MEASURING THE EFFECTS OF PARKING LOTS AND TREE SHADING ON MICROSCALE URBAN HEAT ISLANDS

by

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A THESIS

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Title: Measuring the Effects of Parking Lots and Tree Shading on Microscale Urban Heat Islands

Approved: ______________________________

Marc Schlossberg

This thesis investigates the effects of parking lots and tree shading on microscale urban heat islands on the University of Oregon campus in Eugene, Oregon.

Urban heat islands form because of the high concentration of impervious surfaces in urban areas. Parking lots, generally constructed from impervious surfaces such as concrete and asphalt, are widely accepted to contribute to this phenomenon. This study looks at the magnitude to which the presence of these landscape types increases ambient air temperatures at an extremely localized scale. Additionally, it investigates the power of tree shading to mitigate any increases due to these lots.

Three different locations were surveyed over the course of July through September, 2015 on the University of Oregon campus. Each location was comprised of either grass or asphalt surface cover, with varying amounts of tree shading. Temperature data from these areas showed that parking lots do indeed increase local ambient air temperatures and that tree shading has the power to mitigate these effects.

Acknowledgements

I would like to thank Professor Marc Schlossberg for serving as my primary thesis advisor and for his overall support on this project. His efforts to secure funding for me via the National Institute of Transportation and Communities were critical towards making this project happen. Further thanks go to Professor Mark Carey for his assistance and encouragement in the early stages of this study and for serving as my Clark Honors College representative. Finally, a special thanks goes to the third member of my thesis committee, City of Eugene climate and energy analyst Matt McRae. Conversations with Matt served as the inspiration for this topic and his feedback and support has been very helpful throughout this project.

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Introduction:

If you pull into a parking lot on a hot, sunny day, chances are you will immediately search for a spot in the shade. You'll want to ensure that the interior of your vehicle isn't scorching hot when you return or perhaps you'll want to protect your pets from overheating. Most people understand that parking lots can grow dangerously hot given the right conditions, but fewer could explain the specific attributes that make these expanses of pavement heat up so quickly and retain that heat so readily. These dynamics can be explained by looking at a parking lot as a microcosm of an urban heat island, a phenomenon of great import to the modern city. For my thesis, I will be investigating the magnitude of these parking lot urban heat island microcosms in Eugene, OR and the power of tree shading to mitigate these micro-heat islands. The purpose of this study is to gain an understanding of the way that transportation infrastructure affects the urban climate and to investigate achievable ways to cool down the urban environment.

The urban heat island effect:

The urban heat island (UHI) effect is an environmental effect whereby the surface and air temperatures in built-up urban areas tend to be hotter than in rural areas. This dynamic has serious environmental impacts that are representative of the way that humans' landscape choices influence climate. Generally, UHIs are a negative phenomenon with harmful effects. The most direct effect of UHIs is simply increased urban temperatures, especially during the summer. This can lead to increases in heat-related illnesses and deaths, as well as creating a less comfortable environment for urban residents (Taha, 1997). UHIs have also been shown to contribute to the buildup of smog in heavily urbanized areas (Akbari, Pomerantz, & Taha, 2001). These direct effects influence quality of life in urban areas and should be considered when planning for landscape changes in cities.

The urban heat island effect has not only direct effects on the urban climate by increasing surface and air temperatures, but these changes in temperature also produce indirect effects on the urban climate due to the human response to said changes. These indirect effects have serious environmental consequences. In particular, increased urban temperatures lead to an increase in building energy use, which has negative climatic effects. According to one study, for every one degree increase in temperature, building energy use will increase by 2-4% due to increased cooling needs (Akbari et al., 2001). These effects are strongest in mid-low latitude cities, where high summer temperatures necessitate air conditioning (Wilby, 2003). In Los Angeles, summer heat islands account for about 1.4 gigawatts of power annually, and nationwide that figure is around ten gigawatts each year, according to researchers from The Heat Island Group at

Lawrence Berkeley National Laboratory (Rosenfeld, Akbari, Bretz, Fishman, Kurn, Sailor, & Taha, 1995). The consequences of increased building energy use are mostly environmental; increased power use in general has negative effects on the environment because of greenhouse gas emissions, contributions to residential, industrial, and commercial carbon footprints, and environmental degradation due to extraction of fossil fuels, generation of hydroelectric power, and the utilization of other harmful energy sources. While these indirect effects are prominent at mid- and low-latitude cities, they have less negative effects closer to the poles. According to the Rosenfeld et al. study, the indirect effects of urban heat islands are lessened in high-latitude cities due to a decreased need for cooling energy use. Nonetheless, the effects of UHIs should be considered in settlements anywhere on the planet.

Heat islands are caused by several different factors, including heat from human sources such as automobile emissions or building heat sources, and the prevalence of surfaces such as concrete, asphalt, brick and metal. These surfaces trap solar radiation, rather than reflecting it back into the atmosphere, and are referred to as “low albedo” surfaces, with albedo being a measure of “hemispherically and wavelength-integrated reflectivity” (Taha, 1997). Albedo is generally just a measure of the darkness of a surface. Because dark surfaces like asphalt absorb solar radiation, rather than reflecting it, they are referred to as being low-albedo. Likewise, lighter surfaces like white pavement is high-albedo. Heat from human sources is known as “anthropogenic heat.” These parameters for evaluating the magnitude of the urban heat island effect in a specific area both negatively affect urban temperatures, warming surfaces and increasing sensible air temperatures. Other qualities of an urban area have positive effects on urban temperature and climate.

One such positive parameter that strongly influences the magnitude of UHIs is evapotranspiration, which is defined as the sum of evaporation and transpiration, which results from the release of moisture from plants in the form of vapor from vegetated systems (Taha, 1997; Kurn, Bretz, Huang, Akbari, 1994; Akbari et al., 2001). Evapotranspiration is a key dynamic when it comes to natural cooling. The more vegetation in an area, the higher the rate of evapotranspiration and consequent cooling of air temperature that will occur. This is why the presence of vegetation is such an important factor in mitigating the urban heat island effect.

The principle effects of urban heat islands are not just present during the heat of the day. In fact, while UHIs are very significant during the day, they are most measurably prominent relative to rural temperatures during the night (Wilby, 2003). This is due to the way that impervious surfaces retain heat, slowly giving off radiation throughout the night. This means that the time of day when the difference between urban and rural temperatures is greatest is late in the night, when ex-urban, non-impervious surfaces have cooled off significantly but impervious surfaces in urban areas are still radiating heat from the previous day. UHIs are significant across a broad range of temporal landscapes, and also in a variety of spatial landscapes.

Urban heat islands can manifest at a number of levels. Many studies have focused on city-wide heat islands in large metropolitan areas. The specific purposes and methodologies of these studies have varied greatly, but the results have consistently shown that urban areas are significantly warmer than their surroundings. In large cities, UHIs can have dramatic effects on citywide climate. In London, UK, the urban region has been described as “creating its own microclimate” separate from the climate experienced in south-central Great Britain as a whole (Wilby, 2003). This is a testament to the power of the urban heat island effect in determining the urban climate. Studies have also proved the existence and magnitude of UHIs in Szeged, Hungary (Unger, Sümeghy, Gulyás, Bottyán, Mucsi, 2001), Portland, Oregon (Hart and Sailor, 2007), Indianapolis, Indiana (Weng, Lu, Schubring, 2004), Houston, Texas, Sacramento, California, Salt Lake City, Utah, and Chicago, Illinois (Akbari and Rose, 2007), among a host of other locations. A study of the St. Lawrence Lowlands around Montreal, Canada showed that the UHIs were present in all cities and towns in the region, which ranged from small towns of several thousand people to the two-million person metropolis of Montreal (Oke, 1973). This is important because it justifies heat island studies not only in large cities, but also in small to medium sized towns such as Eugene.

Heat islands can also occur on much smaller scales than the city scale. The UHI effect has been measured at “microscales,” as small as the individual building and landscape feature scale (Oke, 2004; Taha, 1997). Studies have shown the effects of various landscape attributes on localized temperatures, including the effects of grass and shade on surface and air temperatures (Armson, Ennos, Stringer, 2012), the effects of high-albedo surfaces on local temperatures (Akbari et al., 2001), and the effects of tree shading on individual building energy use (Donovan and Butry, 2009). These studies are important because they demonstrate the climatic importance of individual landscape features such as buildings, trees, and expanses of impervious surfaces.

Study Purpose and Design:

As summarized above, there have been a plethora of studies detailing the presence and effects of the urban heat island effect at a variety of scales, however research is lacking regarding the effects of existing parking lots on proximate ambient air temperatures. What this study seeks to explore is the relationship between the presence of parking lots and the fluctuations of ambient air temperatures throughout a typical summer day. Furthermore, it will attempt to identify the effects of a second variable, tree shading, on this relationship.

In order to obtain independent and accurate temperature data from specific locations on the University of Oregon campus, this study used fourteen Onset HOBO U23 temperature data loggers. These loggers are weatherproof and capable of measuring ambient air temperature and humidity at a variety of intervals. Data is stored locally on each logger and then downloaded to a laptop. Each logger was equipped with a solar radiation shield which ensures that temperature measurements reflected ambient air temperatures, independent of direct solar radiation. Each logger was programmed to record temperature and humidity every ten minutes, although humidity measurements were not considered for the study conclusions.

In the real world, it is very difficult to separate landscape variables from the context of landscape that surrounds them, especially when concerned with these variables' effects on ambient air temperature. Ambient air temperatures are highly affected by the landscape around them, which invariably contains numerous sources of heating and cooling. This makes it difficult to isolate which landscape conditions contribute to changes in air temperature. It is very difficult to ascertain, for example, which landscape specific conditions cause temperature differences between two locations in the same urban area. However, this study aims to identify broad trends in temperature variance between three different landscape types within the same university campus with the aim of drawing conclusions about the temperature effects of these landscape types.

