Urban Heat Island's Effects on Electricity Expenditure and Their Relationship with Household Types in Salt Lake County, Utah

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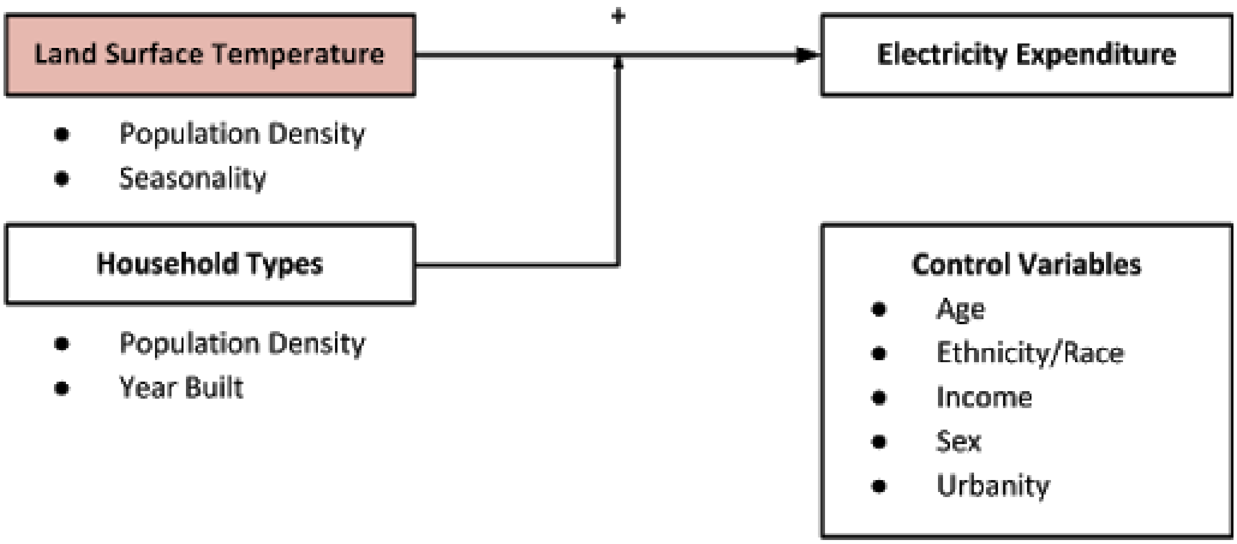
INTRODUCTION

The urban heat island (UHI) effect occurs when soil and vegetation is replaced by impervious surfaces such as concrete and asphalt, urban structures such as tall buildings and streets that change the radiative fluxes are built, and anthropogenic heat is released into the air. (Arnfield, 2003) The result is ambient air and surface temperatures that are several degrees higher than surrounding rural areas. Heat waves in urban areas are considered a natural disaster, and are high contributors to mortality rates. (Borden 2008) Additionally the UHI effect has been connected to higher levels of energy use for cooling, affecting both the climate crisis and people financially. (Stone, 2005) As a result it is important that research highlighting the adverse effects of UHI is continued. Our research focuses on the financial effect of the UHI effect on Salt Lake City county residents. More specifically, closely visualizing the relationship between land surface temperature and electricity expenditure. Moreover, we wanted to see if there was something that could be done from an urban planning and design perspective to try and mitigate the negative effects of UHI. For this reason we also chose to explore the effect residential building population density and type have on the relationship between land surface temperature and electricity expenditure. We identified an environmental occurrence that presented clear social, economic, and health dangers to urban areas at large. We used data and pre-existing research to better understand the economic dangers of UHI. We hope to add the beginnings of a potential solution to the conversation of climate change by presenting data that relates building design to the relationship between land surface temperature and electricity expenditure in order to try and mitigate the negative effects of UHI. What follows is our research questions and a conceptual framework where we state our main hypothesis and present our conceptual models. Followed by a literature review, which specifically explains pre-existing research that has been done regarding this topic, the debates, and the gaps in the research. Next, the methods section will provide a description of data sources and variables. This will be followed by graphics highlighting the results of our research and an analysis of the data. Then a description of our results and an interpretation that will explain how our findings fit into the greater context of the concept. Then we will conclude with key takeaways and suggestions for future research. Lastly, there will be a page for all the references to other papers that were used in our research.

RESEARCH QUESTIONS AND FRAMEWORK



LITERATURE REVIEW

The urban heat island phenomenon is an environmental issue that is commonly found within urban landscapes, much of the information ranging from coarse to fine spatio-temporal data; the subject is well-researched and has been found to have correlation with variables like albedo reflectance level (Ihara et al. 2008), building/household size (Agathangelidis et al., 2016; Yalcintas & Kaya, 2017), cooling and heating consumption and demand (Li et al., 2019; Roxon et al., 2020; Santamouris, 2014), cooling degree days (CDD) and heating degree days (HDD) (Roxon et al., 2020), energy consumption and demand (Azevedo et al., 2016; Fung et al., 2006; Li et al., 2019; Roxon et al., 2020; Santamouris, 2014, 2015; Yalcintas & Kaya, 2017), greenhouse gas emissions (Agathangelidis et al., 2016), median household income (Agathangelidis et al., 2016; Azevedo et al., 2016; Buyantuyev & Wu, 2009; Yalcintas & Kaya, 2017), normalized difference vegetation index (NDVI) (Azevedo et al., 2016), ozone formation (Stone, 2005), population density (Agathangelidis et al., 2016; Arnfield, 2003; Fung et al., 2016; Roxon et al., 2020), street width (Agathangelidis et al., 2016), and heat/thermal stress (Agathangelidis et al., 2016) to list several.

There is a general consensus that urban heat island intensifies as the study area approaches the urban core as opposed to the urban periphery and rural surroundings (Agathangelidis et al., 2016, p. 17; Buyantuyev & Wu, 2009, p. 17), and the more urbanized the region, the more dense the population, which contributes to the increasing urban heat island of cities (Agathangelidis et al., 2016, p. 13-14; Arnfield, 2003, p. 16). Other empirical generalizations include that urban heat island intensities decrease with increasing wind speeds and/or increasing cloud coverage, and that urban heat island intensities increase with increasing city size and/or population (Arnfield, 2003, p. 16). It is to be noted that urban heat island is usually measured and analyzed under two scales: the urban boundary layer and the urban canopy layer (Buyantuyev & Wu, 2009), the former of which is the most commonly researched—for many studies they utilize land surface temperature as a measurement for gauging urban heat island like all of the literature referenced in this paper.

There has also already been thorough research concerning the relationship between urban heat island and energy utilization, specifically, electricity expenditures (Azevedo et al., 2016; Santamouris et al., 2015) as well as electricity consumption's correlation with the fluctuation in the cost of energy (i.e. price elasticity) (Alberini et al., 2011) and how they factor into median household income (Yalcintas & Kaya, 2017). Affluent areas are located in lower temperature regions compared to lower-income and medium-income areas (Agathangelidis et al., 2016, p. 18)—similar spatial distribution is found with urban green spaces and NDVI values as well, denser places and higher ratings located in areas that have lower temperatures rather than areas with higher temperatures (Agathangelidis et al., 2016, p. 11; Azevedo et al., 2016). And while there is a correlation between urban heat island and energy consumption, especially with electricity, and urban heat island and median household income, there is an even stronger correlation between energy consumption and median household income, so this linkage makes it evident that the latter is the most influential factor in the former, and is potentially an indirect factor of household size (Azevedo et al., 2016, p. 64).

Concerning household size there is the consideration of building height (Agathangelidis et al., 2016), household capacity (Yalcintas & Kaya, 2017), and square footage (Alberini et al., 2011). This is a variable compared with urban heat island that has not been as well-studied as variables like NDVI and urban heat island or median household income and urban heat island. It is often hypothesized by researchers that larger buildings, in height, tend to induce higher temperatures within the urban sphere, but in the study concerning urban form, energy fluxes, and heat exposure, it was found that low-rise buildings contributed more to urban heat island than their high-rise building counterparts (Agathangelidis et al., 2016, p. 16). However, this study was conducted in the city of Athens, Greece, where the vast majority of the urban formation consists of low-rise buildings due to the governmental restrictions on building heights and where building density is much more clustered; the article's conclusion is a concept that is likely not applicable to the high-rise buildings found in downtown Salt Lake City, Utah.

Much of the debates that remain and are to be explored in the future are urban heat island's effects and uneven distributions on existing socio-economic inequalities and inequities found within cities (Agathangelidis et al., 2019, p. 21), urban heat island's combined effects on characteristics of urban surfaces (Buyantuyev & Wu, 2009, p. 31), and the hotly contested topic of whether or not urban heat island is an entirely negative anthropogenically-caused phenomena (Roxon et al., 2020, p. 9). An area that is even more understudied and waiting to be explored is about the topic of urban heat island's relationship with residential dwelling type, that is, household categories considering whether or not the buildings are apartment complexes, condominiums, or penthouses, etc. This paper attempts to contribute to that gap and exhibits preliminary findings from cross-sectional data recorded for the Utah county Salt Lake census tracts.

METHODS

Three datasets were used for this paper, that is:

The 2018 5-year American Community Survey (ACS), which took place from the years 2014 through 2018 (United States Census Bureau, 2018) that was an open source extracted from Social Explorer, which provided data for the variables population density, the measurement of population per unit area measured in individuals per square miles (people/mi^2), and median household income, the measurement of annual income per household in U.S. dollars per year ($/year). Both were quantitative and were categorized into Low, Medium, and High.

The housing data, which is data from 2018 that was provided by Dr. Hong from the University of Utah, which consists of census tract data for the categorical, qualitative variables attached/detached households, dwelling types (2 Unit, 3-4 Unit, 5-9 Unit, 10-19 Unit, 20-49 Unit, 50+ Unit, Mobile Trailer, and Boat, RV, Van), and years households were built (Before 1940, 1940-1959, 1960-1979, 1980-1999, 2000-2009, and 2010+) (Hong, 2020). It also provided the quantitative variable electricity expenditure, which is the amount spent per month on electric energy, and this was categorized into three classes: Low, Medium, and High.

The LST data, also from 2018 that was also provided by Dr. Hong, which consists of surface temperatures, measured in degrees Celsius (°C), for Salt Lake's census tracts (Hong, 2020). The data originates from the Remote Sensing Lab that combined data recorded from remote satellites Landsats 5, 7, and 8 (Parastatidis, 2017). This was also categorized into Low, Medium, and High.

