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LNR Spring Internship A Local Scale Urban Heat Island Effect

Introduction:

Urbanization in the United States in the last fifty years has contributed to a consistent rise in temperatures in downtown areas ranging from 0.25-0.2 degrees F annually (McPherson 1994). This phenomenon of local climate change, known as the urban heat island effect (UHIE), can have many environmental consequences including increased peak energy demands, higher air conditioning costs, pollution and greenhouse gas emissions, and poor water quality.

The term "heat island" describes industrialized areas as warmer than surrounding vegetative and rural communities. An annual mean air temperature of a city with 1 million people or more can be 1.8–5.4°F warmer than its surroundings (EPA). In the evening, the difference can be as high as 22°F as buildings begin to release heat absorbed throughout the day. There are two types of heat islands; surface and atmospheric. The total release of thermal heat by building structures, usually composed of cement or asphalt, can be referred to as the surface heat island effect and ranges from a ground level of 1-9 ft. Atmospheric heat islands experience less temperature fluctuation but can measure overall temperature change from either the canopy layer (the ground to roof or tree tops), or the boundary layer (the canopy layer to 1 mi. above surface). Canopy layer will describe the type of heat islands of interest in this study. By analyzing this layer we should see larger temperature changes at night as heat radiates upward from ground surfaces and also be able to note how humidity plays a key role in cooling this effect.

Heat islands' are the most well-known form of anthropogenic climate modification and have been documented for about 150 years (Streutker 2002). Heat released through cars, factories, air conditioning and other man-made sources have led to monumental energy demands and greenhouse gas emissions. Albedo, a prime determinant in a landscapes ability to reflect solar radiation, is often used to measure heat detainment. It is evaluated on a scale from 0 (high absorptive properties) to1 (low absorptive properties). It is predominantly based on color but can also be affected by urban geometry. Dark pavements and tall buildings are examples of low albedo in an urbanized setting. They not only have highly absorptive properties, but can additionally reflect thermal energy to other urbanized structures. At night, these tall buildings impede heat from reaching the atmosphere and often reabsorb heat trapped in the canopy layer.

Plants serve a variety of purposes that are essential to curving problems urbanized infrastructure has caused. In addition to providing shade, vegetation promotes several biological processes key to natural temperature regulation. One process, known as evapotranspiration, is responsible for the transportation of water from soil, understory, and canopies into the atmosphere. By directing energy from the sun into evaporating water, latent heat, or heat transferred through a change in state of matter, is released and used as a cooling agent. Humidity induced by this process accounts for 10% of moisture in the atmosphere and without it can cause detrimental change in precipitation and the hydraulic structure as a whole (EPA). Carbon dioxide sequestration is another vital vegetative cooling function that is absent in urbanized settings. The heat retaining properties of CO_2 cause climate change not only on a local scale but for the entire planet. Cyclic CO_2 patterns and atmospheric moisture are substantial to maintaining stable atmospheric temperature. By ridding significant amounts of vegetation for infrastructure and impermeable surfaces such as roads and parking lots, the environmental consequences of heat islands will continue to be seen.

Mitigation involving urban heat island reduction can be beneficial for several reasons. By planting vegetation around urban infrastructure we can see a direct correlation to the reduction of CO_2 emissions, a decrease in air pollution, improvement in water quality, creation of habitats, along with an increase in property value and personal aesthetics. Trees and scrubs can sequester heat and pollutants by providing shade and absorbing CO_2, making them essential to urban heat reduction. In addition to plantings, construction of green roofs can serve as a viable reduction strategy. Green roofs are vegetative rooftops that are designed to remove heat through evapotranspiration. They lead to a variety of benefits including significant energy savings by reduced AC need, air and water quality improvement through filtering and absorbing of pollutants, and an overall enhanced quality of life. Although green roofs require a higher initial investment, throughout there life they can contribute to savings of $200,000 with 2/3rds of that being energy savings (EPA). Urban areas can also establish cool roofs and cool pavements to offset the urban heat island effect. These surfaces both have high albedo, and can stay 50-60% cooler than traditional materials (EPA). In addition to a significant cut in energy cost, cool pavements can also enhance water evaporation and through permeable surfaces, allow for improved water quality.

