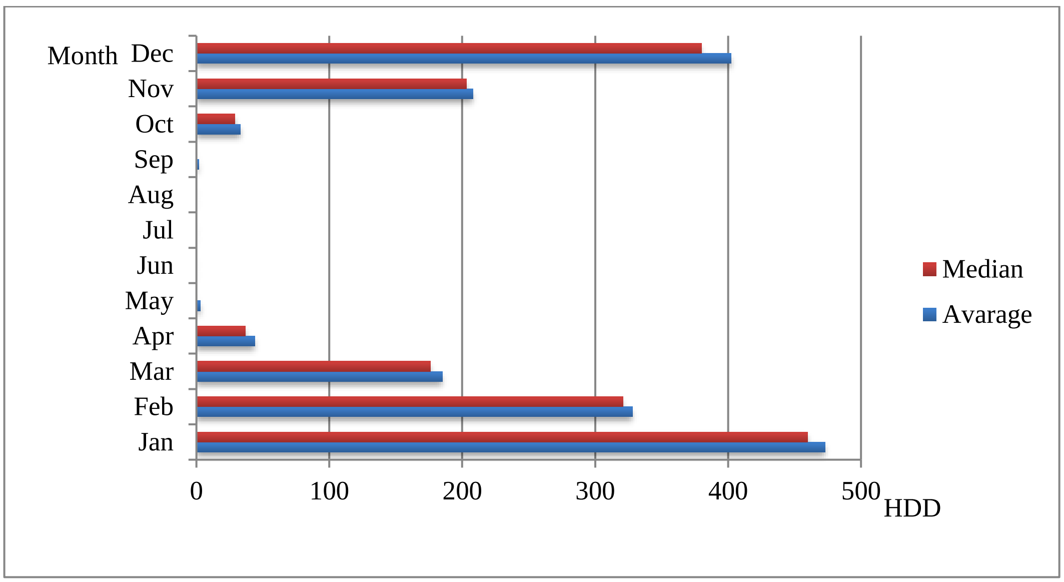


Figure 6. Avarage HDD

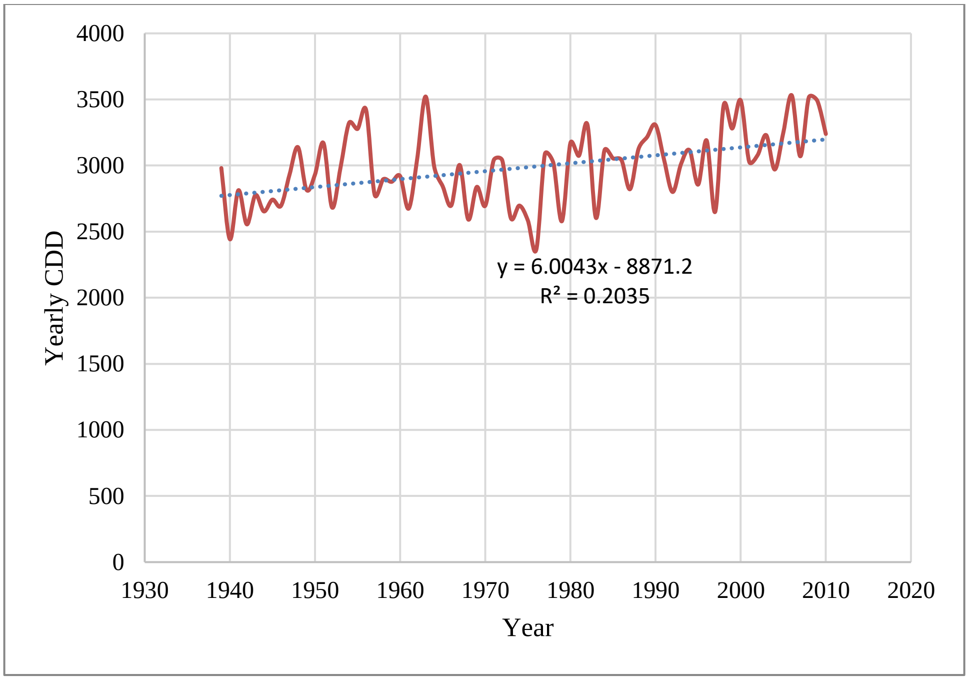


Figure 7. CDD During 1939-2010

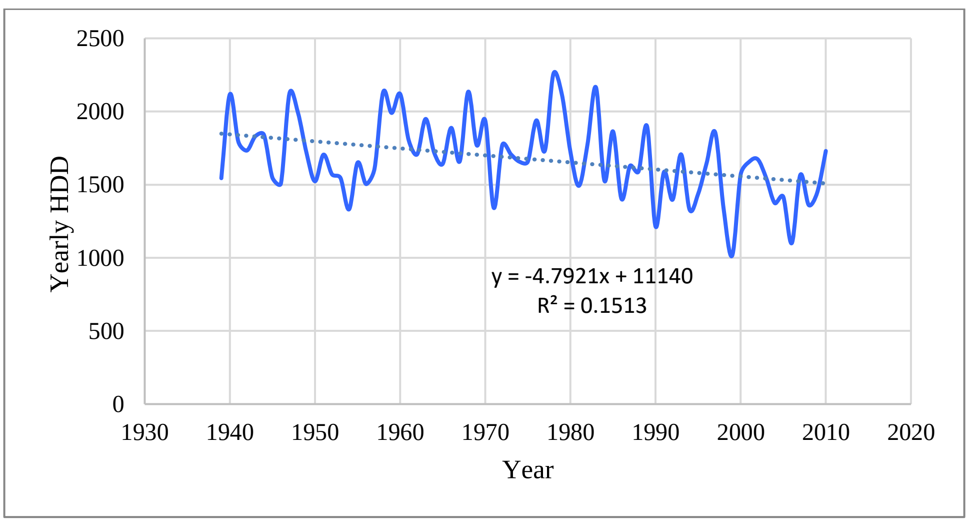


Figure 8. HDD During 1939-2010

Figure 9. Development 1939-2010

The time series regression is used to examine the association between development and CDD/HDD, because it allows a statistical test for causality. Hypothesis 1 and 2 are tested in terms of time series regression of monthly meteorological data (June to August for CDD and December to February for HDD) from development for 1939 to 2010. The development is considered in two categories residential development, and non-residential developments for years 1939 to 2010. The month before CDD/HDD data is included in the base model to account for the unusual changes in the weather in the year of study. Moreover, the monthly CDD and HDD have seasonal fluctuations. These seasonal fluctuations are accounted for by the inclusion of a seasonal lag, where the CDD one year ago is used as a predictor of the current CDD in the present year. Hence the base model is specified as:

$$y_t = a + \Sigma b_i x_i + e_t$$

where y_t is the CDD/HDD at time T, x_1 is estimated CDD/HDD for the month before at time t, x_2 is the CDD/HDD for the same month at t_{-1} (one year ago), e_t is the error term at time t, and i varies from 1 to 2. All hypotheses are tested in the context of this base model. To account for this the Prais-Winsten regression test is used throughout to account for serial correlation. The test calculates the autocorrelation without losing an observation that leads to more efficiency as a result and makes it a special case of feasible generalized least squares for time series analysis.