RESULTS

Study Area: Salt Lake County

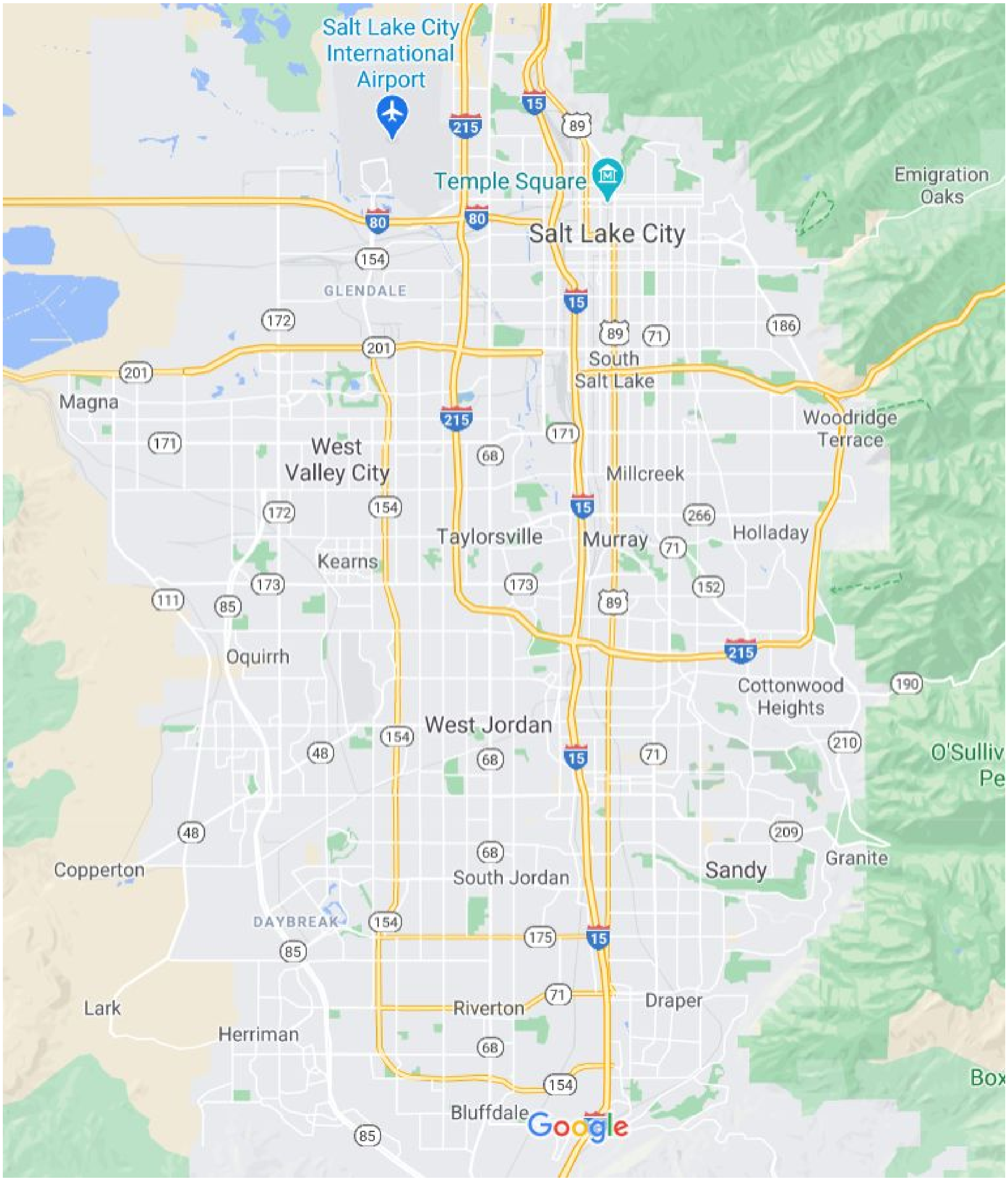


Figure 1a: Mean Land Surface Temperature

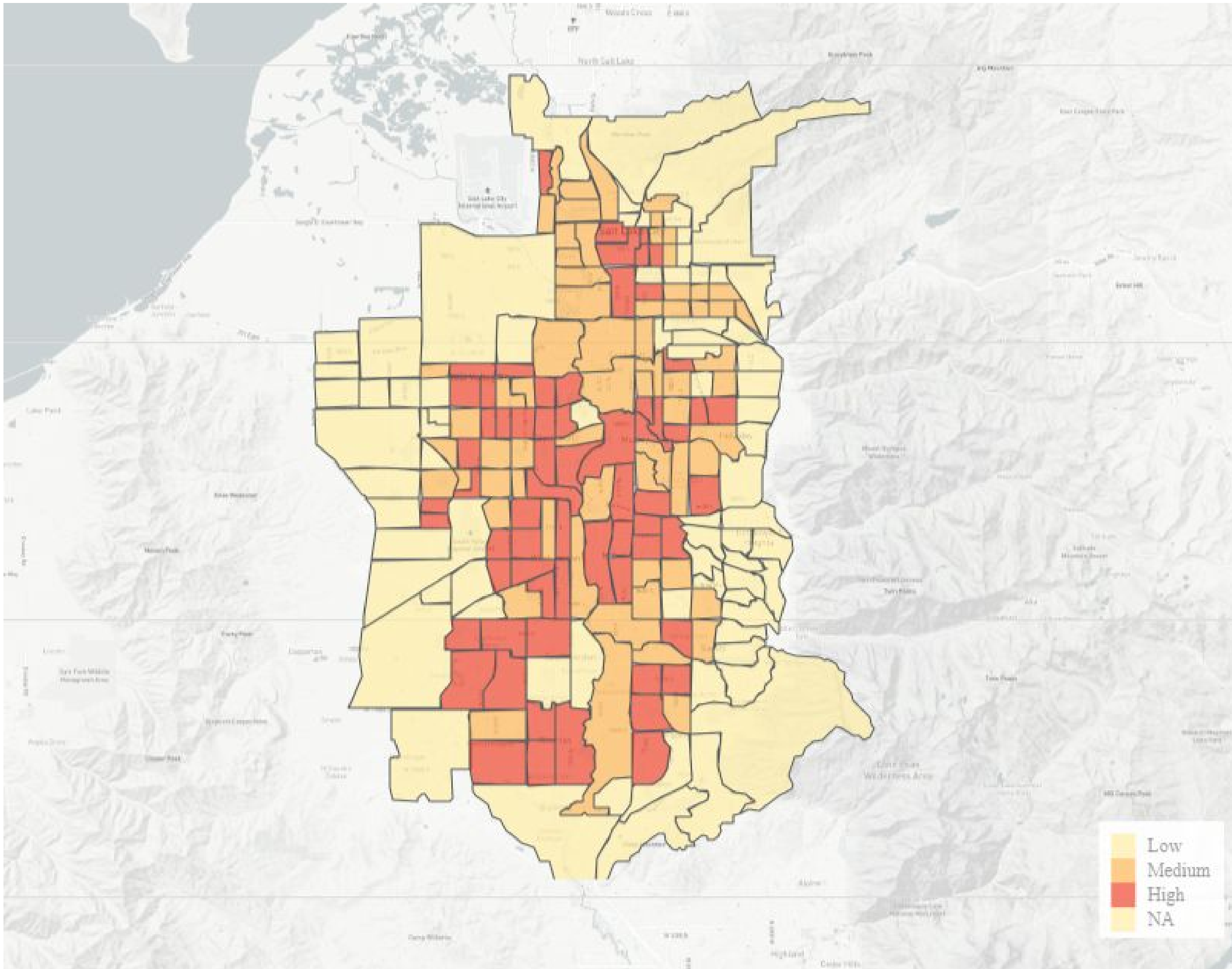


Figure 1a shows the 2018 mean land surface temperature year-round, measured in degrees Celsius (°C), with an equal frequency of three and a graduated color scheme yellow to orange to red (lowest to highest). The three classes are divided into Low with the values ranging from 1.42°C to 17.65°C (34.56°F to 63.77°F), Medium with the values ranging from 17.65°C to 18.57°C (63.77°F to 65.43°F), and High with the values ranging from 18.57°C to 20.30°C (65.43°F to 68.54°F), as well as one that is classified as NA (Not Applicable) for census tracts that are not recorded.

What is immediately noticeable on the map is that Salt Lake county's outskirts possess census tracts that are primarily on the Low scale of the mean land surface temperature, and converging towards the middle the census tracts eventually darken into the Medium and the

High scales. However, there are not many dark areas in the urban core (i.e. Salt Lake City) and there are several Low level spots surrounded by higher level land surface temperatures.

Figure 1b: Summer Mean Land Surface Temperature

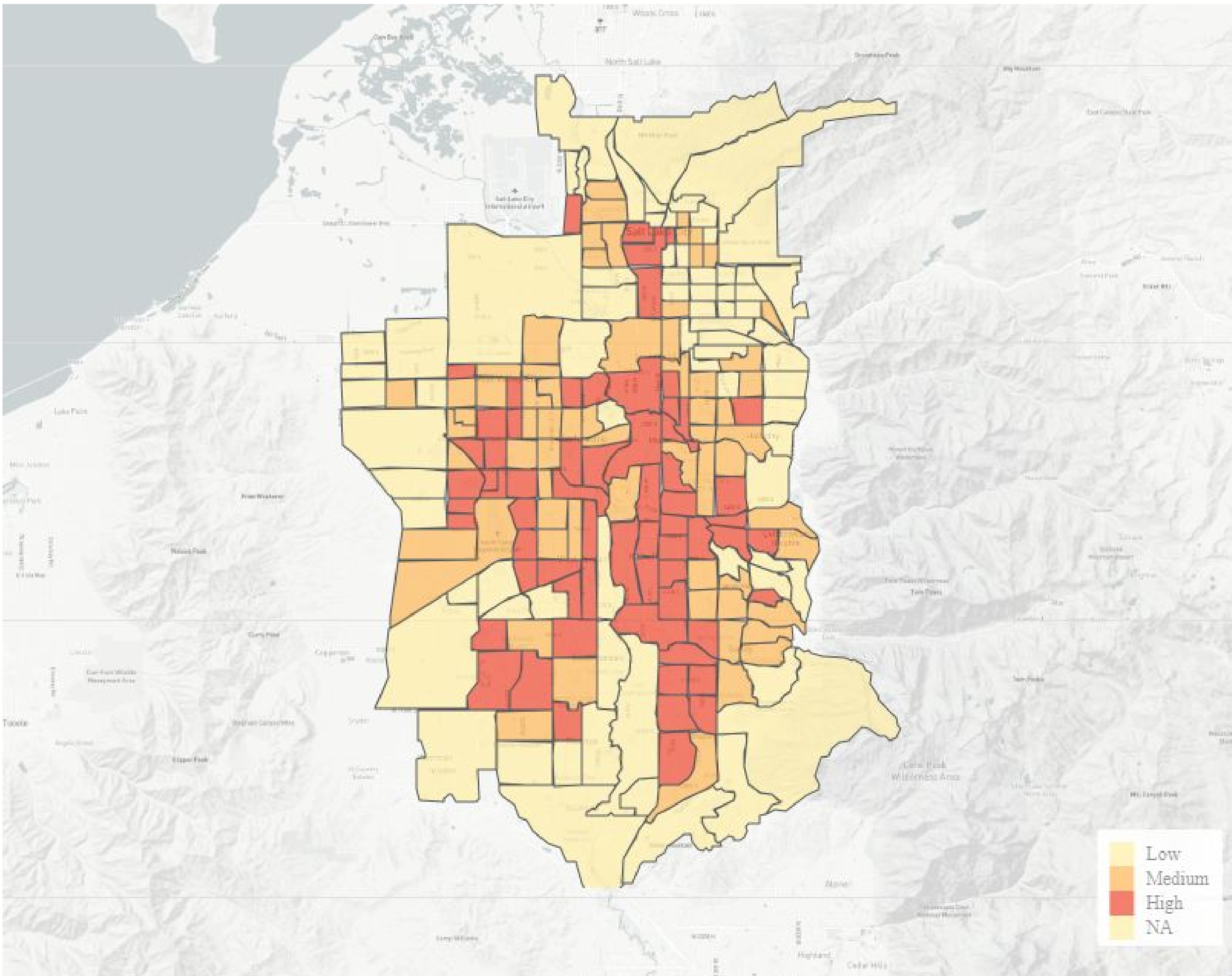


Figure 1b shows the 2018 mean land surface temperature in the summer, measured in degrees Celsius (°C), with an equal frequency of three and a graduated color scheme yellow to orange to red (lowest to highest). The three classes are divided into Low with the values ranging from 16.22°C to 25.68°C (61.20°F to 78.22°F), Medium with the values ranging from 25.68°C to 26.62°C (78.22°F to 79.92°F), and High with the values ranging from 26.62°C to 27.77°C (79.92°F to 81.99°F), as well as one that is classified as NA (Not Applicable) for census tracts that are not recorded.