The purpose of this study is to determine a correlation between urban infrastructure and increased temperatures and to explore the impacts this new climate has on local environments. By analyzing local and micro-scale surroundings including: surface cover; building materials; undercover; traffic density; and canopy, appropriate test sites can be used to measure the true effects of atmospheric UHI. Humidity will also be measured in order to quantitatively assess the natural cooling characteristics of vegetation and conclude their importance to local urbanized environments. By testing our confidence in the UHI effect, further actions can be taken to restore areas of high urban infrastructure with vegetative tree plots to help offset future heating.

The study area was located at the main campus of the University of Central Florida in Orlando. UCF's diverse campus of 1,415 acres allowed for a perfect micro-scale assessment of UHI. Vegetative areas currently incorporate 72 acres of lakes and ponds, 191 acres of conservation easements, and 246 acres of wetland and riparian protection zones (Landscape and Natural Resource Department). In contrast, urban structures comprise over 6,032,365 square feet of campus and typified an industrial landscape. By examining UHI data collected by previous semesters, we designed an experiment to better represent areas of complete infrastructure, vegetation, and intermediate landscape of both. With the relocation of data loggers currently installed, we collected data expressing temperature and humidity fluctuation across developed and vegetative surfaces. We then evaluated our results and provided an improved diagnostic review of the effects of UHI's impact on campus and pinpointed areas in need of planting. Future use of our data was designed to provoke sustainable solutions for reducing heat island effects that benefit the expansion of UCF.

We predicted that areas with greater urban interface would yield higher temperatures and lower humidity compared with vegetative areas that would yield lower temperatures and higher humidity. This led to our assumption that vegetation planted around urban interface will produce natural cooling effects that offset urban heat re-radiation and absorption. Our null hypothesis stated that urbanized areas do not project high temperatures and low humidity and vegetated areas do not project cooler temperatures and high humidity.

Materials and Methods:

The following is provided by the Landscape and Natural Resource Department for this study:

- 15 HOBO Pro V2 Data Loggers
- HOBO shuttle data extracting software
- Laptop for data analysis (must be portable)
- GPS
- Solar radiation shields for each HOBO data logger

  (Note: solar radiation shields are currently installed on data loggers)
- Metal and plastic zip ties
- Measuring tape
- 6 ft ladder
- 4 meter transect
- Golf Cart for transportation

To begin our project, we assessed the locations of 15 data loggers installed currently around the UCF campus based on percent vegetation, urbanization, canopy, and water. We then redistributed the loggers and re-evaluated their landscape within 4 meter transects. A GIS map was created to show the new locations (Figure 1). For accuracy, 5 loggers represented 75-100% vegetative (trees, grass, shrubs), another 5 represented 75-100% urbanized infrastructure (buildings, roads, sidewalks), and the last 5 will characterize a mixture of both (Table 1). The locations also showed varying percents of canopy and water coverage ranging from 0-100%. Each logger was placed 10 ft from ground on either a tree or pole attached by metal or plastic zip ties.