In order to isolate as best as possible the effects of parking lots and shade on air temperature, this study surveys three different locations on the University of Oregon campus, each of which represents a landscape type that features the presence or lack of the two variables in question. Because of the relative proximity to each other and relatively similar characteristics of the surrounding landscape, it is reasonable to attribute differences in temperature to the prominent landscape types in question when aggregated across several logger locations and several months of data collection.

The process of siting study locations was complicated by the lack of similarity between locations characterized by different landscape types and by the types of landscapes that typically surround these locations. Parking lots generally differ in size, shape, and typical surroundings from grassy, shaded lawns. This is especially true when study parameters limit the area from which locations can be chosen, such as the UO campus in this case. These limitations confound a researcher's ability to isolate variables through site selection. In this case, it was impossible to find three locations that were very similar in surface area, shape, and surrounding landscape types. Regardless, the three chosen locations are the three areas that best represent unshaded asphalt parking lots, shaded asphalt parking lots, and shaded, grassy softscape. All three locations reside within the University of Oregon campus and immediate surrounding area, so it is assumed for the purpose of this study that the climatic/atmospheric context for all locations is sufficiently similar.

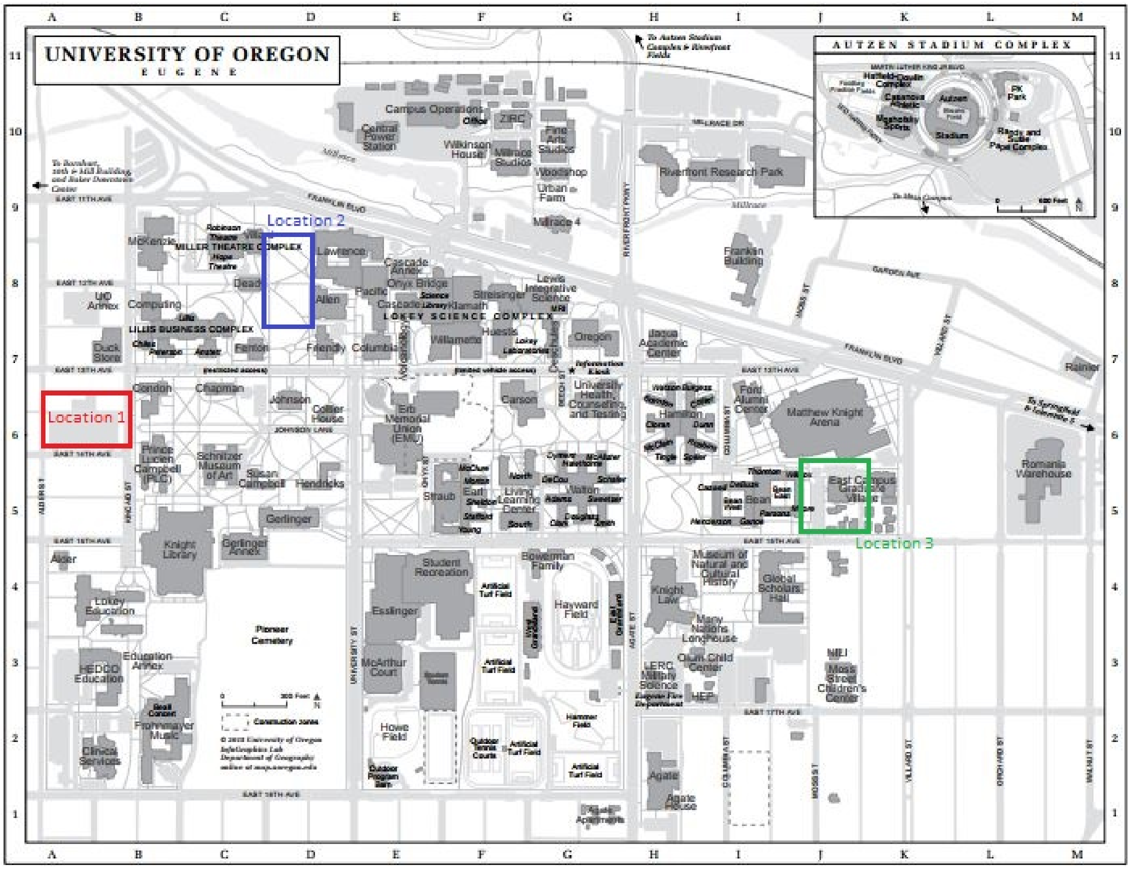


Figure A: Map of Study Locations

The first study location (see Figure B) was a large parking characterized by its lack of shade. This lot is a large rectangle of approximately 70,000 square feet. It takes up the entire east-west block between Alder and Kincaid Streets and half the north-south block between 14th and 13th Streets (ending at 13th Alley). The only vegetation in the parking lot area is a line of small trees running along 14th Street. This parking lot is the closest large lot to the west side of the UO campus, meaning that it is usually at full or close to full capacity with automobiles.

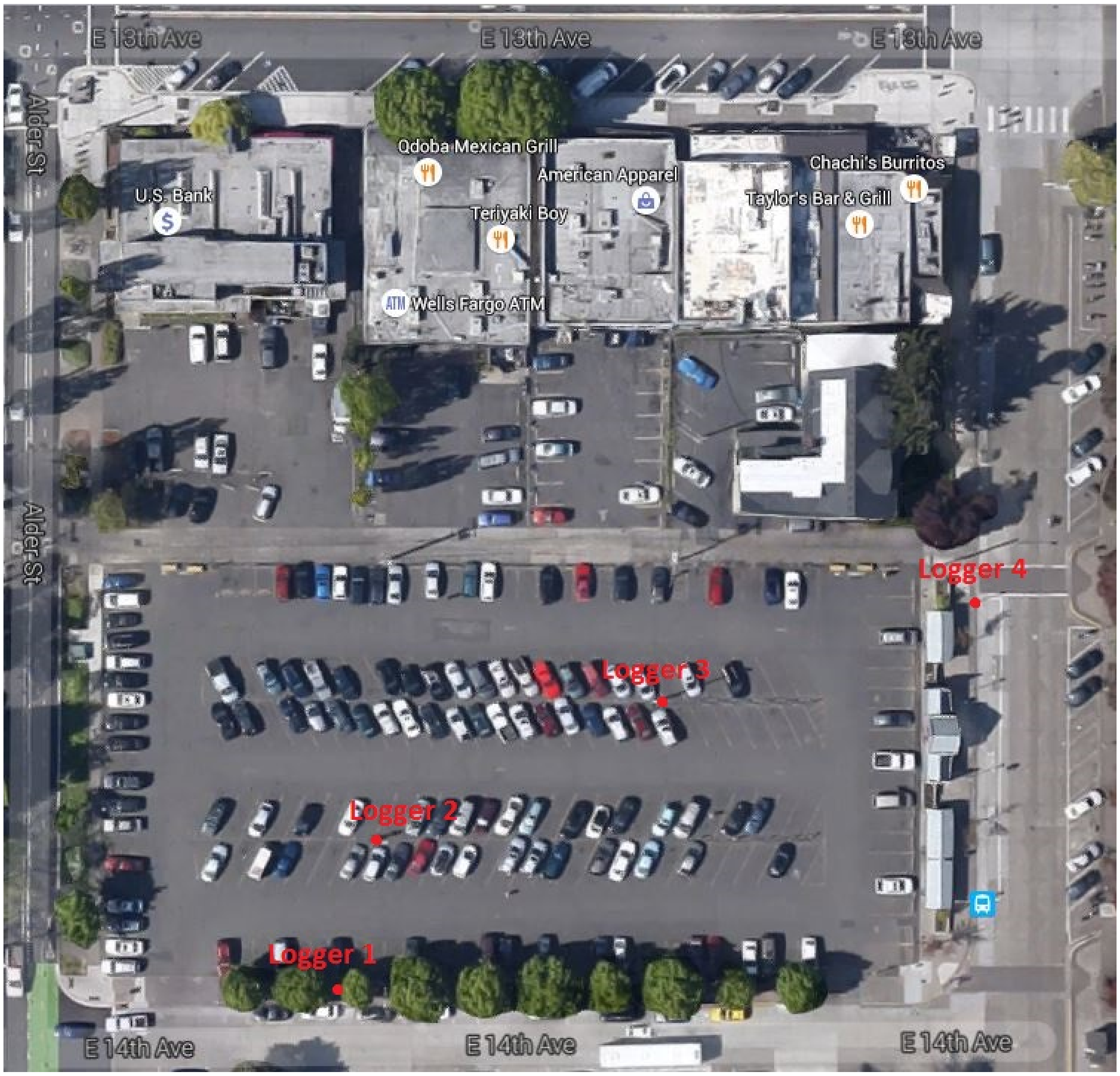


Figure B: Aerial Photo of Location One

The second study location (see Figure C), serving as the control location, was a grassy quad in the north-central UO campus with mixed amounts of shaded and unshaded grass. There are no defined boundaries to the quad area as I refer to it, as this quad connects extensively with other grassy areas on campus, but the large semi-open area in which all five loggers at this location were located was a rectangular space measuring roughly 80,000 square feet. The quad is bordered by Friendly, Allen, and Lawrence Halls to the East and Friendly Hall directly to the west. The only impervious surfaces in this area are the concrete paths that border and criss-cross the quad.