The null hypothesis is H0: t = 0 (no trend) versus the alternative hypothesis is H1: t =/ 0 (trend). P value is calculated for confidence level of 0.05 (95% Conf. Interval). All data were organized, managed, and analyzed using Stata 14.0 software with defining the degree-days of month of interest as the dependent variable and the development as the independent variable including one-year lag for the development to effect degree-days. The degree-days of month before, and degree-days of year before also have been included in the model to minimize the effect of unusualness in the data.

4. RESULTS AND DISCUSSION

Urban Heat Island Effect has an impact on the cooling and heating needs to achieve thermal comfort and for this reason the yearly sums of heating and cooling degree-days have been calculated to capture the trends in the Urban Heat. The yearly measurements of the CDD have been recorded in the study area for the months of June, July, and August during 1939 to 2010 (Table 3). By considering confidence level of 0.05, the results presented in Table 3, shows the existence of UHI in the study area during summer. The P-value for CDD of all the months of study are lower than 0.05. Hence, UHI has a statistically positive trend in all the months of study. This result is in compliance with the former research conducted in Austin that states the average surface temperature for Austin increased by 4.7 degrees Centigrade between 1993- 2011, and the city is experiencing the UHI phenomenon (Richardson 2015). In other words, for the months of June to August the model shows Austin is experiencing warmer days during the summer within 1939-2010 (Table 3). The results also shows the UHIE is developing by the factor of 0.41-0.55% which reflects the need for further consideration in future planning strategies.