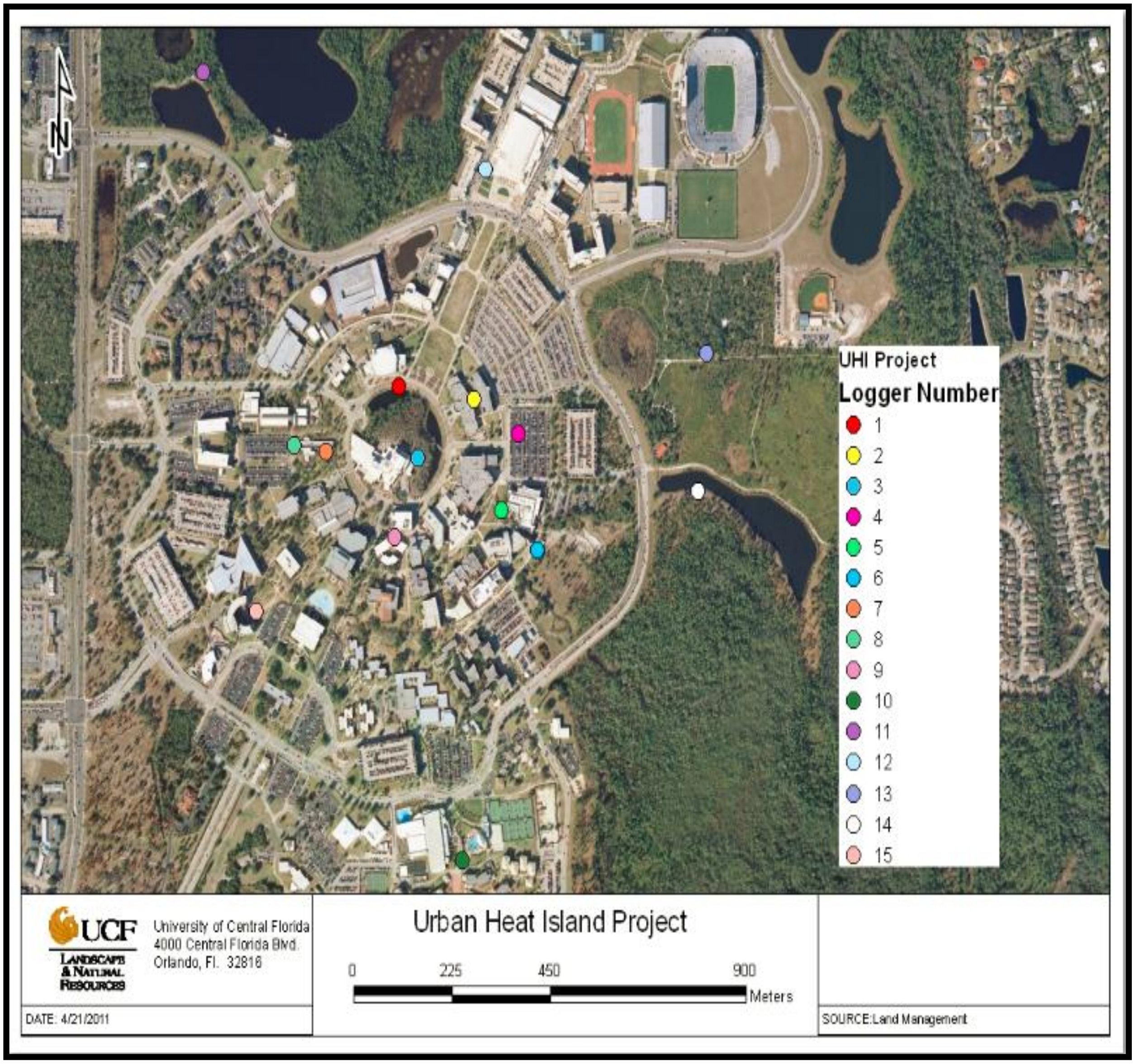


Figure 1: Hobo data logger point locations around the Orlando campus at the University of Central Florida.

Table 1: Percent coverage of data logger locations and corresponding area classification.

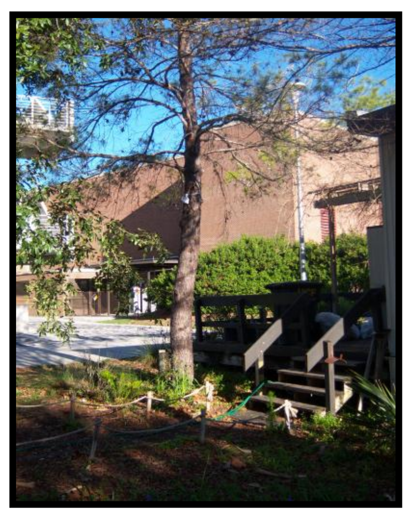
Logger #	Location	Type	%Urban	%Vegetative	%Water	%Canopy	%Open
1	Outside Psychology Bld.	Hybrid	50	40	0	50	10
2*	Between Health & Public Affairs Bld.	Hybrid	60	30	0	75 (half shaded urban)	10
3	Cyprus dome Outside Student Union	Vegetative	20	40	30	50	10
4	Parking Lot C	Urban	100	0	0	0	0
5	Harris Engineering Bld	Urban	70	20	0	15	10
6*	Arboretum	Hybrid	30	60	0	25	10
7*	Honors College Garden	Hybrid	50	50	0	40 (half shaded urban)	0
8	Honors College Sidewalk	Urban	70	20	0	40	10
9	Outside Education Bld.	Hybrid	20	30	0	0	50
10	Pool outside Nike dorms	Urban	50	10	25	0	15
11	Trials at Lake Claire	Vegetative	0	95	0	100	5
12	UCF Arena sidewalk	Urban	80	10	0	0	10
13	Oak Hammock	Vegetative	0	80	0	75	20
14	Lake CREOL wooded area	Vegetative	0	50	40	40	10
15	Alleyway by Teaching Academy	Urban	95	0	0	80 (only urban shading)	5