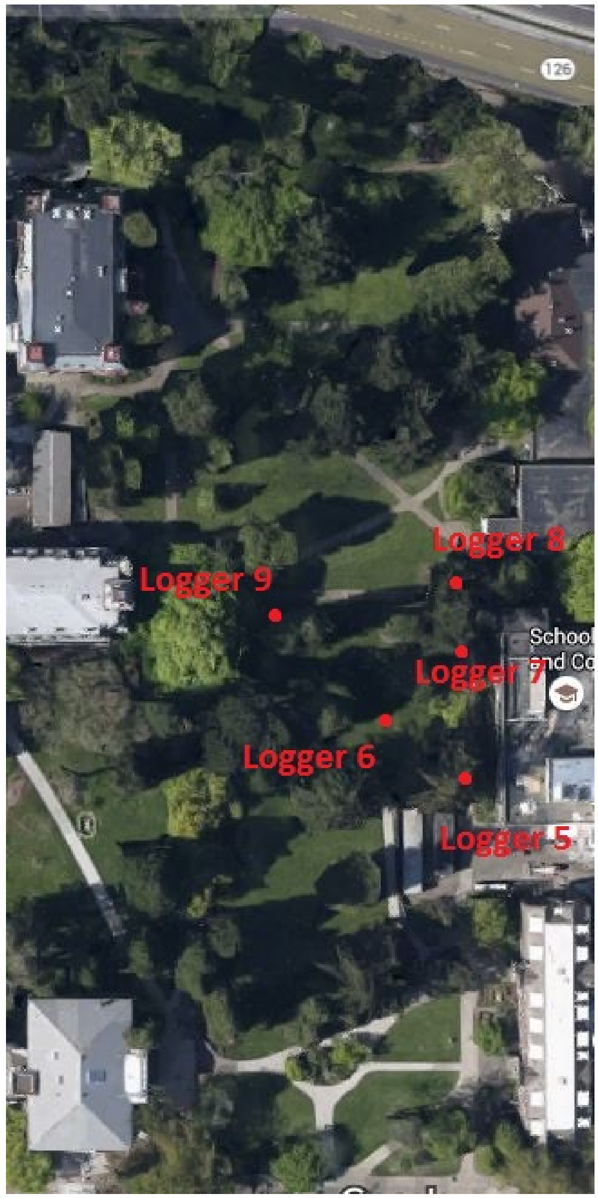


Figure C: Aerial Photo of Location Two

The third study location (see Figure D) is another parking lot that runs between Bean East Hall and the East Campus Graduate Village from 18th Ave to Matt Knight Arena. This parking lot is much narrower than the 14th and Kincaid lot and experiences high amounts of tree and building shading throughout the majority of the day. This lot is smaller than the unshaded lot, about 45,000 square feet, and is L-shaped. It is lined by trees on the east and south edges. This means that large parts of the lot are shaded during much of the day, especially during the morning and evening, when the large trees along both sides, along with three-story Bean Hall and the three-story Graduate Village buildings, which were only fifteen yards from the loggers at the furthest, block the sun. At the northwest corner of the Graduate Village, the parking lot turned 90 degrees to the east and continued half a block at the same width along the north side of the Village between those buildings and Matthew Knight Arena. This area had far fewer large trees and greater overall expanses of asphalt and concrete, but was shaded from the south by the Graduate Village buildings.

The fourteen sensors were distributed as evenly as possible within the three study locations. Four sensors were located at study location one and five at locations two and three. Sensor placement and spacing was determined by the presence of lampposts and/or streetlight poles on which the hardware could be mounted. Each sensor was located approximately 20-50 meters from each other and placed so as to cover as even an amount of the space in question as possible.

Figure D: Aerial Photo of Location Three

Each sensor was sited and installed consistently with each other and with guidelines presented by T.R. Oke in his 2004 paper "Siting and exposure of meteorological instruments at urban sites." These guidelines principally concern achieving adequate heat shielding and ventilation and siting sensors in a way that their measurements accurately reflect the fabric of the environment around them. In particular, the following placement guidelines were followed for each sensor: 1) each logger was covered by a solar radiation shield in order to ensure that *ambient* air temperature would be measured and to protect the hardware from precipitation; 2) each logger was placed 3 meters above ground level. This height does not conform to the standards laid out in the paper referenced above, however it was necessary to place loggers above the recommended 2m in order to deter tampering and theft; 3) each logger was oriented on the north side of the pole on which they were placed in order to further minimize the amount of solar radiation that the logger received; 4) each logger was attached to poles at last 10 meters from buildings to avoid temperature and air-flow influences from the nearby buildings. Together, these siting guidelines ensured that the data gathered for this study was as accurate and consistent as possible.

Funding for this study was provided by the University of Oregon's Student Sustainability Fund and the National Institute for Transportation and Communities. In total I received $3,800, with 50% coming from each funding source. This money was used exclusively to purchase the fourteen Onset HOBO data loggers used for temperature data collection in addition to mounting materials.

Hypotheses:

My hypothesis is that the mean temperatures throughout the three-month course of this study will vary consistently from site to site. Specifically, I predict that the control site on the Knight Library quad will be the coolest, followed by the more shaded parking lot near the Erb Memorial Union, with the 14th and Kincaid parking lot being warmest. There is a plethora of research supporting these hypotheses. Most relevant to my own study is a 2012 experiment by David Armson, Pete Stringer and Roland Ennos that measured temperatures of small plots of shaded and unshaded grass and concrete. This study showed that shading was the most important factor in determining air temperatures. Surface type also affected air temperatures, with grass surfaces being cooler due to increased rates of evapotranspiration. This suggests that an area such as the Knight Library quad with both grass surfaces and shading would be cooler than an area with only shading and an area with neither shading nor vegetated surfaces would be warmest.

A further hypothesis is that mean relative differences between parking lot locations and the control location will be greatest during the night. As discussed, impervious surfaces trap solar heat during the day and slowly radiate this heat during the night. For this reason, it is logical to posit that an area with high concentrations of asphalt or concrete, such as parking lots, would experience higher temperatures during the night relative to areas with low concentrations of impervious hardscape. I do not have a hypothesis about what part of the night this temperature difference will be greatest, so this a key research question.

Due to research showing that urban heat islands exacerbate extreme weather events, another study hypothesis is that the parking lot locations, particularly the unshaded location one, will be home to the highest recorded temperatures on a given day (Taha, 1997; Wilby 2003). Furthermore, the fact that heat islands are most pronounced at night supports a further hypothesis that the parking lot locations will have higher minimum daily temperatures.

Finally, I hypothesize that, due to the urban heat island effect at a macro, city-scale, temperatures at all three University of Oregon campus locations will be higher than ex-urban temperatures as measured at the NOAA weather station at the Eugene Airport. As discussed thoroughly in the introduction, heavily urbanized areas have been extensively shown to have higher temperatures relative to their nearby rural counterparts. Located near the center of the Eugene-Springfield metropolitan area, the University of Oregon is a prime example of an urbanized area. The relatively low amounts of impervious hardscape and the presence of large areas of plant-cover may reduce the effects of the urban heat island effect, but I hypothesize that the effect will be present regardless.

Metrics:

Because of the frequency at which measurements were recorded, I ended up with an overwhelming amount of data to parse out. Each logger gathered over 13,800 discrete temperature and humidity measurements, meaning that there were over 193,000 total measurements for both temperature and humidity. To make better sense of this amount of raw data, I used several different strategies to compare different landscape types (via their respective logger clusters).

I settled on calculating simple means as the most the most valuable method of statistical analysis for several reasons. The first reason was that I lacked a quantitative independent variable necessary for more sophisticated metrics, such as single- or multi-variate regressions or other math-based models. This meant that I needed a clear way of comparing three qualitatively different locations in a way that would completely and accurately portray the differences in the three locations and their respective landscape types. This would allow me confirm or refute my hypothesis of a correlation between the increased presence of impervious surfaces and the decreased presence of tree shading and increased ambient air temperatures.

The second reason for selecting mean values as my main statistic was that means represent a good way to aggregate multiple values into one value that represents a group. In this case, I used a mean to aggregate the four or five values for a given time from each of the different loggers in a location cluster to calculate an overall temperature value for that location. This is important because, again, of the qualitative nature of my independent variable. The study purpose was to determine the impact of two *generally defined* landscape conditions on ambient air temperatures. No single logger most accurately represents these landscape conditions, but each location was chosen to represent a given condition *on aggregate.* As such, the average conditions at that location gives an approximate representation of the effects of the given landscape type when compared with the mean conditions of another location, accounting for random or landscape-dependent variations at individual logger locations.

To narrow down not only how the three different locations differ for a given day as a whole, but also over the course of the day, I also compared means at four different times throughout every day. These times were 8:00 AM, 2:00 PM, 8:00 PM, and 2:00 AM. I chose these four times because they were evenly distributed over the course of a 24 hour day and during the summer were representative of the four different periods of a day: morning, afternoon, evening, and nighttime, respectively. The urban heat island effect has been shown to be more prominent at night, that is areas with high concentrations of impervious surfaces have greater temperature differences to areas with low concentrations at night relative to the difference between these two landscape types during the day (Wilby, 2003). For this reason, it was important to look at mean temperature differences not just for a day as a whole, but at different times of the day to see if this trend held up in my own data, as well as to identify when the effects of the presence of a certain landscape type was greatest. Given the nature of my study, identifying trends between general times of day, rather than specific times, was enough to draw meaningful conclusions.

While looking at just four times of the day is useful for identifying trends that may exist over time, I felt that it was also important to get a picture of how temperatures varied *hourly* over the course of an entire day. For this, I compiled data describing an “average” day for each sampled location during the summer of 2015. To create this metric, I calculated the mean temperature for each location (the mean of all loggers’ temperature values in a location cluster) every hour of every day. Then I found the mean of all values for each hour for each location to create a depiction of an “average day” at each location. This provides a more detailed look at temperature trends for a summer day on the UO campus. The resulting graph (Figure A) shows how, on average, each location’s temperature differs over the course of a twenty-four hour day. The differences are small relative to the scale of the absolute temperatures, so trends may be difficult to see. See Appendix B for more detailed breakdown of this chart.