In his research, Richardson states that the City of Austin is a rapidly growing city during last 30 years and relates the increasing development to the increasing temperature during the years 1993 to 2011 (2015). Other literature also claimed that development has statistical positive relation with UHI (Oke 1987, Ahmed 1994, Bourbia and Awbi 2004, Johnsson 2006). However, the results in the last row of the Table 3 show that although the development and UHI are positively correlated, no statistical significant relation is visible through the summer period. Considering confidence level of 0.05, the P-value for the correlation of total development in Austin and CDD is not below 0.05. The result means, although Austin is significantly experiencing UHIE, there is no significant relation between development and UHIE.

Table 3. CDD and Development

JUN CDD											
	Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|
Seasonal	-.13	.11	0.22	Seasonal	-.13	.11	0.22	Seasonal	-.13	.11	0.22
CDD Year	.42	.10	0.00	CDD Year	.42	.10	0.00	CDD Year	.42	.10	0.00
totdev	0	0	0.41	Resdev	0	0	0.41	Otherdev	0	0	0.42
Prob>F=0.0004,R^2=0.23,AdjR^2=0.20				Prob>F=0.0004,R^2=0.23,AdjR^2=0.20				Prob>F=0.0004,R^2=0.23,AdjR^2=0.20			
JUL CDD											
	Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|
Seasonal	-.11	.10	0.26	Seasonal	-.11	.10	0.25	Seasonal	-.11	.10	0.28
CDD Year	.55	.09	0.00	CDD Year	.55	.0.9	0.00	CDD Year	.55	.09	0.00
totdev	0.00	0.00	0.51	Resdev	0.00	0.00	0.48	Otherdev	0.00	0.00	0.63
Prob>F=0.0000,R^2=0.37,AdjR^2=0.34				Prob>F=0.0000,R^2=0.37,AdjR^2=0.34				Prob>F=0.0000,R^2=0.37,AdjR^2=0.34			
AUG CDD											
	Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|
Seasonal	.23	.11	0.04	Seasonal	.23	.11	0.04	Seasonal	.22	.11	0.05
CDD Year	.41	.11	0.00	CDD Year	.41	.11	0.00	CDD Year	.41	.11	0.00
totdev	0.00	0.00	0.09	Resdev	0.00	0.00	0.10	Otherdev	0.00	0.00	0.05
Prob>F=0.0000,R^2=0.34,AdjR^2=0.31				Prob>F=0.0000,R^2=0.34,AdjR^2=0.31				Prob>F=0.0000,R^2=0.35,AdjR^2=0.33			

No statistical significant relation is visible in total development on this study, although other literature confirmed that development statistically relates with UHI (Oke 1987, Ahmed 1994, Bourbia and Awbi 2004, Johnsson 2006). However, by separating the development in two categories of residential and non-residential, the test shows that the correlation between the development and the CDD is varied among the month of the year and it is not consistent along the whole year. In regard with confidence level of

0.05, results in Table 3 shows the significance correlation between CDD and Non-Residential Development takes place in the month of August with the P-value of 0.04. Also, results have revealed that residential development is not significantly relates to increases in CDD during 1939-2010.

Table 4. HDD and Development

DEC HDD

	Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|
Seasonal	-.25	.12	0.83	**Seasonal**	-.27	.12	0.83	**Seasonal**	-.02	.12	0.85
HDD Year	.03	.16	0.84	**HDD Year**	.03	.17	0.83	**HDD Year**	.03	.16	0.86
totdev	- 0.00	0.00	0.87	Resdev	-0.00	0.00	0.89	Otherdev	-0.00	0	0.82
Prob>F=0.9175,R^2=0.01, AdjR^2=-0.04				Prob>F=0.9195,R^2=0.01, AdjR^2=-0.04				Prob>F=0.9095,R^2=0.01, AdjR^2=-0.04			

JAN HDD

	Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|
Seasonal	.-.25	.11	0.03	**Seasonal**	.-.25	.11	0.03	**Seasonal**	.-.25	.11	0.04
HDD Year	-.09	.14	0.51	**HDD Year**	-.09	.14	0.51	**HDD Year**	-.09	.14	0.51
totdev	-0	0	0.08	Resdev	-0	0	0.09	**Otherdev**	-0	0	0.07
Prob>F=0.0032,R^2=0.18,AdjR^2=0.15				Prob>F=0.0032,R^2=0.18,AdjR^2=0.15				Prob>F=0.0035,R^2=0.18,AdjR^2=0.14			