Notes:
Total percent land cover combines percent urban, vegetative, open land and water.
Open land accounts for grassy areas or urban sidewalks and courtyards.
Percent canopy based on foliage of tree landscape shading the data logger. May also include extreme shading from building canopy (specified).

Photos will be taken to document current conditions in the case of landscape change (Table 2). After downloading the Hoboware software to a laptop, we will do our first analysis on each logger using the Hobo shuttle in order to assure functionality and to clear any previous data collected. The Hobo shuttle is a data extracting unit used to remove information from a data logger and demonstrate results via Hoboware onto a laptop. It requires plugging the logger into the coupler region and a USB cable into the base. Data is then taken from the logger and automatically transferred to a laptop where temperature and relative humidity can be represented in graphic and numeric form. After completing the initial extraction, the loggers will remain in their locations for 30 days before the second extraction process will begin. This will systematically remain for 90 days. After the last data collection on the 90th day, we will compile all temperature and relative humidity records for each data logger location. Finally, we will analyze and interpret our results through graphs and tables to show relations, if any, to high temperatures and urbanized areas.

Installation: Each sensor was placed in a solar radiation shield to eliminate any differing albedo that may effect temperature and humidity readings. The shield and loggers were placed in equal 10 ft altitudes to account for temperature fluctuations from released surface heat. Plastic and metal zip ties were used to secure the loggers to light posts and trees in varying vegetation densities.

Table 2: Photo documentation of data logger locations.