This is a fascinating comparison to that of figure 1a in that several of the census tracts that were higher on the scale fell to lower categories, and several of the census tracts that were lower on the scale rose to higher categories. However, it is to be noted that the overall temperature scales for the summer have been shifted upward in comparison to the year-round map (i.e. the summer map's Low maximum is higher than the year-round map's High maximum).

Figure 1c: Sum Land Surface Temperature

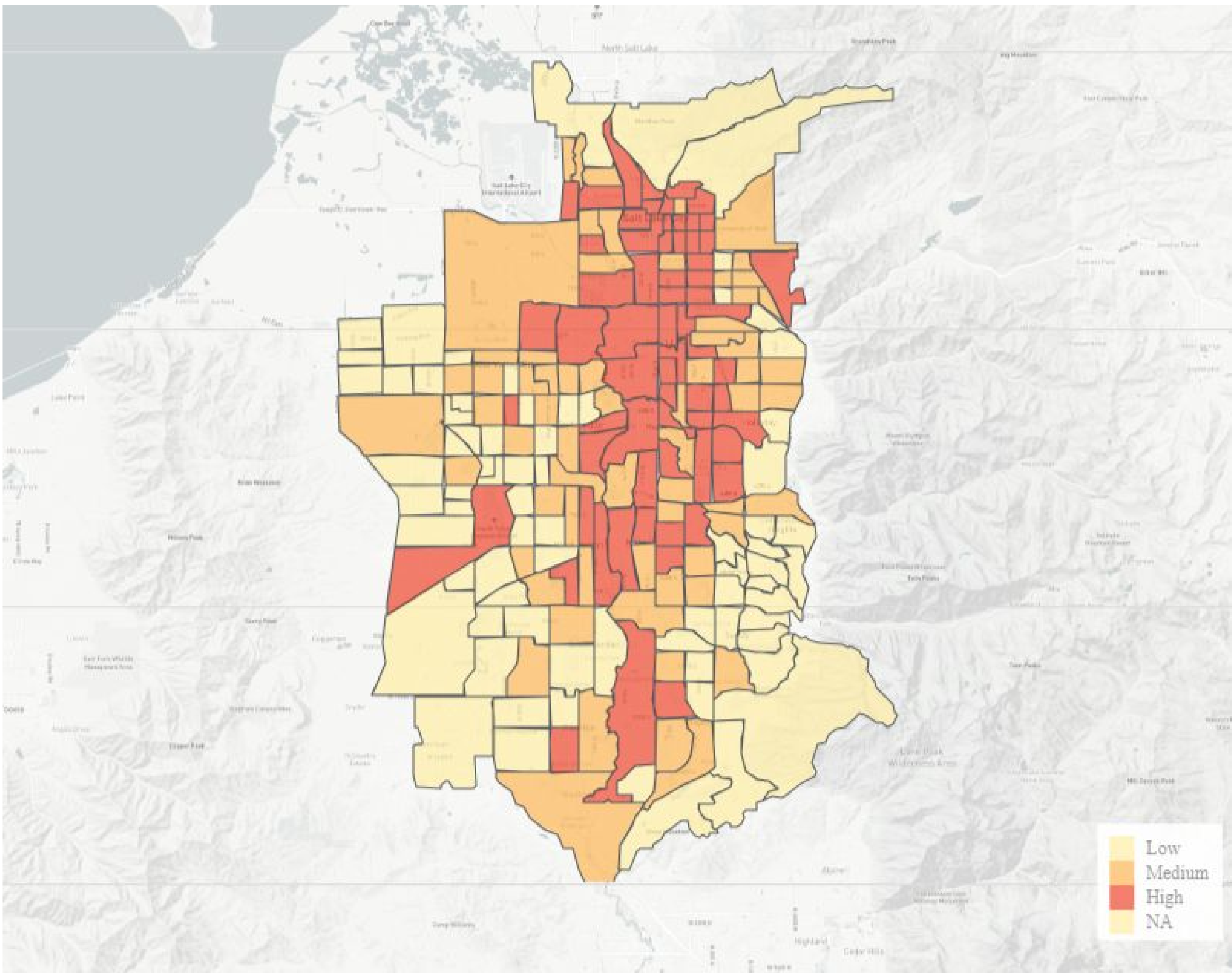


Figure 1c shows the 2018 sum land surface temperature year-round, measured in degrees Celsius (°C), with an equal frequency of three and a graduated color scheme yellow to orange to red (lowest to highest). The three classes are divided into Low with the values ranging from 17.07°C to 4,871.71°C (62.73°F to 8,801.01°F), Medium with the values ranging from 4,871.71°C to 9,311.08°C (8,801.01°F to 16,791.94°F), and High with the values ranging from 9,311.08°C to 21,046.63°C (16,791.94°F to 37,915.93°F), as well as one that is classified as NA (Not Applicable) for census tracts that are not recorded.

From observing this map it is evident that temperatures year-round are, in total, higher in the more urbanized areas than the urban outskirts of Salt Lake county. There is also a number of High temperature census tracts that follow the heavily-trafficked freeway named Interstate 15, colloquially known as I15. The High census tract to the west likely has higher temperatures due to the South Valley Regional Airport that is situated there.

Figure 1d: Summer Sum Land Surface Temperature

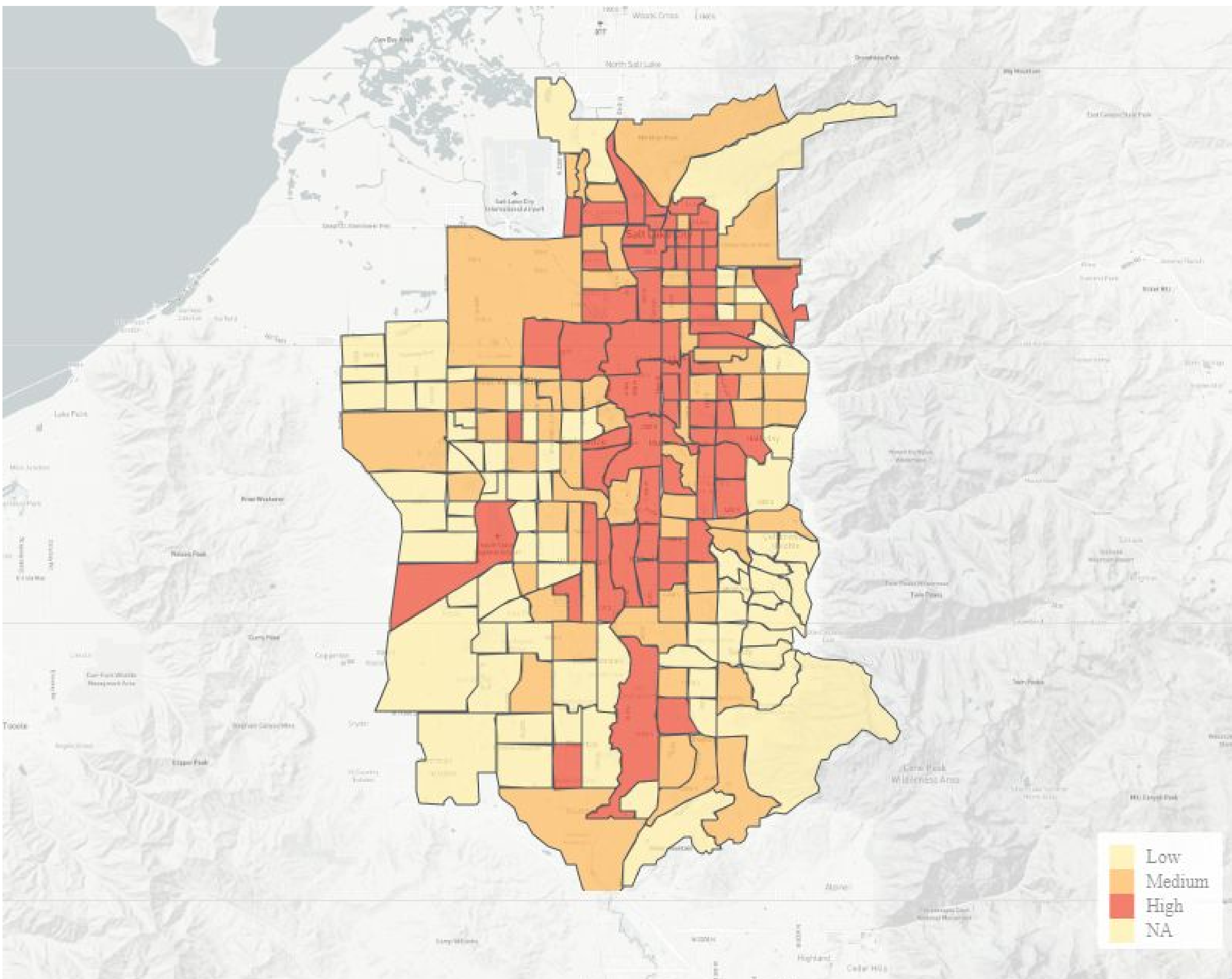


Figure 1d shows the 2018 sum land surface temperature in the summer, measured in degrees Celsius (°C), with an equal frequency of three and a graduated color scheme yellow to orange to red (lowest to highest). The three classes are divided into Low with the values ranging from 24.10°C to 6,971.59°C (75.38°F to 12,580.86°F), Medium with the values ranging from 6,971.59°C to 13,172.13°C (12,580.86°F to 23,741.83°F), and High with the values ranging from

13,172.13°C to 29,700.20°C (23,741.83°F to 53,492.36°F), as well as one that is classified as NA (Not Applicable) for census tracts that are not recorded.

This map is similar to figure 1c in their spatial patterns where the higher land surface temperatures are clustered in the center of Salt Lake county's urban core than its urban periphery, also aligning with the highway I15 and the South Valley Regional Airport. There is a large upward shift in the land surface temperatures and Medium level census tracts have appeared to the north and to the southeast of Salt Lake county.