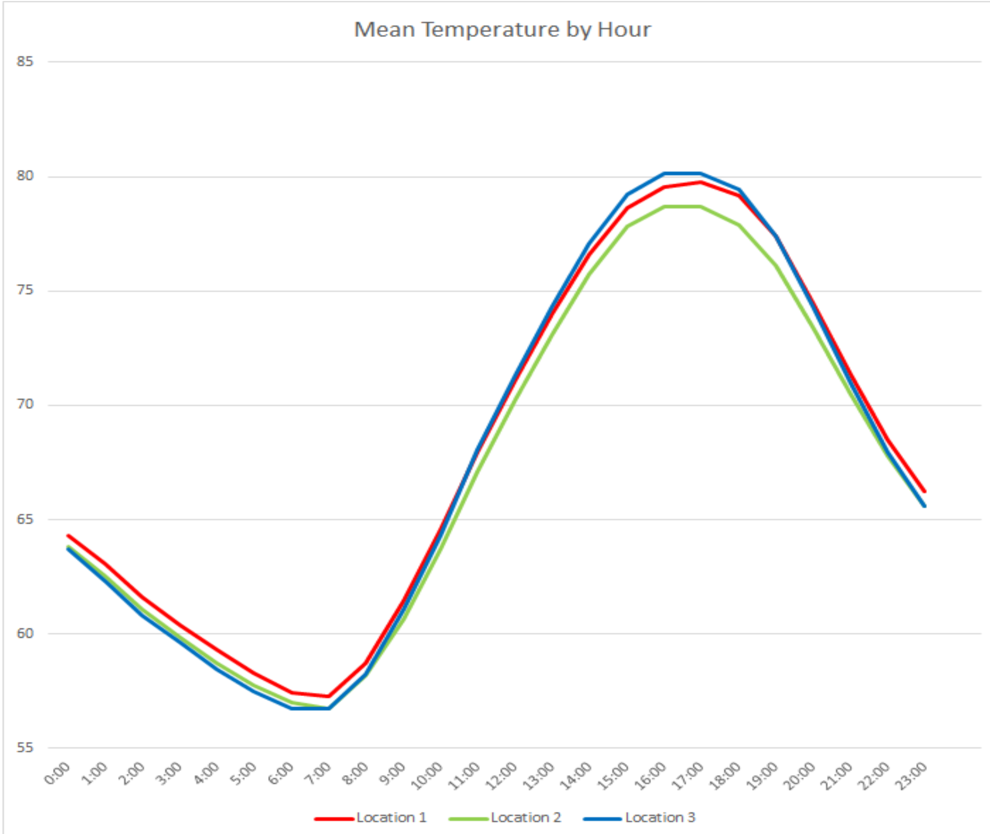


Figure E: Mean Temperatures by Hour for All Days and Loggers

Another valuable statistic when used to compare locations is maximum temperature for a given day. The urban heat island effect is characterized by impervious surfaces' increased capacity for solar heat absorption and storage and one of the most recognized consequences of this effect is heat islands' propensity to exacerbate extreme weather events (Wilby, 2003). As such, it is valuable to look at the most extreme temperatures, particularly maximum temperatures for day. This statistic gives a rough idea of different landscape conditions' abilities to exacerbate extreme heat conditions.

Minimum temperature statistics are also telling, although they can be used to indicate a different property of impervious surfaces and urban heat islands. The coldest temperatures during a day come during the evening, so minimum temperatures approximate an area's capacity for solar heat storage. An area with higher relative minimum temperatures would have a higher capacity for heat storage, indicated by the higher temperatures due to reduced evapotranspiration and increased radiation of stored heat from impervious surfaces, all other conditions held constant.

Minimum and maximum temperature statistics are very imprecise metrics for indicating the presence of or quantifying the effects of parking lots or tree shading. There are a plethora of outside factors that could potentially influence these statistics, including surrounding landscape features and the presence of anthropogenic heat sources. However, when considered in tandem with the other statistics discussed in this paper, minimum and maximum temperatures can help confirm or refute my hypotheses regarding the effects of parking lots and tree shading on localized urban heat islands.

A final statistic that adds context to locational temperature data from the UO campus is the difference between these temperatures and local ex-urban temperatures as measured at NOAA weather station at the Eugene Airport's Mahlon-Sweet Field. While this data is imperfect and subject to its own exposure to the effects of impervious surfaces, it does add valuable information about how regional temperatures outside of the context of Eugene's urban environment compared to urban temperatures gathered on the UO campus at the same time. In particular, this data is valuable in analyzing how temperatures vary throughout the day. Drastic differences were seen between daytime and nighttime temperatures at the airport relative to campus temperatures taken at the same time.

Locational Temperature Data:

When comparing the three study areas, the main statistic considered was mean temperatures of the four or five loggers at that location. To get an idea of the effects of each different landscape type on localized ambient air temperatures, overall means of *all* values for all observed times at each location were calculated. This creates a value that incorporates all measured values in the study. Looking at absolute temperatures, presented in Figure A above, is useful for identifying how temperatures typically vary over the course of a day. However, this metric does a poor job of illustrating the locational differences which characterize microscale urban heat islands, particularly graphically.

Rather than compare absolute temperatures, it proved useful to consider each location in relation to each other (see figure B). This metric was used as a direct proxy for illustrating the magnitude of a localized urban heat island, as it compared areas with high concentrations of impervious surfaces with areas that did not feature large amounts of these surfaces. It allowed for more meaningful conclusions about the effect of the isolated variables in question. The temperature differences between the different locations unsurprisingly varied drastically depending on time of day.

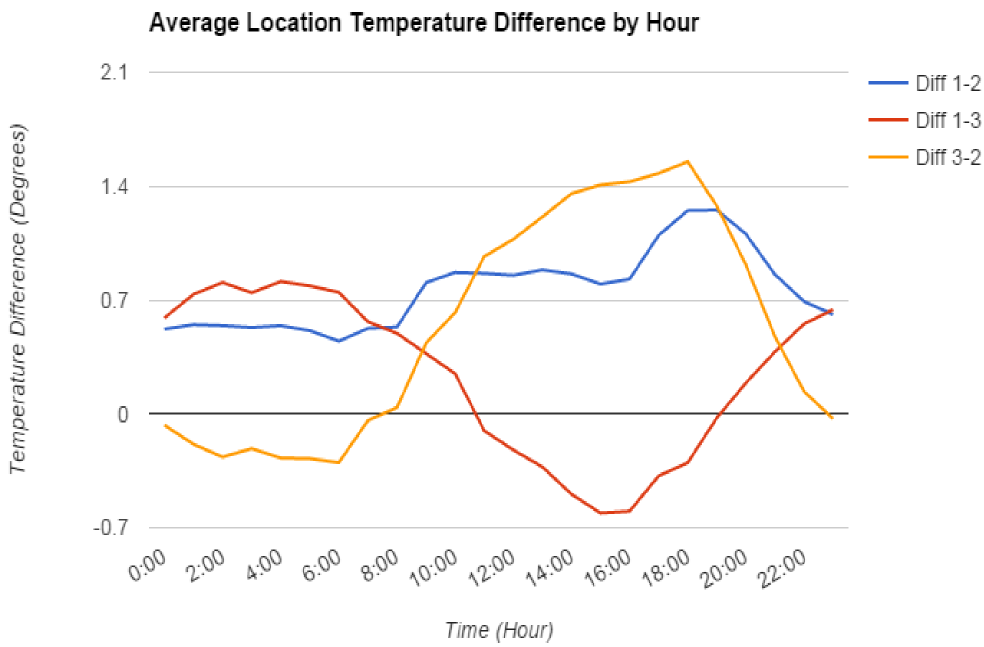


Figure F: Average Locational Temperature Difference by Day

The mean temperature difference between locations one and two was greatest around dusk, with the mean difference dropping significantly during the night and morning before climbing through the afternoon. Considering only hourly temperatures, the mean difference between the two locations topped out at 1.253 degrees at 7:00 PM, before falling steadily to a 0.52 degree difference at 12:00 AM. Mean differences plateaued at approximately this 0.5 degrees until 8:00 AM before climbing steadily throughout the afternoon until 6:00.

Mean temperature differences between locations two and three followed a similar trend to locations one and three; however, contrary to the study hypothesis, these differences were of higher magnitudes than location one differences. Location three peaked at an average of 1.55 degrees hotter than location two at 6:00 PM before falling to a mean 0.3 degrees *cooler* than location two at 6:00 AM. Between these times this differential statistic changed much more rapidly than the corresponding statistic for location two, especially between 6:00 AM and 2:00 PM (positive) and 6:00 PM and 2:00 AM (negative).

These results show that micro-scale urban heat islands on the UO campus, characterized by the difference between parking lot locations and the control location, are of greatest magnitude in the afternoon and early evening. During the night and early morning, times of the day when the urban heat island effect is expected to be strongest, parking lot-grass location differences level out at low to negative magnitudes. This paints a different picture of urban heat islands at a small level than is encountered in most heat island studies, most at larger scales.

As a summary statistic for the overall differences between the three study locations, I calculated overall mean temperature values for each location by aggregating all temperature readings across all days, times, and logger locations. This statistic reveals that locations one and three were, as hypothesized, the hottest locations on average. Location one had a mean temperature of 68.346 degrees across the four loggers at the location. The mean temperature for location three's five loggers was 67.909 degrees. Location two's five-logger mean was 67.314 degrees. This reveals that locations one and three were, on average, 1.032 and 0.595 degrees warmer than the location three control area, respectively. These values are not particularly large, but in the context of a college campus show significant differences between locations with substantially different landscape types.

Minimum and maximum daily temperatures, proxies for the effects of shaded and unshaded parking lots on extreme weather conditions, do not reveal any clear evidence for relationships between study landscape types and extreme temperatures. Location three experienced the most extreme temperatures for a day, both hot and cold, most frequently. On average, this location's coolest daily temperature was 0.51 degrees cooler than location one's coolest temperature and 0.527 degrees cooler than location two's coolest temperature. The coolest temperature for the day was recorded at a location three logger on 62 of the 96 (64.6%) of the measured days.

Location three was also home to the most extreme hot temperatures as well as the coolest temperatures. The graduate village parking lots sensors' hottest measurements were, on average, 0.589 degrees hotter than location two's maximum daily temperatures and 0.283 degrees hotter than the maximum daily temperature for location one loggers. Location three loggers recorded the hottest temperature on 63 of the 96 (65.6%) measured days.