Logger 1		**Logger 2**	
Logger 3		**Logger 4**	
Logger 5		**Logger 6**	

Logger 7		**Logger 8**	
Logger 9		**Logger 10**	

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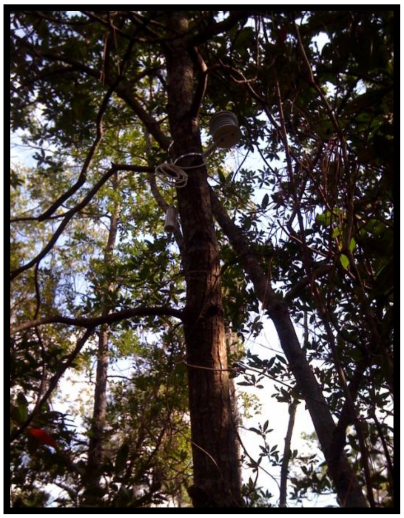
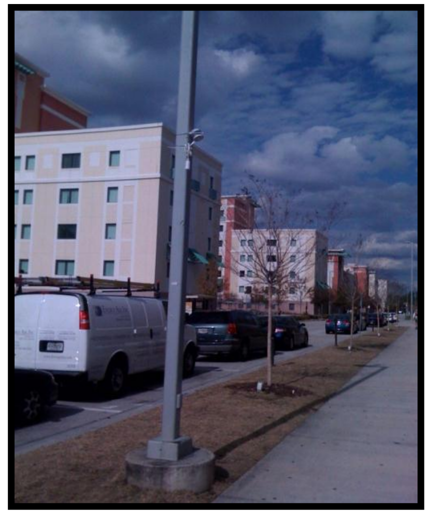
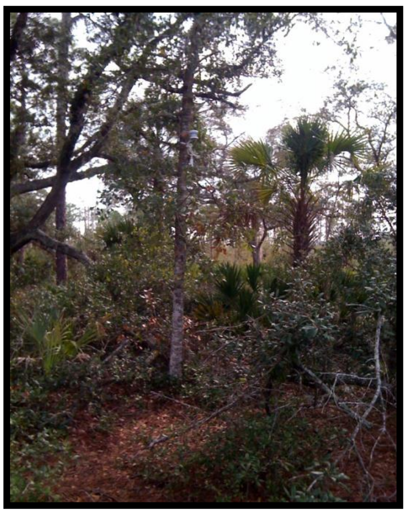
<tr><td>Logger 11</td><td></td><td>Logger 12</td><td></td></tr>
<tr><td>Logger 13</td><td></td><td>Logger 14</td><td></td></tr>
<tr><td>Logger 15</td><td></td><td></td><td></td></tr>
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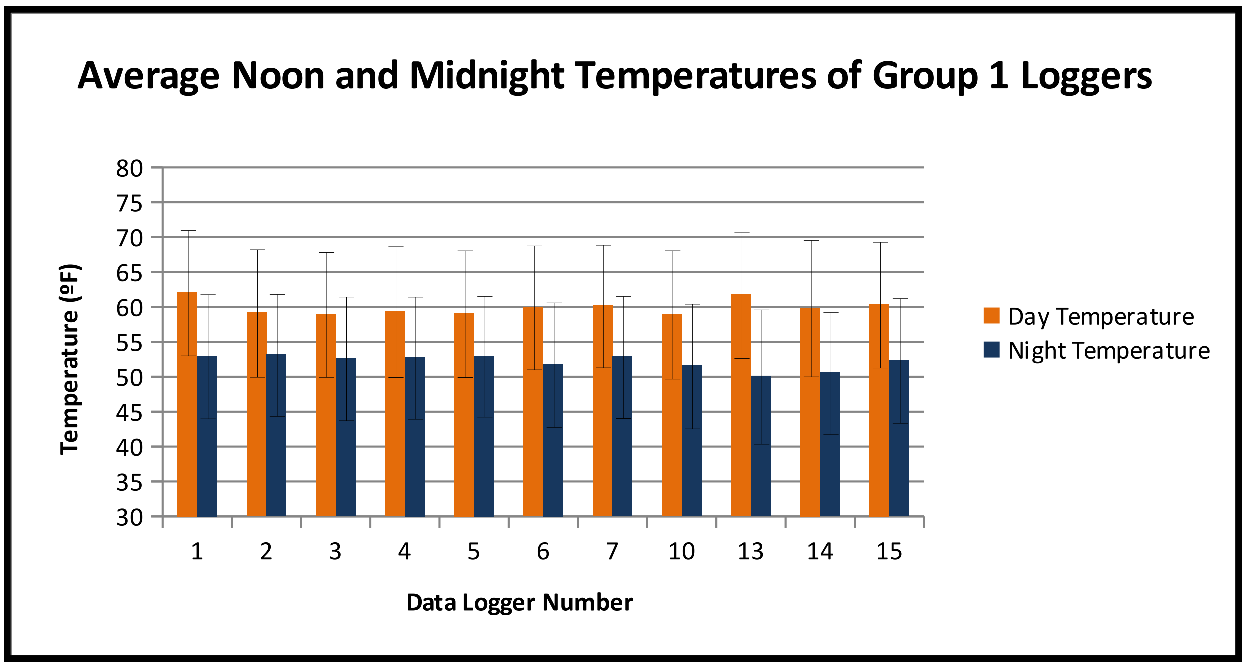
<u>Results</u>:

To begin analysis, we first used the Hobo Shuttle to obtain raw data from the 15 Hobo loggers. Unfortunately, when extracted, data logger 11 only contained content over a 5 day span and data logger 12 had malfunctioned and was unable to record any data. In addition, there were loggers that either logged a period from 12/22/10-2/13/11 or from 2/13/11-4/10/11 while some logged both time spans. In order to organize our results, we had 11 loggers represent data from December to February (Group 1) and 7 that collected data from February to April (Group 2). Loggers 11 and 12 were not used in this analysis because they did not yield any relevant datum.