Figure 2a: Mean Household Electricity Expenditure

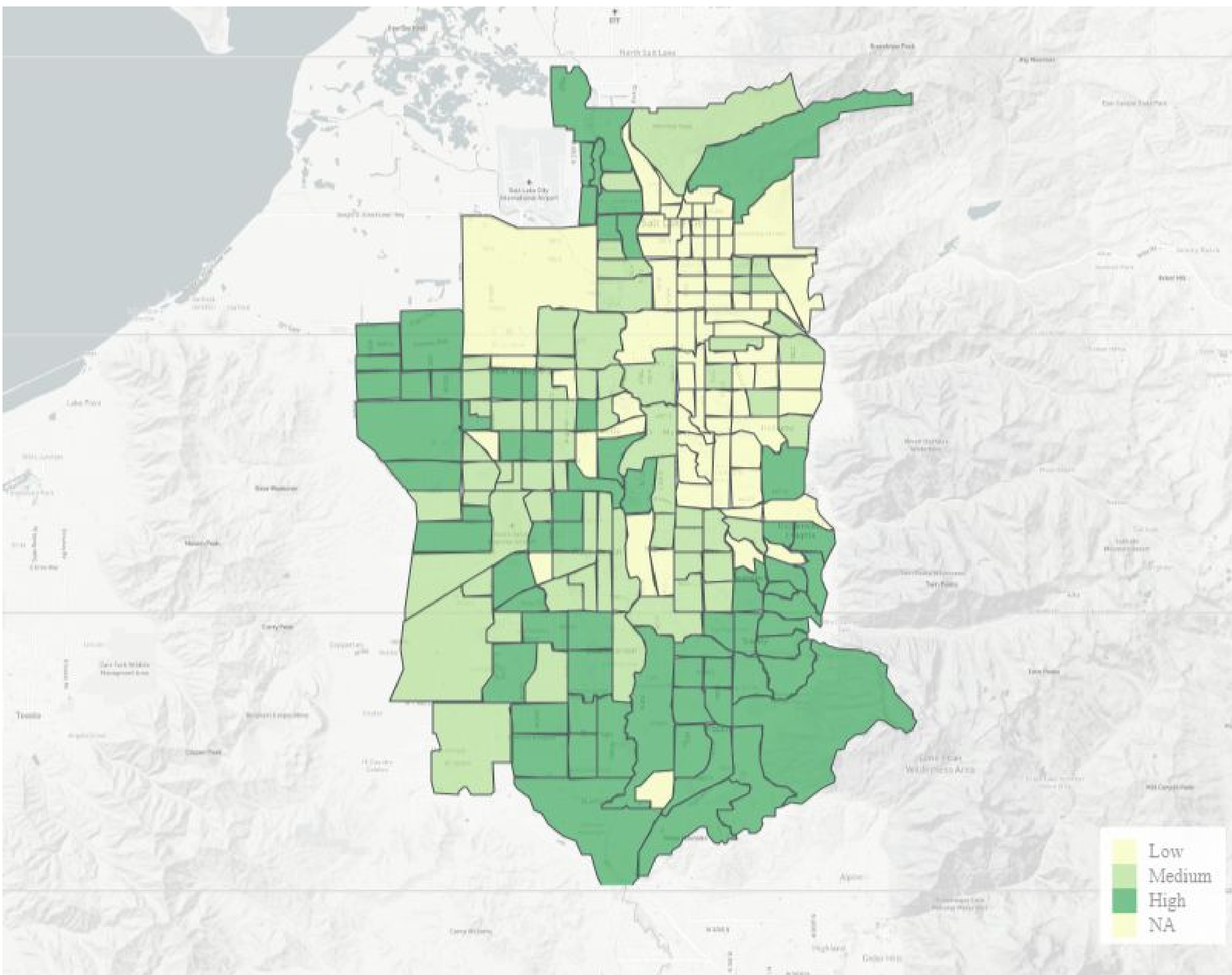


Figure 2a shows the 2018 mean household electricity expenditure, measured in U.S. dollars per month ($/month), with an equal frequency of three and a graduated color scheme yellow to green (lowest to highest). The three classes are divided into Low ($476.80/month to $786.46/month), Medium ($786.46/month to $899.59/month), and High ($899.59/month to

$1,192.50/month), as well as one that is classified as NA (Not Applicable) for census tracts that are not recorded.

From observing the map it is clear that the higher electricity expenditures are located in the urban periphery, primarily the northernmost, southernmost, southeasternmost, and westernmost regions. Lowest electricity expenditures are congregated in the urban core and upper-central region of Salt Lake county.

Figure 2b: Sum Household Electricity Expenditure

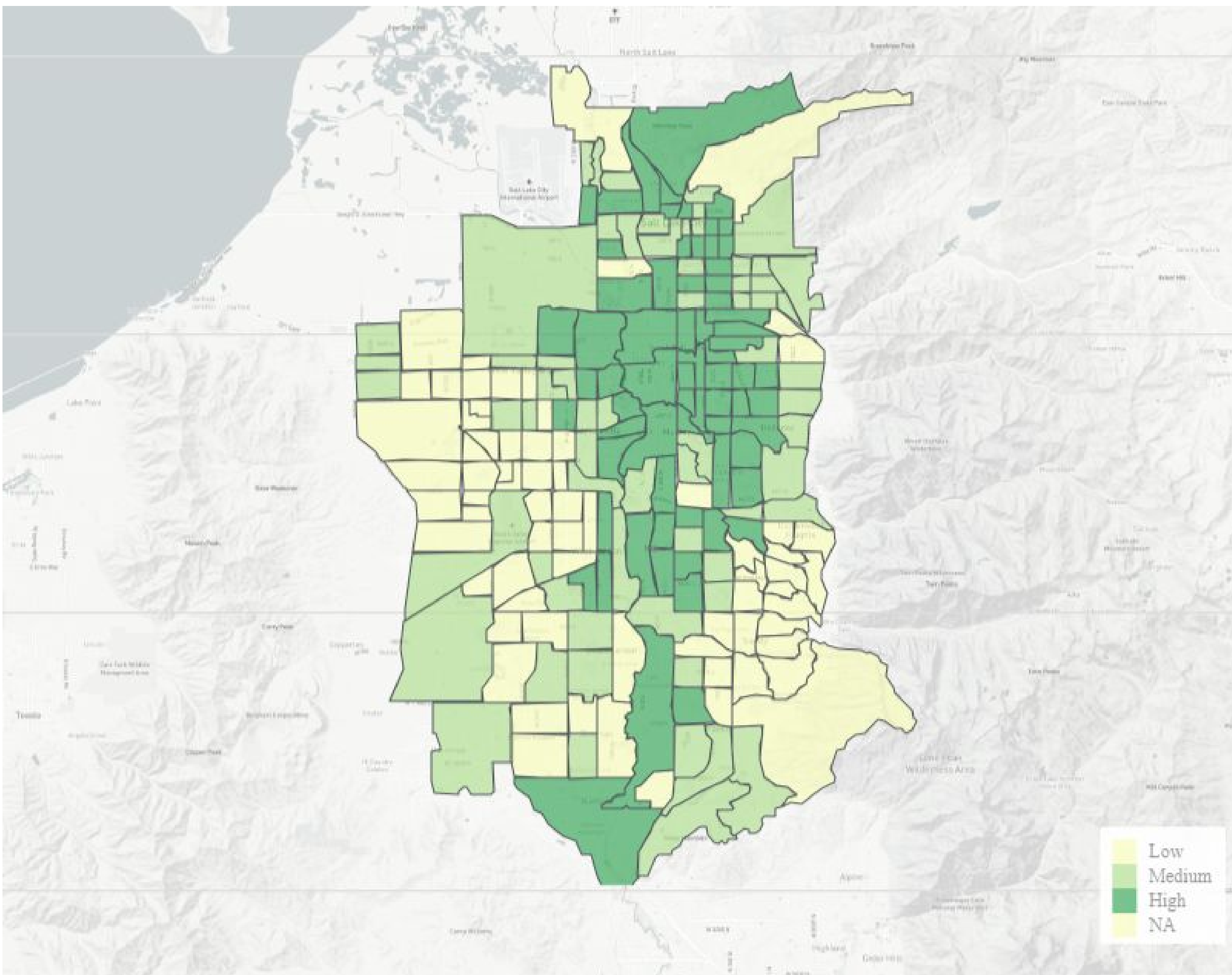


Figure 2b shows the 2018 sum household electricity expenditure, measured in U.S. dollars per month ($/month), with an equal frequency of three and a graduated color scheme yellow to green (lowest to highest). The three classes are divided into Low ($35,751.53/month to $103.988.48/month), Medium ($103,988.48/month to $158,507.89/month), and High

($158,507.89/month to $272,331.18/month), as well as one that is classified as NA (Not Applicable) for census tracts that are not recorded.

The total household electricity expenditures have a spatial pattern where spending is most intense within the urban core in contrast to figure 2a's spatial pattern where spending is most intense outside of the urban core. This inverted visual rhythm between figures 2a and 2b are likely due to differences in electricity pricing of the census tracts and/or the income levels of the census tracts as well as the population density and/or urbanity of the areas.

Figure 3: Attached and Detached Households

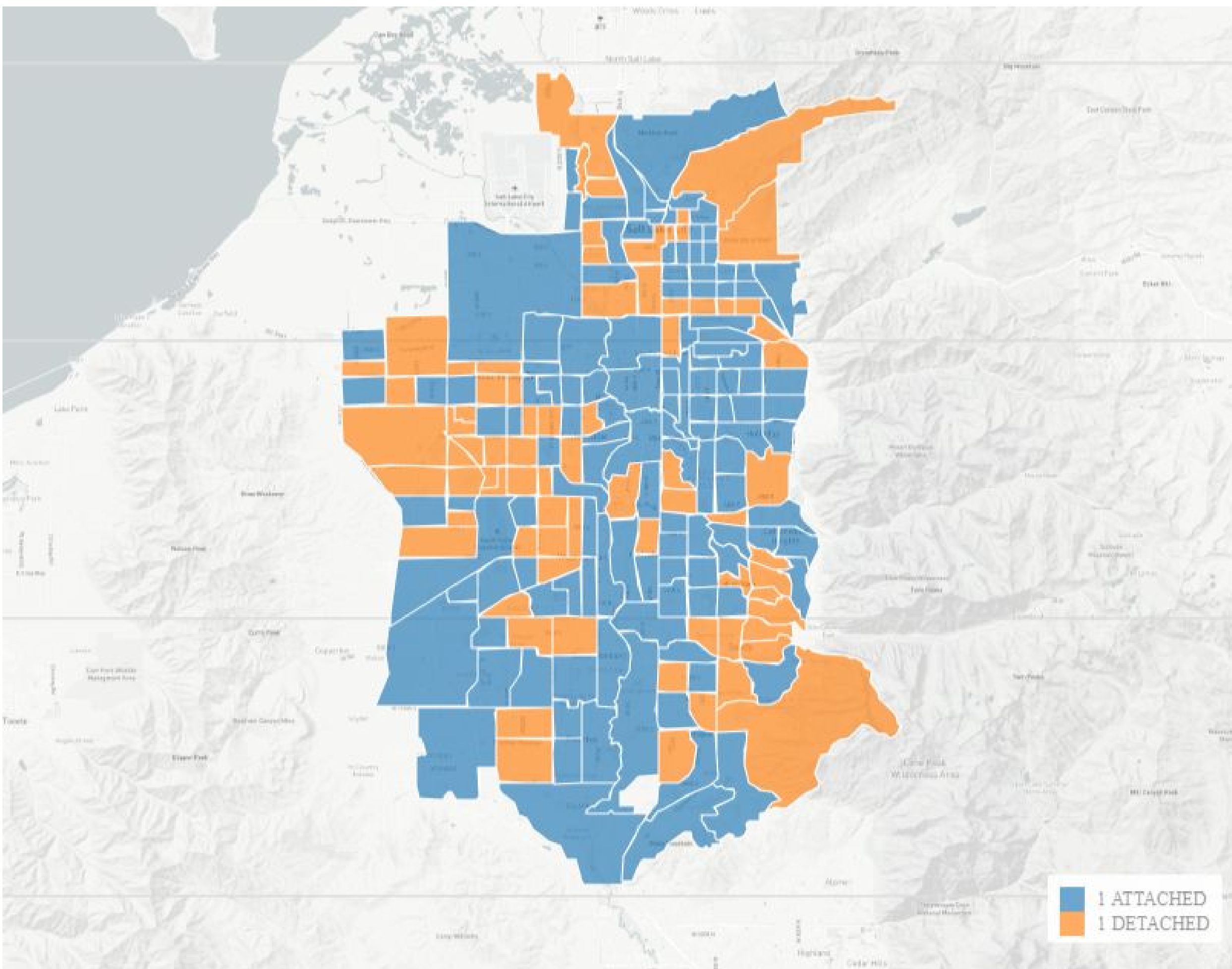


Figure 3 showcases the most dominant housings that are found in each of the census tracts, attached in blue and detached in oranged. Detached households seem to lean more toward the outskirts of Salt Lake county whereas Attached households are the most dominant forms in the urban center as well as for Salt Lake county as a whole. This could have a relationship with the population density as higher urban areas are less likely to have single, free-standing households and are more likely to have Attached households clustered together.