The fact that location three loggers recorded the most extreme temperatures on an average day-to-day basis is inconsistent with two study hypotheses. The first hypothesis was that parking lots (especially unshaded lots, represented by location one) would exacerbate extreme heat events most. The validity of this hypothesis proved inconclusive. The two parking lots, locations one and three, had maximum daily temperatures that were 0.283 and 0.589 degrees hotter than location two maximums, respectively. While these results do support the above-stated hypothesis, it is surprising that the more shaded location was 0.306 degrees warmer on average at the hottest point of a day. There were no obvious factors to attribute the high maximum temperatures at location three, although the surrounding landscape features, such as the metallic and reflective Matthew Knight Arena, could very well influence peak daily temperatures.

The second hypothesis in question is that parking lot locations would display higher minimum temperatures due to stored solar radiation release during the nights. Location three loggers again unexpectedly registered the most extreme daily temperatures, in this case at the cool end of the spectrum. Location three's coolest daily temperatures were, on average, 0.51 and 0.527 degrees cooler than location one and two's coolest temperatures, respectively. The difference between location one, expected to have the highest average minimums, and location two, expected to have the lowest, was a negligible 0.017 degrees on average. Again, there were no obvious factors to which these results could be attributed.

Urban-rural Differences:

When looking at measured campus temperatures in comparison with Eugene airport temperatures, there is mixed evidence of a substantial urban heat island effect. I observed very drastic discrepancies between daytime and nighttime temperature differences when comparing campus and airport measurements. While nighttime temperatures were predictably higher on campus than at the airport location, during the daytime ex-urban temperatures were consistently and significantly higher than campus temperatures.

The six-hourly data shows very clearly the stark difference between nighttime and daytime differences. At 2:00 AM and 8:00 PM, campus locations had mean temperatures (measured across all locations and all days) that were 3.58 and 5.34 degrees higher than airport temperatures, respectively. This data alone would suggest that the urban heat island effect is significant in the Eugene area. However, morning and afternoon differences paint a different picture of the effects of urbanized landscapes on local ambient air temperatures. At 8:00 AM and 2:00 PM mean campus temperatures were 3.28 degrees and 3.75 degrees *lower*, respectively.

These results were unexpected considering current research on the effects and magnitudes of urban heat islands. There are multiple studies supporting the fact that urban-rural temperature differences were higher during evening and nighttime, however these studies still show a positive, although reduced, difference during the day (Wilby, 2003; Kenward, Yawitz, Stanford and Yang, 2014). In the context of the greater body of research related to the urban heat island effect, it is surprising to see a higher rural than urban temperatures at any time of day. These results cast some doubt on the reliability of the airport temperature data and its characterization as “rural” or “ex-urban” data. The Eugene Airport is unquestionably located in a rural area. It is ten miles from the University of Oregon and surrounded principally by farmland. However, the exact landscape conditions surrounding the NOAA weather station were unknown for this study.

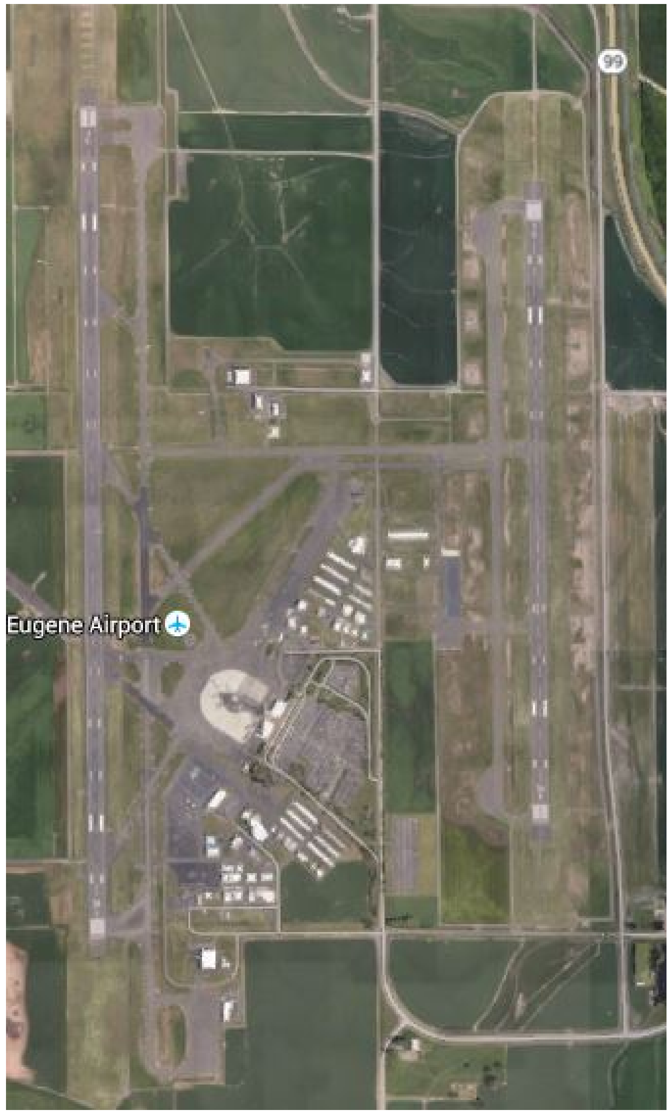


Figure G: Eugene Airport Satellite Photo

Depending on proximate surface types, as well as the landscape makeup of the airport area as a whole, this weather station could very conceivably report temperatures in excess of typical rural temperatures for the area. Google Earth satellite imagery shows that the airport is, predictably, home to large swathes of impervious surfaces which could easily skew the data (see Image C).

There have been no major studies examining the reliability of NOAA weather station data on an hour-to-hour basis nor has the agency posted any acknowledgements about the accuracy of their data or guidelines around how to use it. One University of Oregon physics professor who is familiar with said data and experienced with processing it, Gregory Bothun, stated in an email conversation that NOAA weather station data can be unreliable, is easily biased by local conditions, and that "Eugene airport data is particularly bad." While I am unable to provide empirical evidence for the unreliability of this airport data, the inconsistency of the results suggest that the reader should take conclusions drawn from this section with a grain of salt.

Conclusions:

This study is descriptive, rather than explanatory or normative. Its purpose is to identify and describe trends related to parking lots, tree shading, and their relationship to the urban heat island effect. It is beyond the scope of my research, and I am not in fact qualified, to make explanatory conclusions about the trends that have become apparent in this research. While I can identify possible causes and effects related to the data that I have collected, these are above all else educated guesswork and speculation. There are simply too many variables present in the study of real world urban heat islands, especially at the scale that I chose to investigate, to make concrete conclusions about exactly why the phenomena that I have identified occur. My conclusions, therefore, focus mostly on what I trends that I have identified between ambient air temperatures and *broad* and *qualitative* landscape types. To make concrete statements about causation or correlation is not within the scope of this study.

As hypothesized, the presence of impervious surfaces in the form of parking lots had warming effects on localized ambient air temperatures. Both location one, a large unshaded parking lot, and location two, a smaller parking lot with substantial tree shading, were warmer on average than the location three control area, which featured large amounts of tree shading and minimal impervious surface ground cover. This suggests that the presence of impervious surfaces in the form of parking lot asphalt as well as the lack of tree shading does, as hypothesized, increase localized ambient air temperatures.

When broken down by time of day, mean temperature differences still support the overall study hypothesis but show trends that do not conform to typical urban heat island temperature behavior. Parking lot-control site differences were greatest during the afternoon and lowest at night, whereas most UHI studies have found that heat island magnitudes are greatest at night. These results, while surprising, have interesting implications regarding the impact of parking lots on the users of these areas.

The fact that impervious surfaces increase temperatures relative to grassy areas most during the afternoon means that these effects are felt most during the time of day when the lots are being used most. The impacts of impervious surfaces on human comfort may be increased because of this. During the night, increased temperature differences would not impact as many people as during the day due to the high decrease in parking lot users during night hours.

One important consideration regarding this data is that increased use during the day may in fact have positive temperature effects. During the day, parking lots are much more full of vehicles. These vehicles are made of another low-albedo impervious surface material, metal. The effects of metal versus asphalt on ambient air temperatures are not well-researched. I have no definite conclusions to offer regarding the temperature effects of parking lots being full or empty, but this is an important consideration.

Another consideration which could explain in part the lower-than-expected night time differences is that the presence of vehicles for long periods of time during the day would shade the parking lot surfaces from solar radiation, preventing that radiation from being trapped by the actual surface of the parking lot and released as heat later in the day. This provides a possible explanation for the fact that nighttime temperature differences were not as high as expected.

Evidence of a city-scale urban heat island, ascertained by comparing measured campus temperatures with NOAA ex-urban weather data collected at the Eugene Airport, was, in my estimation, inconclusive. Temperature differences were not consistent and showed large and unexpected discrepancies between nighttime and daytime temperatures. Furthermore, the NOAA temperature data used for these comparisons may not accurately represent the landscape fabric as accurately as necessary to draw conclusions regarding city-scale urban heat islands. I do not believe that these results are compelling evidence for the presence of a city-scale urban heat island in Eugene. By no means do I suggest that UHIs are not present in the Eugene metro area, only that my own study data, in combination with NOAA data, does not provide enough evidence to show that they are present.

Overall, this study does provide reasonably definitive answers to the research questions of whether parking lots create microscale urban heat islands and whether tree shading can mitigate these heat islands. The presence of impervious surfaces in the form of parking lot asphalt consistently resulted in higher temperatures than at locations without high concentrations of asphalt. Tree shading at these parking lots resulted in lower mean temperatures, although this result was not as consistent.

The implication of these result is that traditional parking infrastructure does indeed contribute to microscale urban heat islands. These heat islands have negative direct effects on comfort and negative indirect effects on the environment. More greenery surrounding parking lots is good. Not only do green surfaces increase evapotranspiration, but this study has shown that they can play a role in mitigating microscale heat islands. More tree shading on and around parking lots can lower temperatures in high-use parking lots, increasing comfort for drivers, passengers and passers-by.

In conclusion, reducing the surface area of impervious parking lots is an important factor in increasing urban comfort. Shading these lots can also improve localized temperatures on hot days. Policies discouraging unshaded parking infrastructure can have significant positive effects on urban comfort, energy use, and overall climate.