FEB HDD

	Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|		Coef.	Std. Err.	P>|t|
Seasonal	.28	.11	0.01	**Seasonal**	.28	.11	0.01	**Seasonal**	.28	.11	0.01
HDD Year	.29	.09	0.00	**HDD Year**	.29	.09	0.00	**HDD Year**	.29	.09	0.00
totdev	- 0	0	0.80	Resdev	- 0	0	0.83	Otherdev	- 0	0	0.72
Prob>F=0.0002,R^2=0.25,AdjR^2=0.21				Prob>F=0.0002,R^2=0.25,AdjR^2=0.21				Prob>F=0.0002,R^2=0.25,AdjR^2=0.21			

Former researches claimed that the Urban Heat Island Effect is stronger during the winter period December–February rather than the summer period June–August (Theophilou and Serghide 2015). However, the results of the study of UHIE characteristics in City of Austin reveal a positive, statistically significant trend regarding the cooling degree-days, meaning that the needs for cooling are increased during the examined period for the city of Austin. In contrast, the needs for heating is not consistently reduced for the examined period, since for the heating degree-days, the station have shown a negative trend just for the months of December and January. Also, the trend is not statistically significant for December and January. These results are not supporting the significance of Urban Heat Island Effect in the winter. These results indicate that the urban Heat Island Effect is stronger during the summer period (Table 4). Moreover, although there is a consistent statistically negative trend in the changes in the HDD in correlation to the all types of development on the months of studies, no statistically significant trend is visible between development and UHIE in the winter.

By analyzing the results to estimate the characteristics of UHI in Austin from climate data and using quantitative methods to quantify the extreme of UHI intensities, this study has found that Austin is significantly experiencing UHI during June to August. That means Austin is experiencing warmer days during the hottest months of summer within 1939-2010, and also the effect is developing with the factor od 40-50% that presents the idea that Austin is exposing to almost twice heat exposures in each year compared to the year before.

However, development of built areas of land has minimal correlation with the developing of UHIE. Only in month of August, and only in non-residential development the correlation of the development and UHIE is significant. The results also suggest that residential development does not significantly amplify the UHIE. This partially is in contrast with the assumption implied by previous research that high-density city configuration enhancing the UHI effect (Martilli 2014). Instead, at least in the city of

Austin, the development of land itself has minimal impact on UHIE in term of increasing the degree-days (that have been used as an indirect method for calculating the urban heat due to their measuring abilities in the differences of the environmental temperatures from standard base temperatures). Therefore, UHIE could be the result of other factors than development, which paves the way for further in-depth research and investigations in this area. Additionally, UHIE intensity in correlation with the development is dependent of season. In other words, the UHIE in winter is not affected by development as significant as it is in the summer. In another words, the UHIE in Austin resulted in significantly warmer days and higher cooling demands in summer.

5. URBAN PLANNING IMPLICATIONS AND CONCLUSIONS

This research developed a methodology to estimate UHI intensities from atmospheric weather data and utilizing regression analysis to quantify urban development relation with UHIE. Degree-days have been used as an indirect method for calculating the urban heat due to their abilities to be aggregated yearly in term of the differences of the environmental temperatures from standard base temperatures. The warming trends calculated from the yearly sums of heating degree-days (period December to February), and cooling degree-days (period Jun to August) in Austin presented in Table 3 and Table 4 for the period1939–2010. The ultimate purpose was to detect the effect of development on the Urban Heat Island Effect in the city of Austin.

The analyzed data states that CDD has statistically positive changes during 1939-2010. Hence, experiencing warmer days during the summer confirms the idea that Austin experience UHI in the summer time. However, the trend was not consistent through the winter as the months of December and February are offering colder days compared to the year before during the winter. The fact reveals that UHIE is significantly affecting the city in the summer. Therefore, in strategic planning strategies the results suggest the possible plans for Austin to significantly focus on the cooling strategies for summer to reduce UHIE in the city area. Hence, power companies can adopt more efficient strategies in managing their power supplies and smoothing demands. Also, based on 40% factor of increasing DD, the study suggests the tracking of the CDD and HDD on an annual basis in order to monitoring the UHIE's strength in

Austin and plan for the situation. This will allow the authorities to analyze the data, investigate the causes, and adopt policies efficiently. These remedying actions can be in the form of State Implementation Plans (EPA 2017) through the state Authorities, creating incentives for improving energy efficiency, or design guidelines and ordinances in a local level.