Figure 4: Household Types

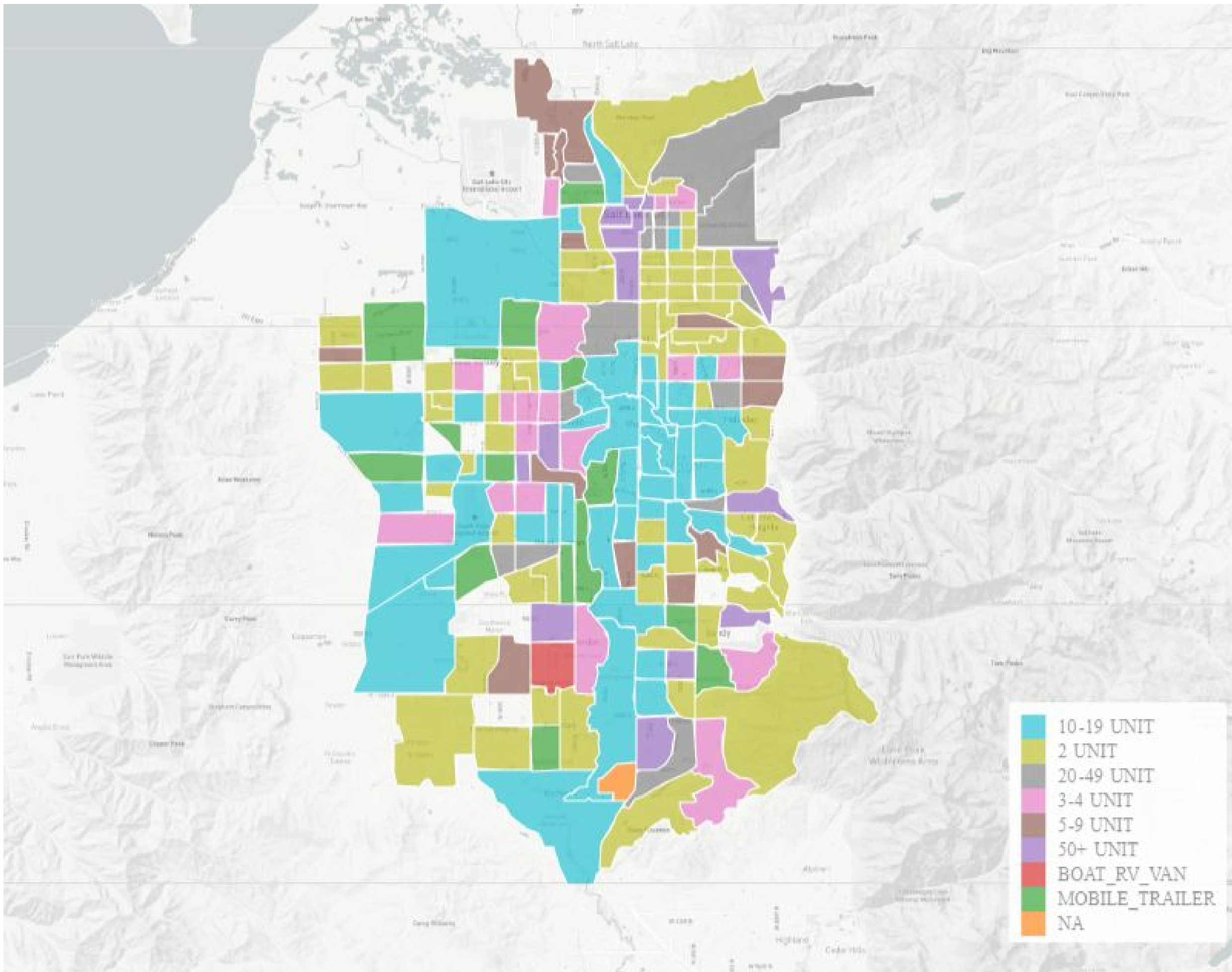


Figure 4 maps out the different housing types in different, contrasting colors: NA (Not Applicable) is represented by orange, 2 Unit is represented by light green, 3-4 Unit is represented by pink, 5-9 Unit is represented by brown, 10-19 Unit is represented by blue, 20-49 Unit is represented by gray, 50+ Unit is represented by purple, Mobile Trailer is represented by dark green, and Boat, RV, Van is represented by red.

The dwelling types are distributed in no particular spatial pattern, but it looks like 2 Unit and 10-19 Unit household types dominate Salt Lake county, and categories that are above 10 units seem to take up more of the urban center.

Figure 5: Mean Population Density

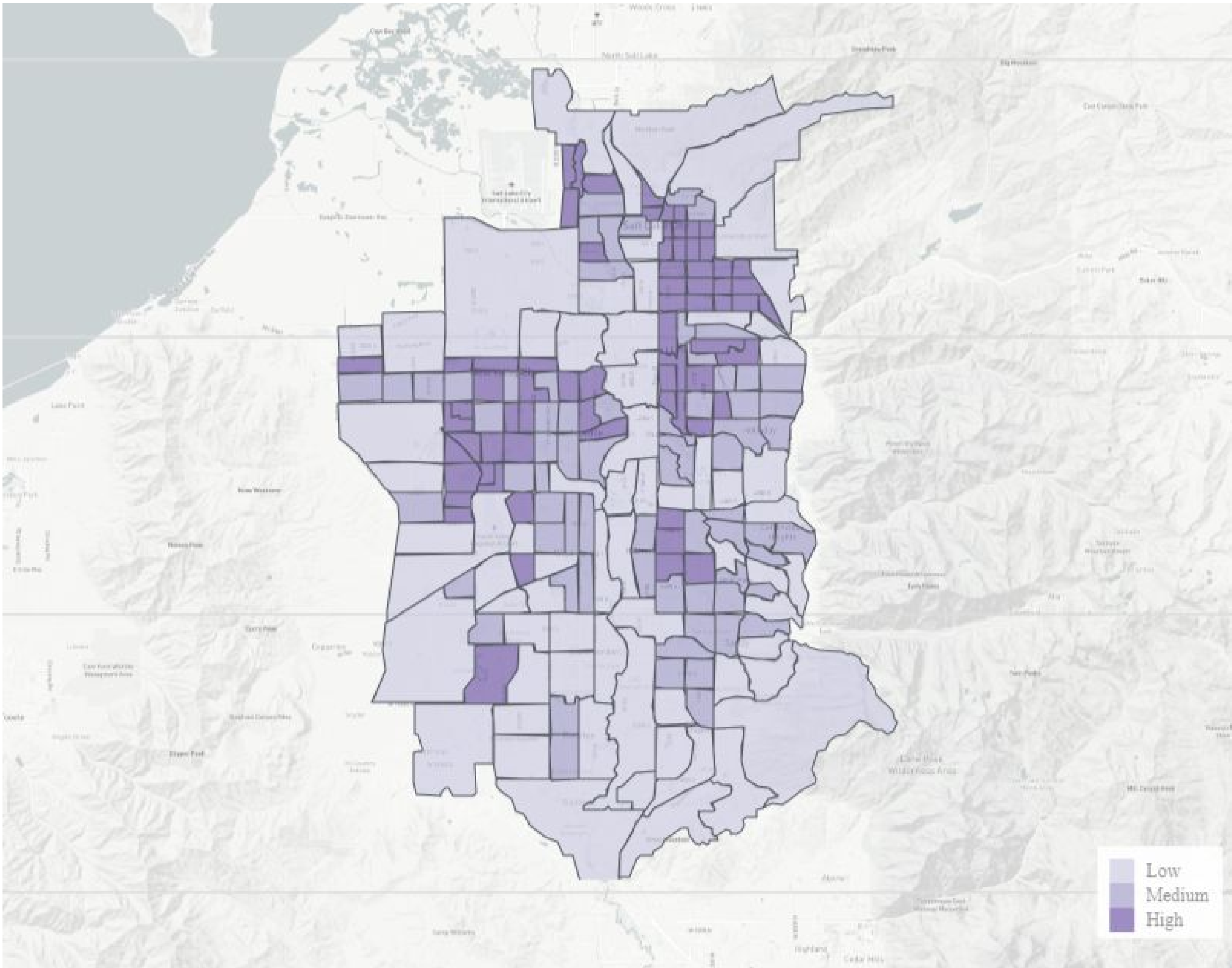


Figure 5 shows the mean population density, measured in individuals per square mile (people/mi^2), with an equal frequency of three and a graduated purple scheme (lowest to highest). The three classes are divided into Low (145.46/mi^2 to 4,307.91/mi^2), Medium (4,307.91/mi^2 to 6,462.01/mi^2), and High (6,462.01/mi^2 to 18,279.08/mi^2).

There seems to be a high population density in the urban core in Salt Lake City as well as in the western part of the county, where a large amount of the population live in Daybreak, Kearns, and West Valley City. Other areas that are densely populated are Millcreek, south of Salt Lake City, Midvale, the isolated cluster below Millcreek, and Rose Park, northwest of Salt Lake City. There is less population density among census tracts that are located on or near highways like I15 (vertical gap), I80 and I215 on the east side, and