Appendix A: Logger Location Maps, Descriptions, and Photos

Overall Study Area:

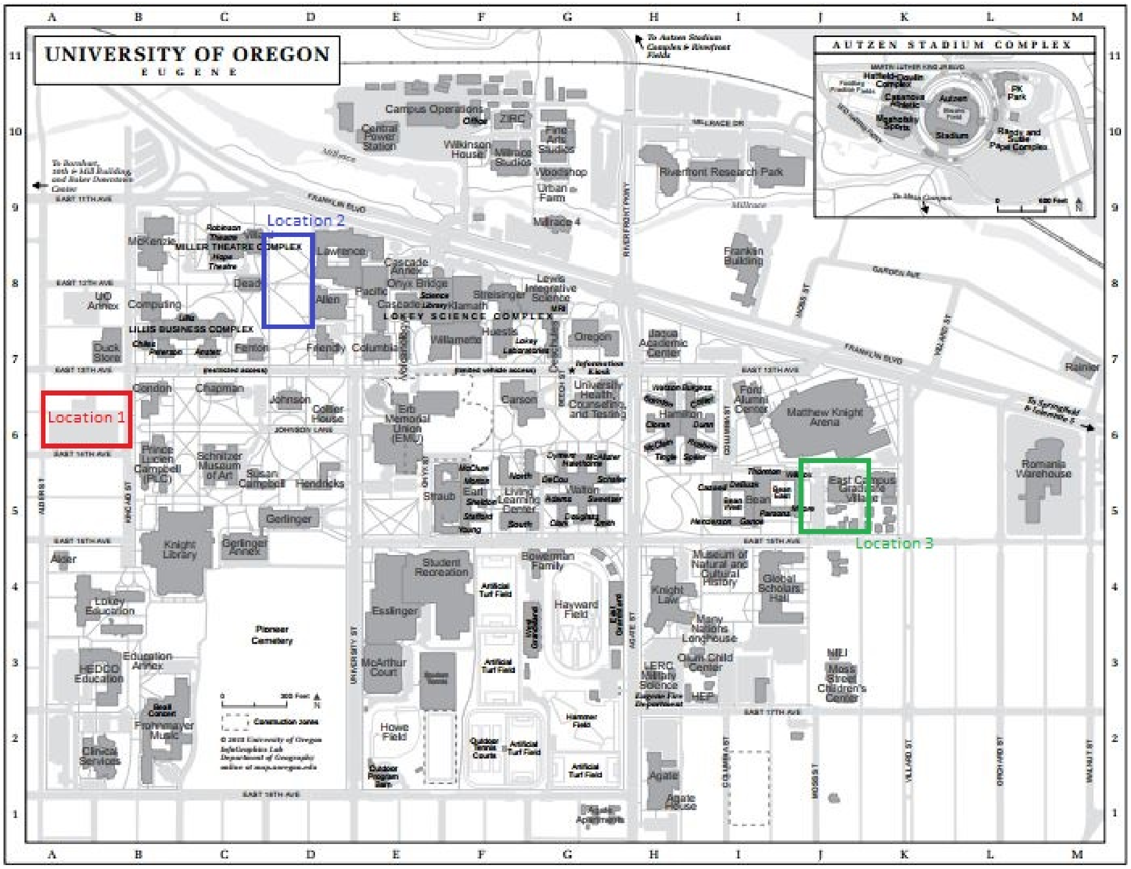


Image courtesy of the University of Oregon Infographics Lab

Location 1:

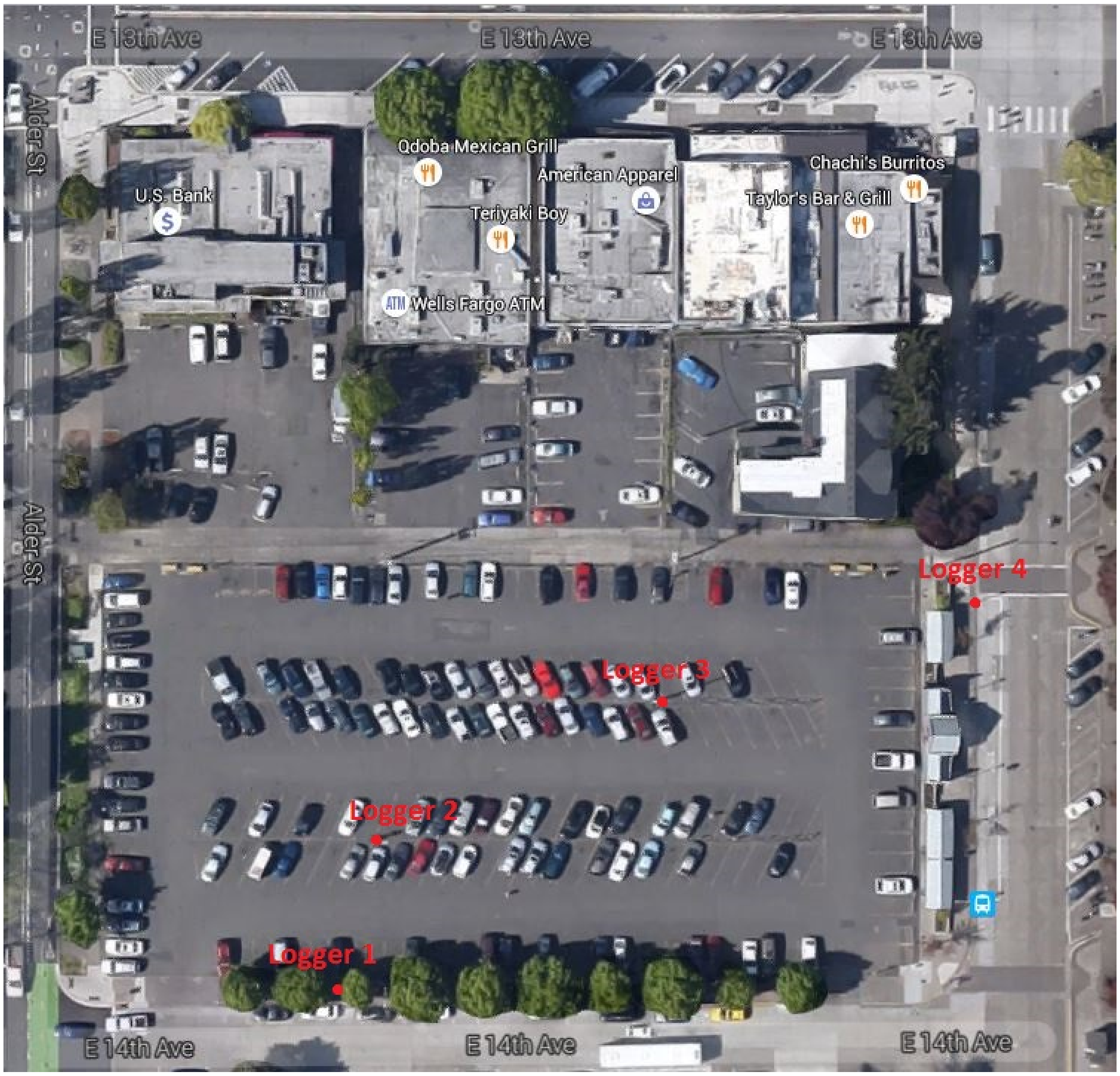


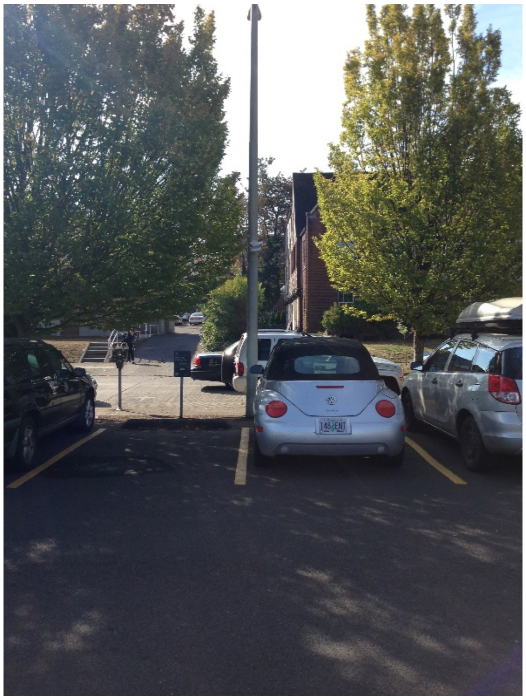
Image from Google Earth

Logger 1: Logger 1 was located along the south edge of the parking lots on a lamppost among a row of trees. Directly to the north was the large expanse of the parking lot. To the south was a sidewalk and 14th Street. The only source of shade was the line of small trees among which the logger was situated. For most of the summer, the shade expanded several feet into both the parking lot and sidewalk sides, however the majority of the surrounding area was exposed to ultraviolet rays from the sun. This part of the parking lot was usually filled with cars during the day.

Logger 2: Logger 2 was located near the center of the parking lot on a lamppost. It was surrounded completely by asphalt, with no trees, grass, or permeable surfaces within fifty meters. During the day, it was usually surrounded on all sides by parked cars.

Logger 3: Logger 3 was located towards the east side of the parking lot, but still in the middle of the paved parking area. It was about twenty meters east of logger 2. Another twenty meters to the east was the UO South Bus Station, consisting of a small glass and metal three sided shelter and several concrete planters with native plants.

Logger 4: Logger 4 was located on a lamppost at the far northeast corner of the parking lot, alongside Kincaid Street. It was just north of the UO South Bus Station, described above. When busses were present, they parked within several meters of the logger with their exhaust pipes pointing in the direction of the logger. To the north of the logger was a fraternity house with a grass lawn, landscaped beds, and several small trees.