Moreover, analyzing UHIE in correlation with development shows that the significance of correlation in Austin is not as significant as it was expected. Also, the correlation is not consistent through the summer. The time series analysis has shown a statistically significant positive correlation between UHIE and development only for the month of August (P-value 0.04), and only for the non-residential development. This brings the statement that: although Austin experiencing UHIE but the role of development impact on the CDD is not as extreme as expected. Therefore, the planning authorities may focus on other issues, such as transportation, hard surfaces material, building details, and etc. for further investigations.

Not experiencing extreme relation between development and UHIE in Austin as it is expected logically relates to the existence of bodies of water in the city of Austin that has been proved as a strategy to mitigate UHIE (Steeneveld et al. 2014). Water bodies form urban cooling islands to mitigate the UHI effects (Coutts et al. 2013). This assumption is also in line with the results from a field survey during spring and summer for a river in Sheffield shows a mean level of daytime cooling of over 1.5 °C above the river in spring, but this was reduced in summer when the river water temperature was warmer (Hathway and Sharples 2012). Moreover, Austin's tree protection ordinances in a local level do not allow someone to prune or remove trees without a city permit City of Austin (City of Austin 2017). Evaporation of liquid water occurs at the leaf surface of vegetation lowers the local air temperature (Arnfield 2003, Johnsson 2006, Meng and Liu 2013). Akbari and Konopacki averred that for all building types over 75% of the total saving is from direct effects of shade trees (2005).

An ulterior motive of this research was to suggest the urban planning implications of this central finding and potentially clarify if decreasing urban development is a viable UHI mitigation strategy. Based on the correlations and regression models, more non-residential development magnifies the UHI effect. This should focus the attention on defining solutions and design recommendations for reducing UHIE on non-residential land uses rather than residential land uses. The Urban Heat Island effect has an impact on the building's needs for heating and cooling to achieve thermal comfort. This information can be used for reducing energy consumption in the cities by adopting regulations for larger scale projects including non-residential to decrease the heat retention of these building in the cities.

Based on literature, the distribution of urban buildings and structures in a city affects the formation of the urban heat island by determining the absorption of solar energy and the formation of wind streams (Ratti et al. 2003). Optimal designs can reduce energy consumption and CO2 emissions, which can counteract the negative effects of the heat island (Futcher et al. 2013). The optimization of urban design/planning in relation with the energy consumption of buildings allows savings of up to 30% (Gago et al. 2013). This regulation would include the recommendations on materials used in the exterior elevations and ceilings, landscaping, and air-conditioning strategies. Building designs also may provide cooler Eco climate by adopting simple strategies like green roofs, white surfaces to reduce the cooling demand of the building as an outcome of city development and urbanization.

Furthermore, the significance of non-residential development influence on UHIE in this study just observed in the month of August, and Jan and that does not represent the need for high priced strategies and policies regarding land development. However, the results offer to plan on focusing only on the cooling strategies for one month of the year (August) to reduce UHIE in the city area considering development. Also, based on this study power companies can adopt more efficient strategies in managing their power supplies and smoothing demands.

The results of this study do not show an extensive significant correlation between development and UHIE, which pointed out the fact that the planning strategies need to focus on other factors resulted from development rather that development itself. Also, since residential sectors are not driver of the UHI phenomenon, the issue of UHIE may not related to sprawl development, but other issues coming with it such as automobile dependent transportations, excessive highways and road (Oke 1987, Bourbia and Awbi 2004, Luo et al. 2014)

5.1. Potential Sources of Error and Future Studies

Potential uncertainties in atmospheric temperatures may be attributed to the limitation of weather stations. Based on the funding resources and available data, weather stations, which are the most commonly used tool to measure air temperature, are very limited in terms of time and space. In this study the efforts put in to have the longest period of time to reduce the errors and have the most reliable data, but still in terms of geographic area of study, the area is largely depended on availability and coverage of data available. Future research may consider at least two stations; one covers highly urbanized area, and one covers less-urbanized area to compare the effect of development.

Also, this research results show the probability of UHIE correlation with other factors rather than development of land itself. This fact opens the doors for further researches in the other development dependent areas such as green spaces, the geometry of space, building materials, and the effect of body of water in Austin on UHIE during development era.

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