Figure 6: Median Household Income

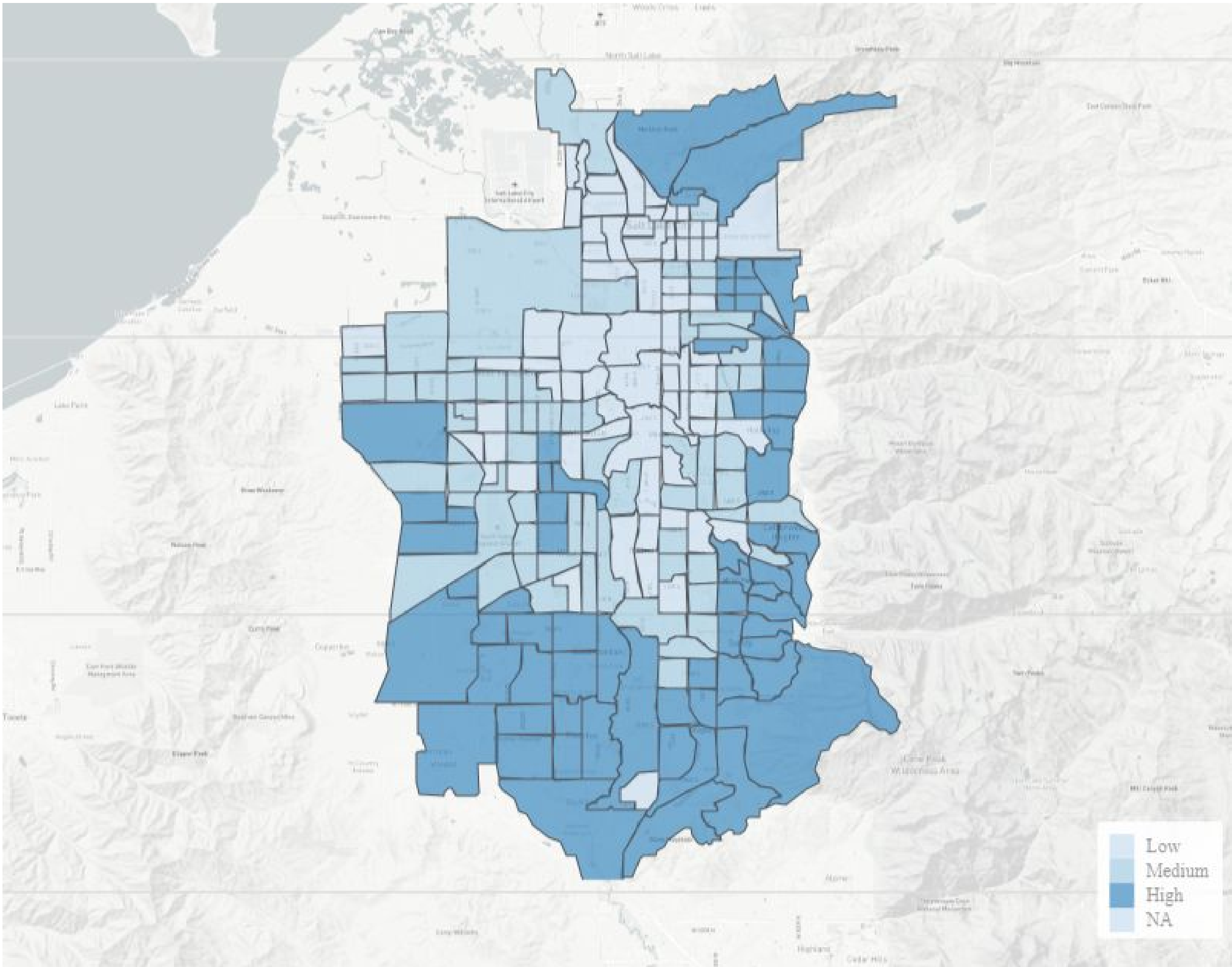


Figure 6 provides a picture of the mean median household income distribution across Salt Lake County, measured in U.S. dollars per year ($/year), with an equal frequency of three and a graduated blue scheme (lowest to highest). The three classes are divided into Low ($24,396.00/year to $61,140.67/year), Medium ($61,140.67/year to $82,285.67/year), and High ($82,285.67/year to $203,194.00/year), as well as one that is classified as NA (Not Applicable) for census tracts that are not recorded.

The vast majority of the census tracts that are considered high income are distributed across the periphery of Salt Lake county in the northernmost, easternmost, some of the westernmost, and particularly the southernmost regions. The vast majority of the census tracts that are considered medium income or low income are distributed across the center of the county, and it seems the lowest income is in the center followed by a ring of medium income then the outer ring of high income.

Figure 7: Year Built

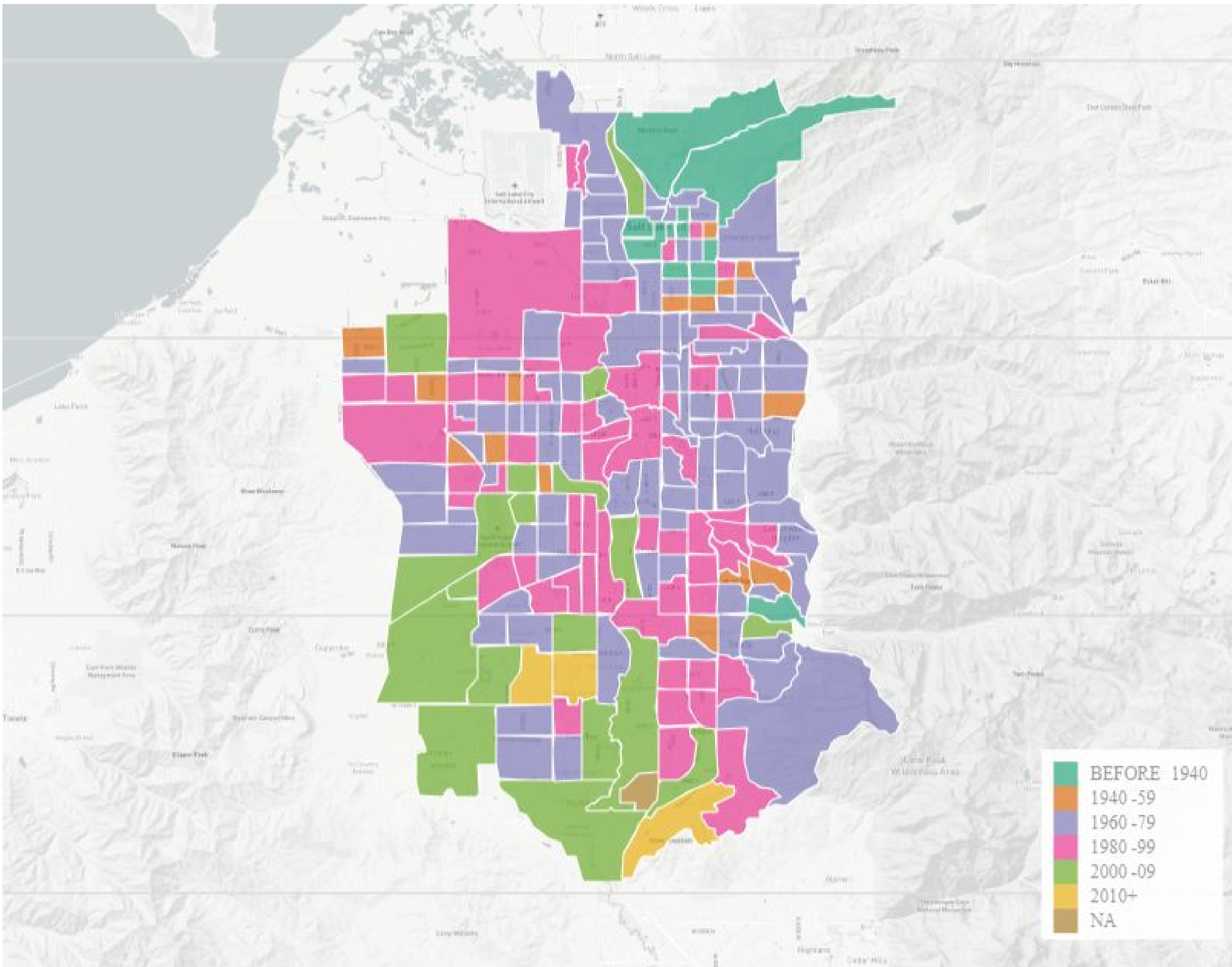


Figure 7 shows the census tracts colored by households by the year they were built: NA (Not Applicable) is represented by brown, Before 1940 is represented by dark green, 1940 to 1959 is represented by orange, 1960 to 1979 is represented by purple, 1980 to 1999 is represented by pink, 2000 to 2009 is represented by light green, and 2010+ is represented by yellow.

There is no noticeable spatial pattern to the map, but it can be observed that Salt Lake county is dominated by households built between the years 1960 to 1979 and 1980 to 1999.

Figure 8: Year-Round Household Type and Electricity Expenditure

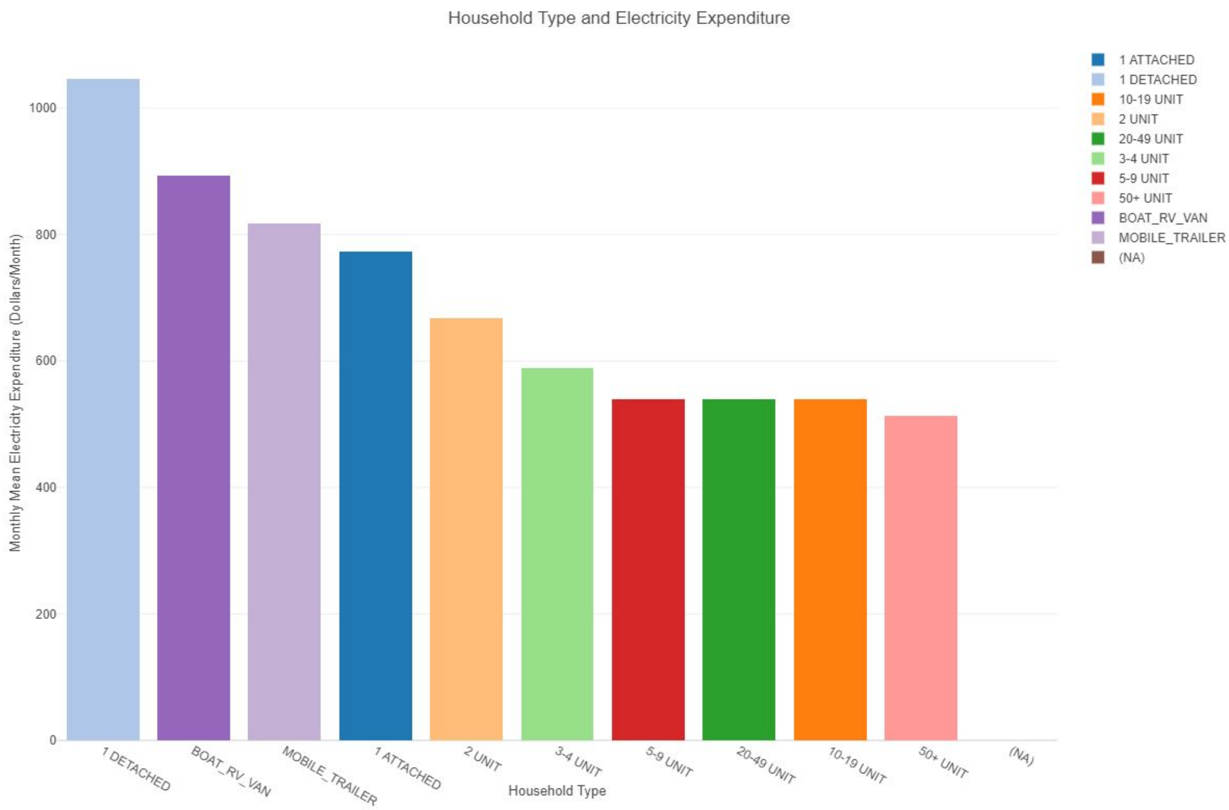


Figure 8 is a bar chart that shows which household types on average spend the most on electricity with Detached (light blue) leading with $1,045.48/month, followed by Boat, RV, Van (dark purple) with $892.45/month, then Mobile Trailer (light purple) with $817.81/month, Attached (dark blue) with $772.39/month, 2 Unit (light orange) with $667.76/month, 3-4 Unit (light green) with $588.81/month, 5-9 Unit (red) with $539.50/month, 20-49 Unit (dark green) with $539.40/month, 10-19 Unit (dark orange) with $539.33/month, and lastly 50+ Unit (pink) with $512.88/month.

It might be surprising and unexpected at first to see that Boat, RV, Van and Mobile Trailer in the top three average monthly electricity expenditures, but the vehicles rely primarily on electricity to power air conditioning and heating whereas other forms of household types have several options for energy other than electricity and are more well-insulated compared to mobile vehicles. It also seems that as the units increase the lower the electricity expenditure is, this could be attributed to a variety of potential factors beyond the scope of this paper, like the cost of electricity, the household's income, the location, or the property value.