Logger 1

Logger3

Logger 2

Logger 4

Location 2:

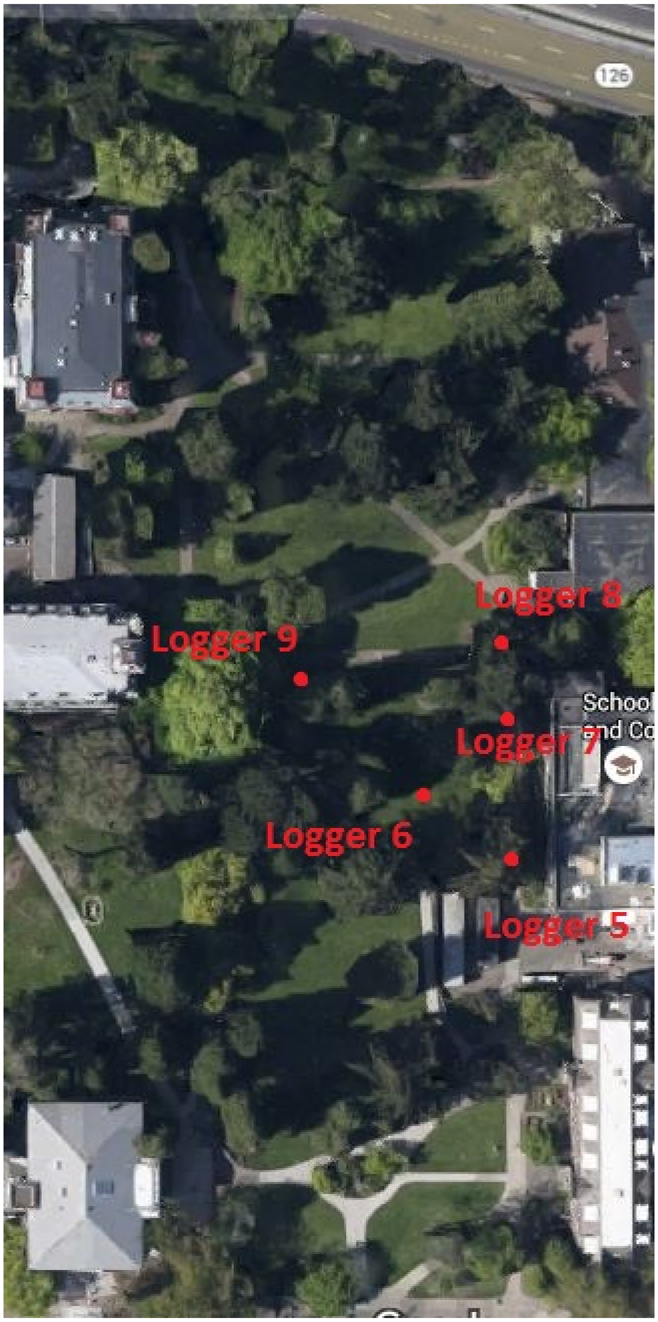


Image from Google Earth

Logger 5: Logger 5 was located along a north-south path that runs along the west sides of Friendly, Allen, and Lawrence Halls. It was near the south end of this path, near the north corner of Friendly Hall on the west side of the path. Directly to the west was a large conifer that shaded the logger and surrounding quad throughout most of the day. The three story building to the east also supplied shade during the morning. On the west side of the path was grass and bare dirt and pine needles. On the east side of the path was a long planting bed with a variety of shrubs, bushes, and ground cover.

Logger 6: Logger 6 was located on the south side of a southeast-northwest diagonal path leading from Friendly to Deady Hall. Directly to the north of the path was a large conifer and another large conifer was some ten meters to the south of the logger. Together, these two trees shaded the logger throughout most of the day. To the east and west were sizeable expanses of shaded grass.

Logger 7: Logger 7 was also located on the west side of the same north-south path as logger 5, about fifty meters to the north of that logger. Two different trees, a large conifer and a smaller deciduous, were located within ten meters of the logger, providing shade along with the Allen Hall, directly to the east.

Logger 8: Logger 8 was located just north of logger 7 near the southeast corner of Lawrence Hall, also along the same north-south path. It was located in a small triangle of grass between three paths, meaning there was relatively more concrete around this location than around other loggers in this grouping. It received shade from the three-story Lawrence Hall, but there were not any substantially-sized trees in the immediate vicinity of the logger. To the west of the logger was a large expanse of grass.

Logger 9: Logger 9 was located some seventy yards west of logger 8 along an east-west path. It was also at the junction of three paths. Also there was a small concrete pad with a bench in close proximity to the logger location, meaning the amount of concrete directly around the logger was greatest for this logger out of all the loggers at this location. However, there was a very significant amount of shading from several very large evergreens. To the east of the logger was a large expanse of grass, but to the west was Deady Hall, which has significant amounts of impervious surfaces, including a small parking lot to the north.

Logger 9

Logger 8

Logger 7

Logger6

Logger 5

Location 3:

Image from Google Earth

Logger 10: Logger 10 was located on a lamp post along the east side of the parking lot on the corner of 18th Ave. The logger itself is located under a wide deciduous tree, although much of the surrounding area, including 18th Ave and the proximate section of the parking lot, is unshaded for much of the day. The logger was bordered on two sides , rather than one side, by a street or parking lot. Because of recent construction, the unpaved area on the north corners of the parking lot and 18th Ave were dirt rather than grass.

Logger 13: Logger 13 was located on another lamp post some 20 yards north of logger 10 on the same side of the parking lot, on the corner of a shrub-filled bulb-out. There was a large tree located in this bulb-out that shaded much of the surrounding parking lot.

Logger 12: Logger 12 was located on a lamp post another 20 yards north of logger 13 in very similar conditions to the aforementioned logger, except that it was located along the sidewalk, rather than on a bulb-out. Being on the sidewalk meant that it was closer to the Graduate Village and more affected by the shade from that building.

Logger 14: Logger 14 was located on another lamp post 20 yards north of logger 12, near the corner of parking lot where it turned to the east. As a result, the logger was bordered on two sides, rather than one side like loggers 13, 12, and 11. The lamp post was surrounded at ground level by shrubs, short bushes, and a small deciduous tree. Like logger 12, this logger was located along the sidewalk, around fifteen yards from the Graduate Village building.

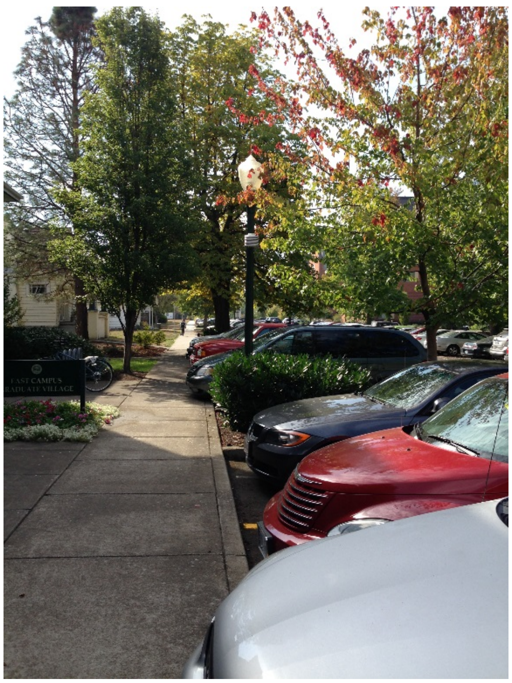
Logger 11: Logger 11 was located some seventy yards east of logger 14 along the south side of the parking lot. The lamp post on which it was mounted was on the southwest corner of a large, bulb-out that was covered in large, chest-height shrubs and that contained a medium-sized deciduous tree. To the south was a small open courtyard with bushes, a concrete area with benches and bike racks. The Graduate Village buildings were far enough away that they did not directly shade the logger.