The individual logger data was examined through HoboWare software that expressed temperature and relative humidity levels collected through 15 minute increments and showed corresponding heat flux graphs of the data. The information from HoboWare was then extracted to Microsoft Excel to further be manipulated to show more specific results. Generally, both time

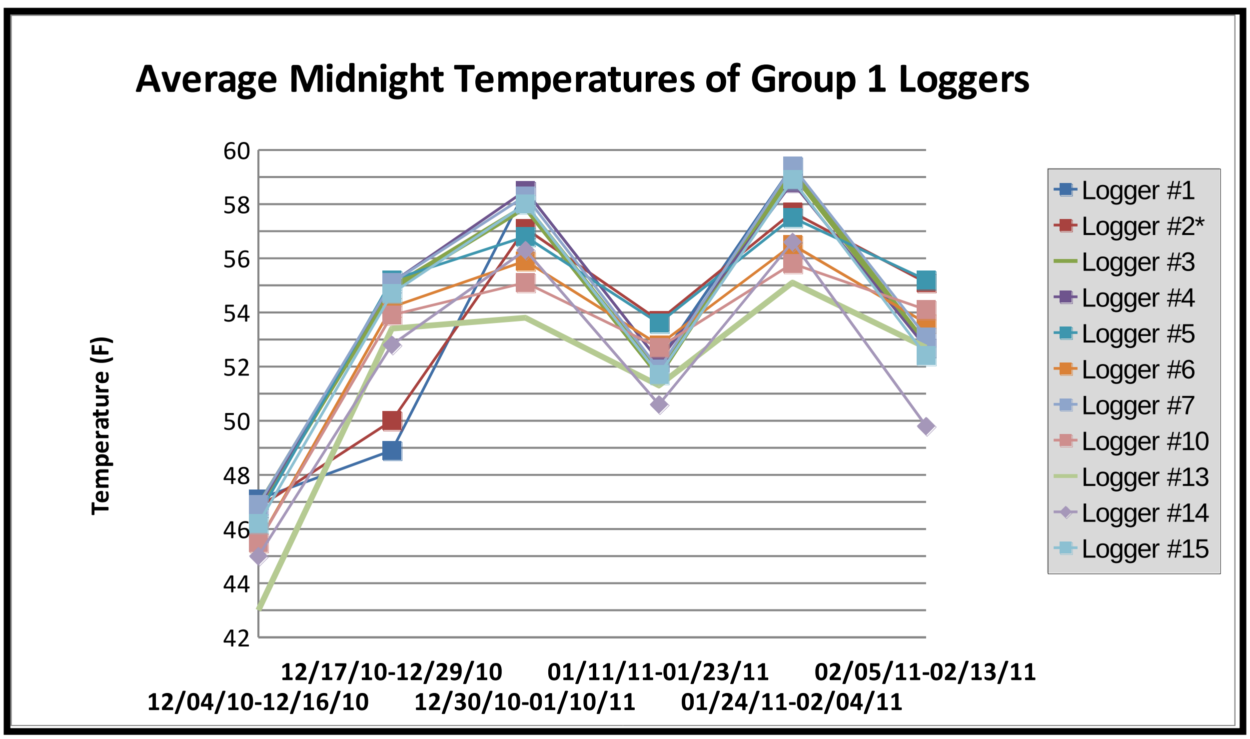


periods had similar outcomes of temperature and humidity changes within the differing areas.

Figure 2: Average day and night temperatures of group 1 loggers over entire 3 month period.

Within Group 1, vegetative logger 3 demonstrated the lowest temperatures for both noon and midnight data sets (Figure 2). Logger 2, representing an ideal combination of vegetative and urban settinga, also showed the coolest temperatures both day and night differing only 0.6º from logger 3. Interestingly, vegetative logger 13 did show the highest day temperatures; however, along with vegetative logger 14, it yielded the lowest nighttime average. This could be a product of direct sunlight during the daytime hours and a vegetative cooling effect during the night. Urban loggers 4 and 5 showed average to high day temperatures but experienced the most warming at night. Because both were located in highly urbanized areas within tall infrastructure, heat re-radiating from concrete could have played an inductive role at night.