Figure 9a:Year-Round Land Surface Temperature, Electricity Expenditure, and Household Type

Household Type	Low (1.42°C - 17.93°C)	Medium (17.93°C - 18.58°C)	High (18.58°C - 20.30°C)
Attached	$776.08/month	$769.76/month (*0.81% decrease*)	$774.32/month (*0.59% increase*)
Detached	$1,027.36/month	$1,018.95/month (*0.82% decrease*)	$1,075.05/month (*5.51% increase*)
2 Unit	$652.33/month	$664.24/month (*1.83% increase*)	$671.98/month (*1.17% increase*)
3-4 Unit	$554.71/month	$589.11/month (*6.20% increase*)	$618.36/month (*4.97% increase*)
5-9 Unit	$478.57/month	$529.30/month (*10.60% increase*)	$595.49/month (*12.50% increase*)
10-19 Unit	$505.93/month	$557.66/month (*10.22% increase*)	$546.93/month (*1.92% decrease*)
20-49 Unit	$542.85/month	$522.75/month (*3.70% decrease*)	$541.99/month (*3.68% increase*)
50+ Unit	$510.71/month	$503.61/month (*1.39% decrease*)	$522.63/month (*3.78% increase*)
Boat, RV, Van	NA	NA	NA
Mobile Trailer	NA	NA	NA

Figure 9a and its accompanying table shows the varying electricity expenditures for each of the household types grouped by the land surface temperature level. The only household types that show an overall increase in electricity expenditure are the 2 Unit, 3-4 Unit, and 5-9 Unit. The 10-19 unit shows an increase in expenditure from Low to Medium, but from Medium to High there is a decrease. The other dwelling types—Attached, Detached, 20-49 Unit, and 50+ Unit—show a decrease in expenditure from Low to Medium, then an increase from Medium to High temperature categories.

Figure 9b: Summer Land Surface Temperature, Electricity Expenditure, and Household Type

Household Type	Low (16.22°C - 25.64°C)	Medium (25.64°C - 26.62°C)	High (26.62°C - 27.77°C)
Attached	$774.39/month	$754.21/month (*2.61% decrease*)	$793.18/month (*5.17% increase*)
Detached	$1,036.26/month	$1,018.62/month (*1.70% decrease*)	$1,067.72/month (*4.82% increase*)
2 Unit	$658.97/month	$657.88/month (*0.17% decrease*)	$670.30/month (*1.89% increase*)
3-4 Unit	$543.39/month	$595.74/month (*9.63% increase*)	$636.57/month (*6.85% increase*)
5-9 Unit	$475.83/month	$518.94/month (*9.06% increase*)	$614.88/month (*18.49% increase*)
10-19 Unit	$507.12/month	$553.87/month (*9.22% increase*)	$552.09/month (*0.32 decrease*)
20-49 Unit	$511.10/month	$531.73/month (*4.04% increase*)	$564.35/month (*6.13% increase*)
50+ Unit	$499.32/month	$502.05/month (*0.55% increase*)	$534.79/month (*6.52% increase*)
Boat, RV, Van	NA	$892.45/month	NA
Mobile Trailer	$1,001.47/month	$773.91/month (*22.72% decrease*)	$784.84/month (*1.41% increase*)

Figure 9b and its accompanying table shows the varying electricity expenditures for each of the household types grouped by the land surface temperature level. The only household types that show an overall increase in electricity expenditure are the 3-4 Unit, 5-9 Unit, 20-49 Unit, and 50+ Unit. The 10-19 unit again shows an increase in expenditure from Low to Medium, but from Medium to High there is a decrease. The other dwelling types—Attached, Detached, 2 Unit, and Mobile Trailer—show a decrease in expenditure from Low to Medium, then an increase from Medium to High temperature categories.

Figure 10: Household Year and Electricity Expenditure

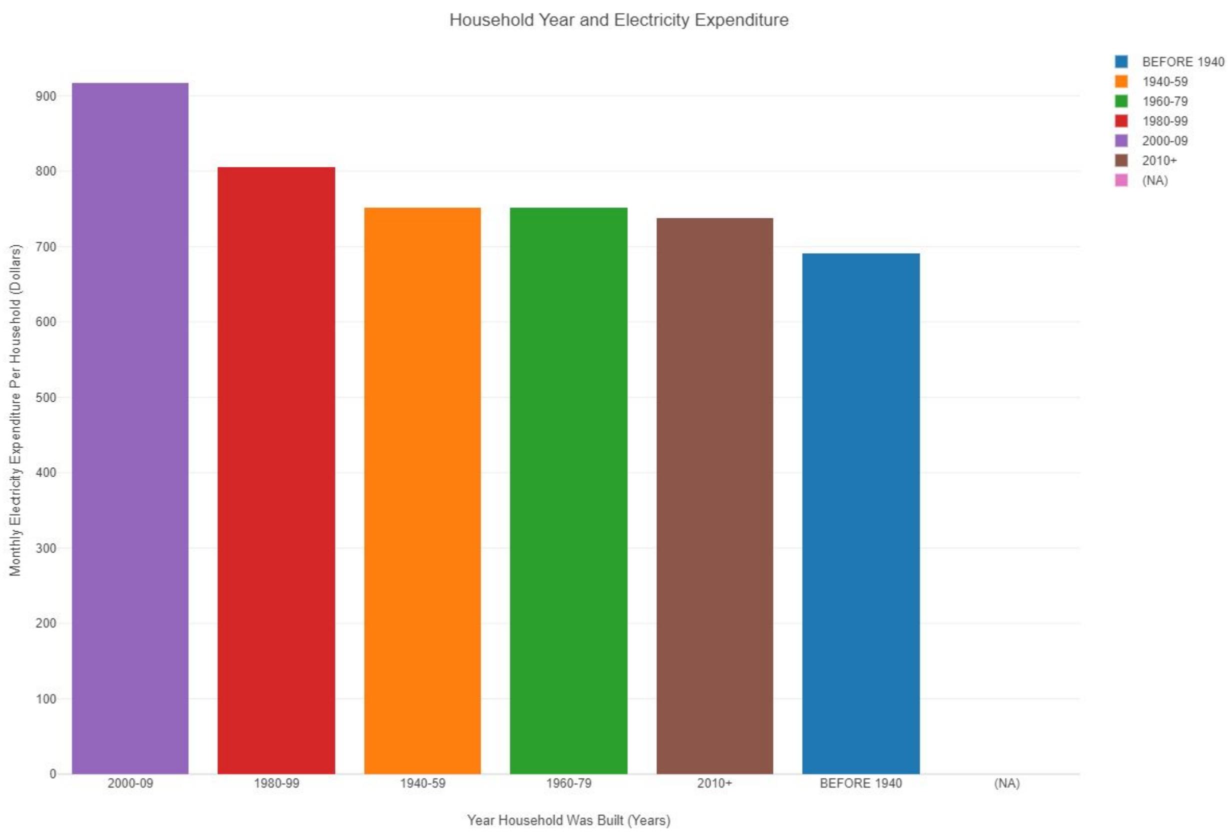


Figure 10 is a bar chart that shows the years in which the household was built in ten-year intervals and how much on average the most was spent on electricity. Households built between 2000-2009 (purple) leads with $917.08/month, followed by 1980-1999 (red) with $806.01/month, then 1940-1959 (orange) with $751.87/month, 1960-1979 (green) with $751.78/month, 2010+ (brown) with $737.46/month, and lastly Before 1940 (blue) with $690.67/month.

The results may be surprising as it would be expected that homes built past 1999 would spend less on electricity as opposed to older homes built before 1999 as more recent households are constructed to be more energy efficient. However, there is the explanation that newer homes are larger and can be equipped with more appliances and amenities like saunas and swimming pools that older homes often do not have.

Figure 11a: Year-Round Land Surface Temperature, Electricity Expenditure, and Household Type

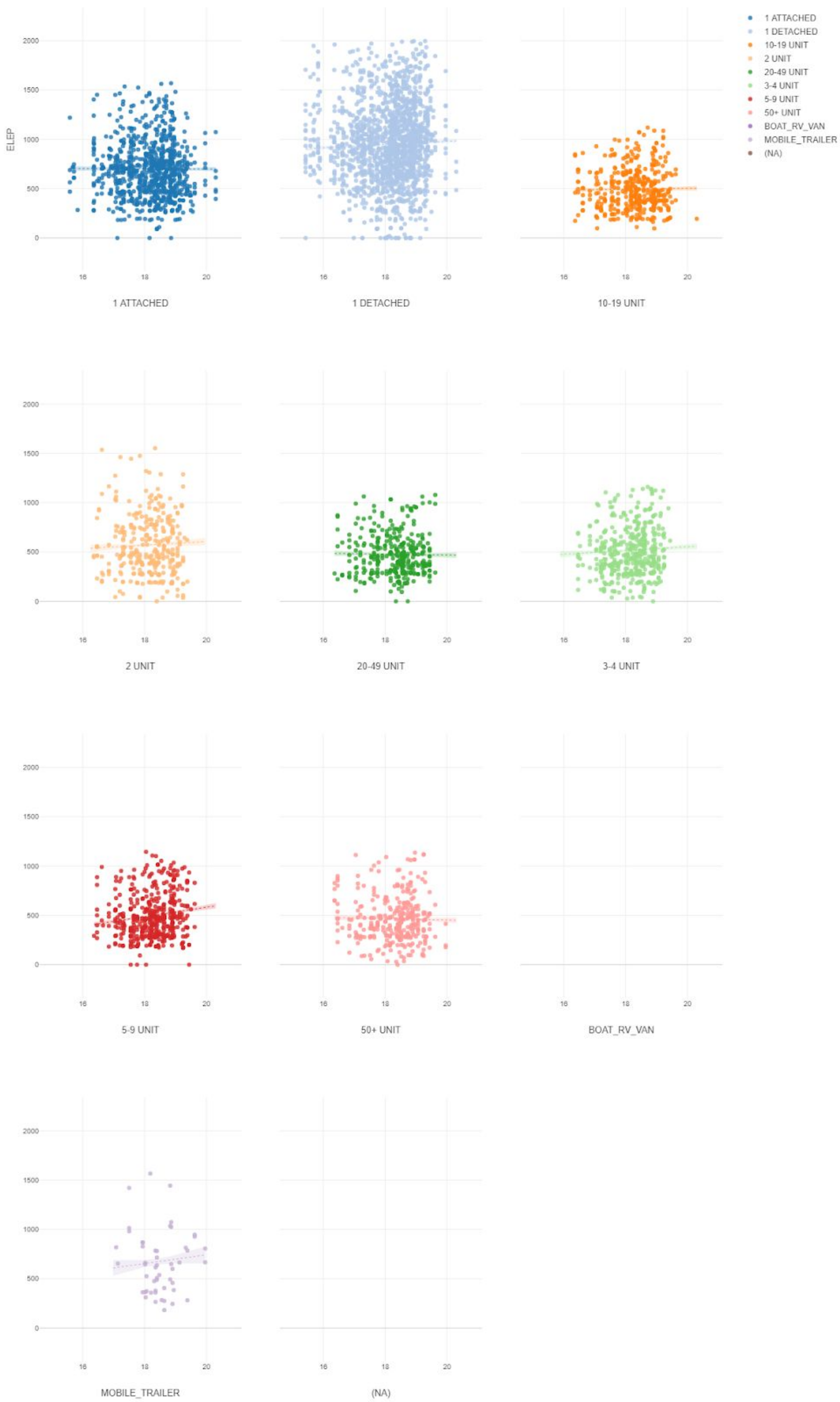


Figure 11a is a scatterplot showing the different dwelling types and their relationships with year-round land surface temperature, on the x-axis, and electricity expenditure, on the y-axis.