Logger 11


Logger 14

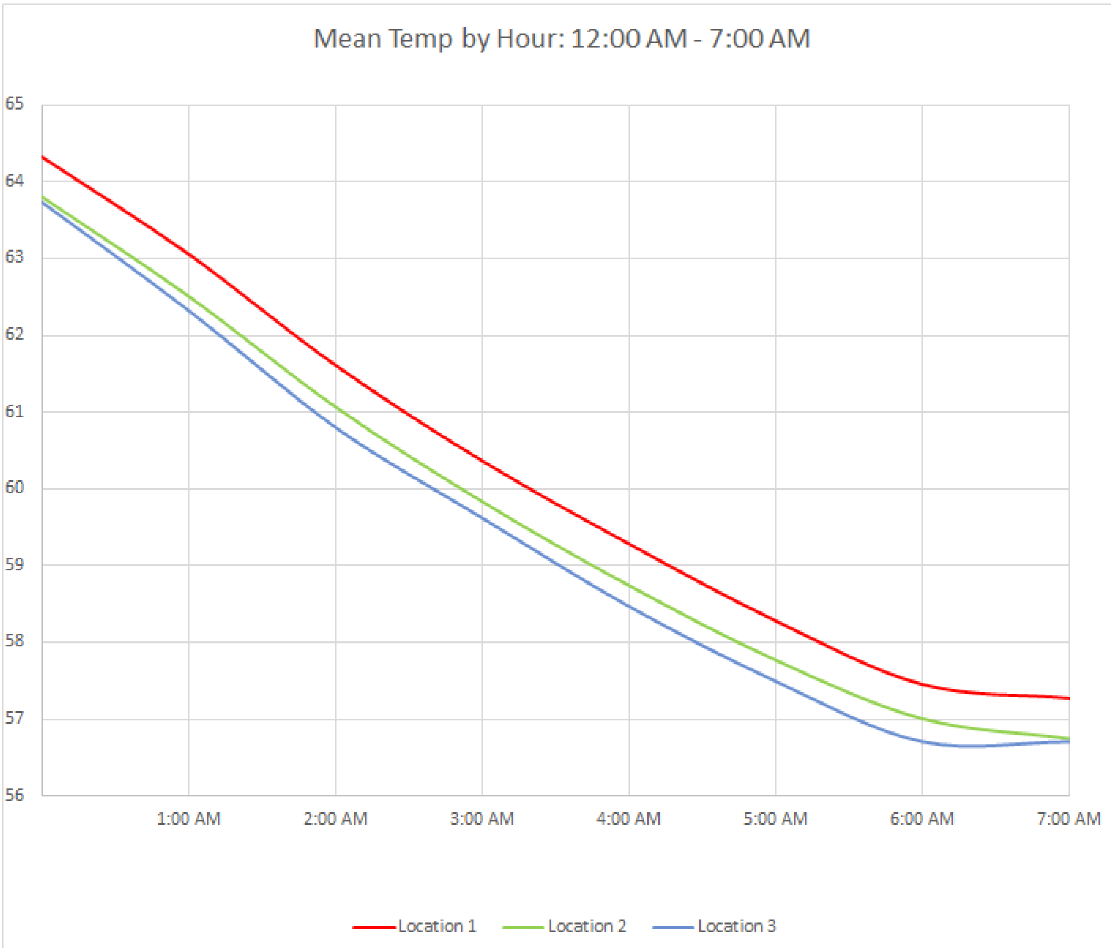
Logger 10

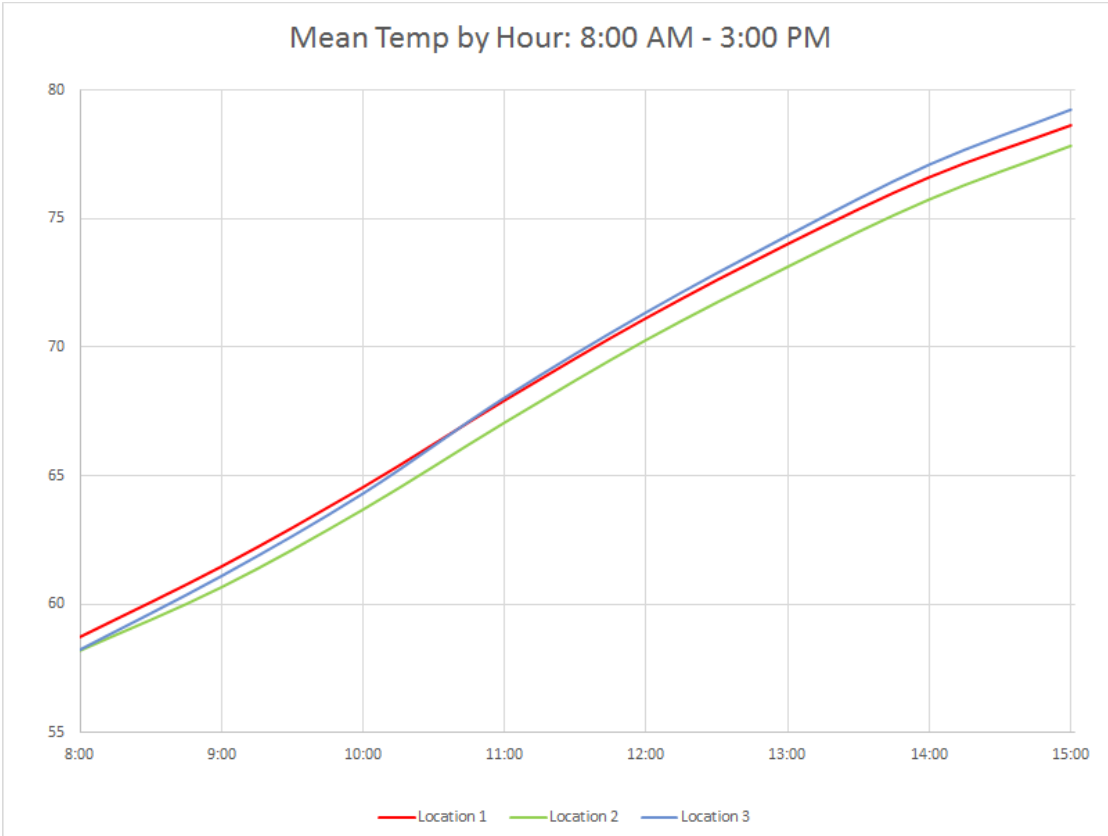
Logger 12

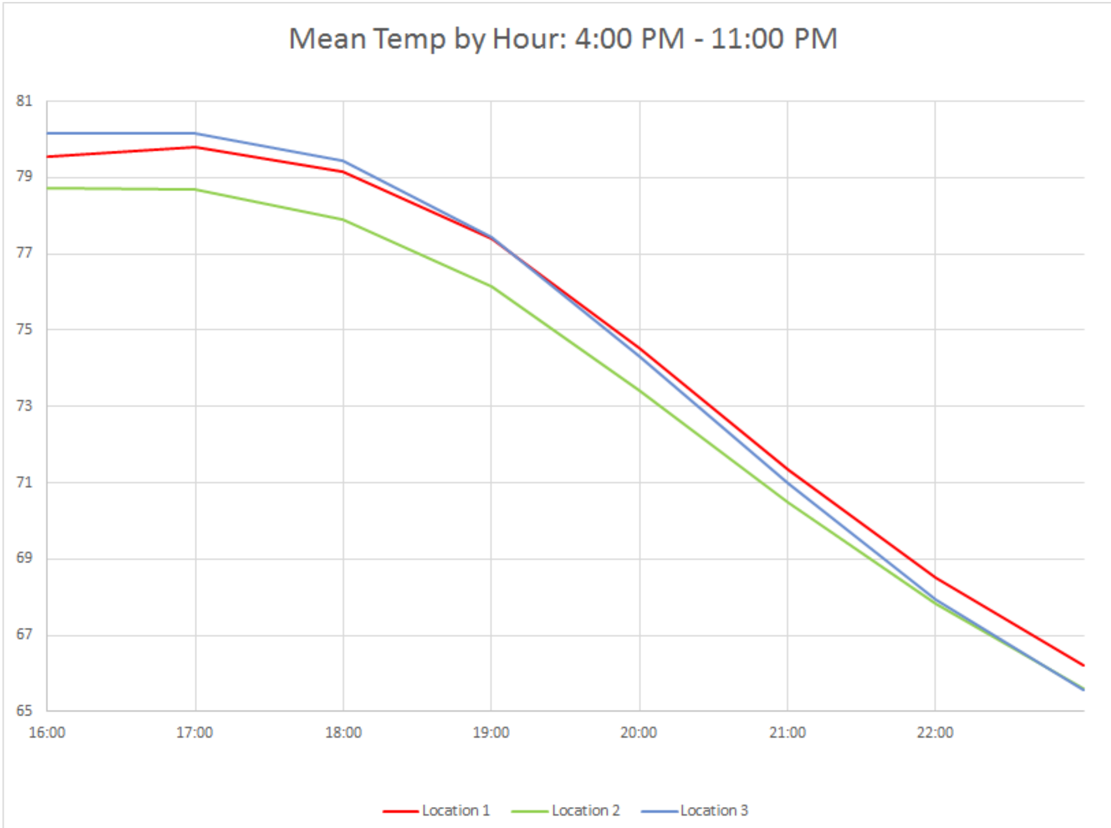


Logger 13

Appendix B: Mean Daily Temperature Curve Deconstructed




Mean Temp by Hour: 8:00 AM - 3:00 PM
80
75
70
65
60
55
8:00
9:00
10:00
11:00
12:00
13:00
14:00
15:00
Location 1
Location 2
Location 3


Mean Temp by Hour: 4:00 PM - 11:00 PM
81
79
77
75
73
71
69
67
65
16:00
17:00
18:00
19:00
20:00
21:00
22:00
Location 1
Location 2
Location 3

Bibliography

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Urban Environment, 70 (3),* 295-310.

Akbari, H., & Rose, L. S. (2008). Urban surfaces and heat island mitigation potentials. *Journal of Human-Environmental System, 11 (2),* 85-101.

Armson, D., Stringer, P., & Ennos, R. (2012). The effect of tree shade and grass on surface and globe temperatures in an urban area. *Urban Forestry and Urban Greening, 11 (3),* 245-255.

Donovan, G. H., & Butry, D. T. (2009). The value of shade: estimating the effect of urban trees on summertime electricity use. *Energy and Buildings, 41 (6),* 663-668.

Hart, M. A., & Sailor, D. J. (2007). Quantifying the influence of land-use and surface characteristics on spatial variability in the urban heat island. *Theoretical and Applied Climatology, 95 (3-4),* 397-406.

Kenward, A., Yawitz, D., Stanford, T., & Wang, R. (2014). Summer in the City: Getting Hotter and Hotter.

Kurn, D.M., Bretz, S.E., Huang, B., & Akbari, H. (1994). *The potential for reducing urban air temperatures and energy consumption through vegetative cooling*. United States.

Oke, T. R. (1973). City size and the urban heat island. *Atmospheric Environment, 7 (8),* 769-779.

Oke, T.R. (2004). Siting and exposure of meteorological instruments at urban sites. *27thNATO/CCMS International Technical Meeting on Air Pollution Modelling and its Application, Banff, 25-29 October, 2004.*

Rosenfeld, A, H., Akbari, H., Bretz, S., Fishman, B., Kurn, D. M., Sailor, D., & Taha, H. (1995). Mitigation of urban heat islands: materials, utility programs, updates. *Energy and Buildings, 22 (3),* 255-265.

Simpson, J. R. (2002). Improved estimates of tree-shade effects on residential energy use. *Energy and Buildings, 34 (10),* 1067-1076.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. *Energy and Buildings, 25 (2),* 99-103.

Unger, J., Sümeghy, Z., Gulyás, A., Bottyán, Z., & Mucsi, L. (2001). Land-use and meteorological aspects of the urban heat island. *Meteorological Applications, 8,* 189-194.

Weng, Q., Lu, D., & Schubring, J. (2004). Estimation of land surface temperature–vegetation abundance relationship for urban heat island studies. *Remote Sensing of Environments, 89 (4),* 467-483

Wilby, R. L. (2003). Past and projected trends in London's urban heat island. *Weather, 58,* 251-260.

Yuan, F., & Bauer, M. E. (2007). Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote Sensing of Environment, 106 (3),* 375-386.