Attached P-Value: 0.81 | greater than 0.05 | accept null hypothesis | no correlation.

Detached P-Value: 0.00 | less than 0.05 | reject null hypothesis | positive correlation.

2 Unit P-Value: 0.06 | greater than 0.05 | accept null hypothesis | no correlation.

3-4 Unit P-Value: 0.01 | less than 0.05 | reject null hypothesis | positive correlation.

5-9 Unit P-Value: 0.00 | less than 0.05 | reject null hypothesis | positive correlation.

10-19 Unit P-Value: 0.44 | greater than 0.05 | accept null hypothesis | no correlation.

20-49 Unit P-Value: 0.47 | greater than 0.05 | accept null hypothesis | no correlation.

50+ Unit P-Value: 0.25 | greater than 0.05 | accept null hypothesis | no correlation.

Boat, RV, Van P-Value: NA.

Mobile Trailer P-Value: 0.09 | greater than 0.05 | accept null hypothesis | no correlation.

From the figure 11a, the only household types with correlation are Detached, 3-4 Unit, and 5-9 Unit. However, the correlation coefficients (r) are extremely weak with 0.04, 0.05, and 0.15 as their values respectively. While they do have positive correlations, they are very weak and their relationships with electricity expenditure and land surface temperature are nominal.

Figure 11b: Summer Land Surface Temperature, Electricity Expenditure, and Household Type

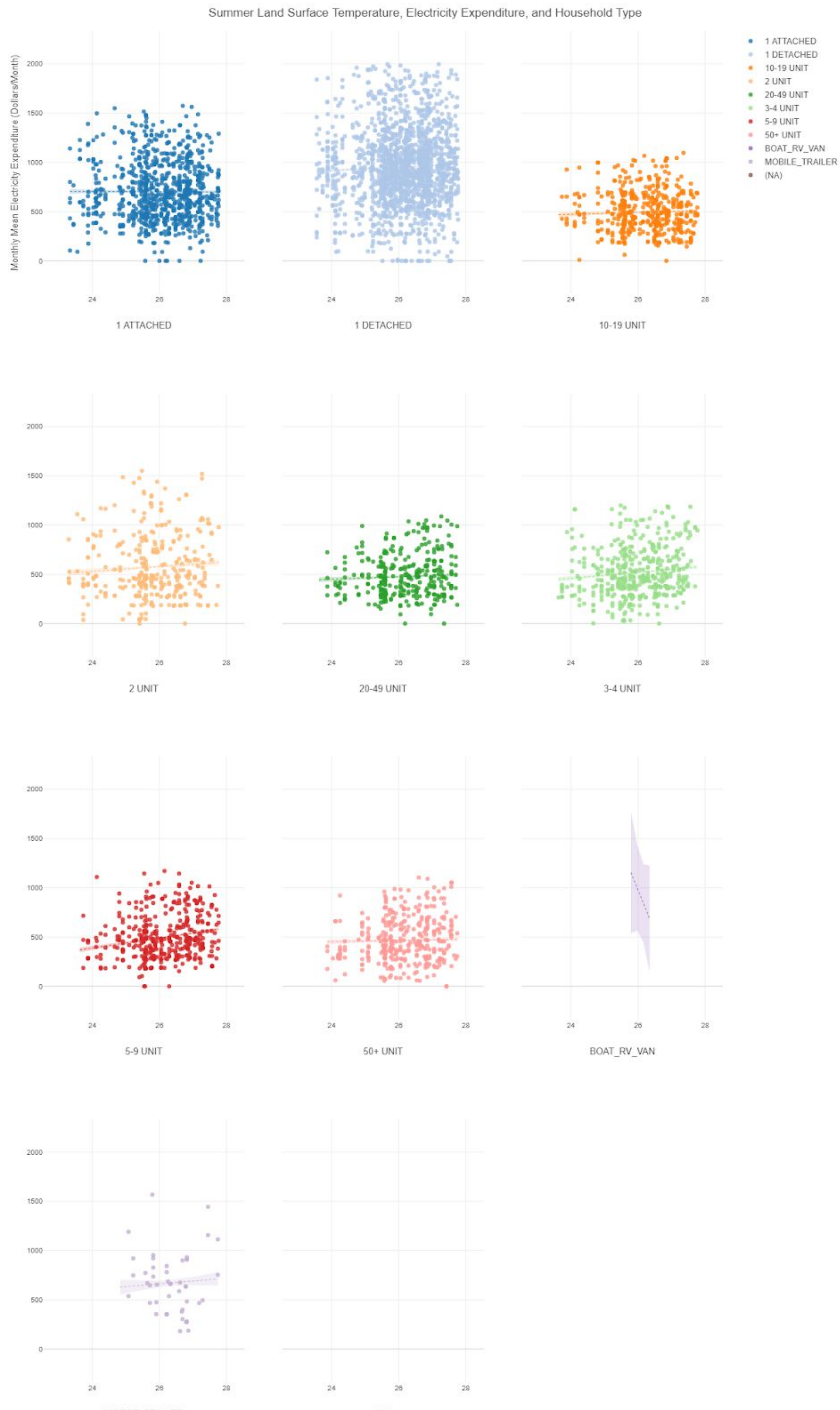


Figure 11b is a scatterplot showing the different dwelling types and their relationships with summer land surface temperature, on the x-axis, and electricity expenditure, on the y-axis.

Attached P-Value: 0.71 | greater than 0.05 | accept null hypothesis | no correlation.

Detached P-Value: 0.00 | less than 0.05 | reject null hypothesis | positive correlation.

2 Unit P-Value: 0.00 | less than 0.05 | reject null hypothesis | positive correlation.

3-4 Unit P-Value: 0.00 | less than 0.05 | reject null hypothesis | positive correlation.

5-9 Unit P-Value: 0.00 | less than 0.05 | reject null hypothesis | positive correlation.

10-19 Unit P-Value: 0.03 | less than 0.05 | reject null hypothesis | positive correlation.

20-49 Unit P-Value: 0.01 | less than 0.05 | reject null hypothesis | positive correlation.

50+ Unit P-Value: 0.22 | greater than 0.05 | accept null hypothesis | no correlation.

Boat, RV, Van P-Value: NA.

Mobile Trailer P-Value: 0.20 | greater than 0.05 | accept null hypothesis | no correlation.

From the figure 11a, the only household types with correlation are Detached, 2 Unit, 3-4 Unit, 5-9 Unit, 10-19 Unit, and 20-49 Unit. However, the correlation coefficients (r) are extremely weak with 0.04, 0.08, 0.12, 0.20, 0.04, and 0.06 as their values respectively. While they do have positive correlations, they are very weak and their relationships with electricity expenditure and summer land surface temperature are also nominal.

DISCUSSIONS

The findings on LST and electricity expenditure are in agreement with part of the hypothesis stating temperature and electric spending are positively correlated, especially when comparing maps 1c and 1d to 2b, and it is also in agreement with the conclusions of other studies (Agathangelidis et al., 2019; Arnfield, 2003; Azevedo et al., 2016; Fung et al., 2016; Li et al., 2019; Santamouris, 2014, 2015)—higher temperature areas spent the most on electricity in total. Analyzing the mean is a different outcome as the households that spent the most on electricity on average were in the urban periphery (see 2a). It is likely it has less to do with LST and more to do with the median household income of figure 7, similar to other literature that was reviewed concluding that affluence has a strong impact over spending on all types of energy, especially electricity (Alberini et al., 2011; Bridge, 2016; Energy Information Administration, 2019; Environmental Protection Agency, 2020; Yalcintas & Kaya, 2017).

Population density does not have as much of a strong correlation to LST as was previously anticipated and researched (Arnfield, 2003; Buyantuyev & Wu, 2009; Stone, 2005). Toward the western area of the map there is high density in figure 6, but low LST and Detached housing (see 3). This is a counterintuitive finding as it was expected that the higher the population density, the higher the LST and the more Attached households. An explanation for this might be the concept that low-rise buildings generate higher LSTs if they are clustered tightly, resulting in small street widths and “canyon trapping” (Agathangelidis et al., 2019).

On dwelling type in figure 4 there is no noticeable correlation other than that Attached households in figure 3 are situated in most of the high temperature areas looking at 1c and 1d. 2 Unit and 10-19 Unit dominate the high temperature areas as well, but comparing dwelling type to electricity expenditure there is even less correlation when looking between figures 4 and 2a—figures 4 and 2b have similar spatial patterns as 4 does to 1c and 1d. Salt Lake county is considered urban, and Attached households represent the majority of the census tracts because Attached or multiple housing units are able to be more clustered together and hold more people due to the tightness of urban areas. Detached housing, as opposed to multiple units like apartments, occupies more land so there is less population density.

In reference to figure 8, the spending discrepancy between Attached and Detached is likely due to the fact that individuals in attached housing don't have as large of an income as individuals in detached housing so there is a difference in purchasing power. Also, Attached and multiple units are likely renting and the Detached are likely homeowners and can spend more on entertainment and other comforts (Yalcintas & Kaya, 2017). In figure 9, there is a confounding result that households built between 2000 to 2009 spends the most on electricity, and the Energy Information Agency states that it is because recently built residences, although they may be energy efficient, come built in with more electricity-draining features. However, if that was the case, then 2010+ should also be leading the bar chart, not placed near the end—this is a finding that is worth looking further into.

The scatterplots showed little correlation among LST, electricity expenditure, and dwelling type. While the former two variables have a noticeable positive relationship, the moderating variable dwelling type has no significant correlation with either variables. However, this does not warrant any disregard for further studying their relationships.

CONCLUSION

Heat waves in urban areas are considered a natural disaster, and are high contributors to mortality rates (Borden, 2008) and that the UHI effect has been connected to higher levels of energy use for cooling, affecting both the climate crisis and people financially (Stone, 2005). These two key factors are why this study was conducted and although the findings did not yield correlation with dwelling types' effects on the relationship between UHI and electricity expenditure, it does provide a closer look into the potentially adverse effects of rising urban temperatures.

UHI has effects on community and environmental health, many of the consequences will particularly affect marginalized groups and socio-economically struggling minorities (Stone, 2005). While UHI is a continuously developing problem and does not have immediately noticeable effects, it still warrants early action and engagement (Roxon et al., 2020). Suggestions that are well-studied and proven beneficial in adapting to UHI are constructing buildings and city streets with different materials that do not have low albedo like asphalt and concrete (Ihara et al., 2008), utilizing high-albedo white paints to increase heat reflectivity and decrease heat absorption (Ihara et al., 2008), increasing urban green space and surrounding properties' affordability while simultaneously preventing ecological gentrification (Roxon et al., 2020). These all have potential to reduce the severity of UHI and heatwave peaks in the summers as well as improve the comfort, health, and safety of local communities (Roxon et al., 2020).

While this paper's findings yielded results that suggested dwelling types had no significant effect on the relationship between UHI and electricity expenditure; the data used were limited to the year 2018 and all the studies that were referenced were conducted over time with more than three datasets, and/or had accessibility to higher resolution spatio-temporal data at their disposal. There is the potential for further study and possibly new insights, especially when investigating commercial and industrial sectors instead of residential sectors. It could also be worth looking into how square footage, an indirect factor in determining dwelling type, factors into UHI and electricity expenditure as well.

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