Noon and midnight temperature averages were also calculated over 12 day intervals in each group. Analyzing night temperatures between the different loggers was of significant interest because of the phenomenon of urban areas to store heat throughout the day then gradually

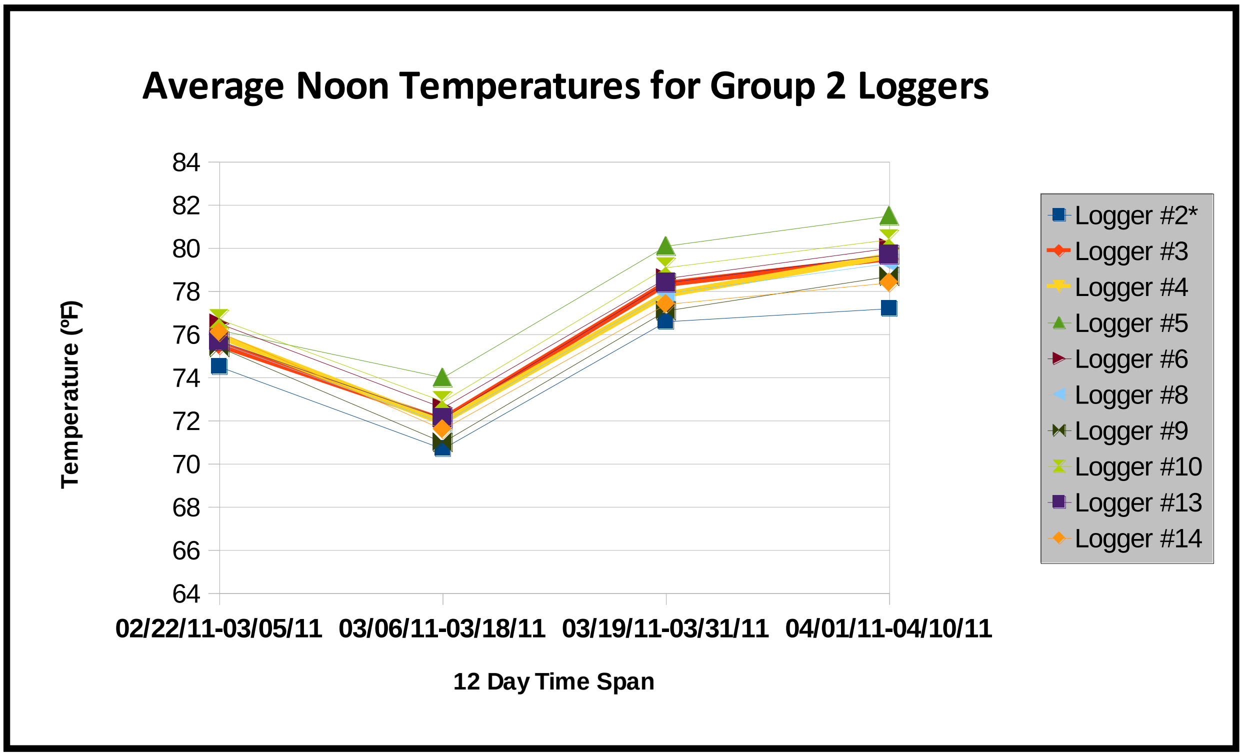


release the energy at nightfall.

Figure 3: Average 11:59pm temperatures for group 1 loggers over a 12 day interval.

Urban loggers 4 and 5 experience the highest temperatures at midnight while vegetative loggers 13 and 14 experience the lowest (Figure 3). Here, urban loggers are 3-5º warmer from vegetative loggers locations and even some hybrid sensors such as logger 10.

Compared to group 1, group 2 loggers showed a more steadied results. Because of the change of season experienced in group 1 (December to February) temperatures showed greater fluctuations and less reliable results. The averages of group 2 were less varied and skewed making it a



consistent time span to study and graphically demonstrate.

Figure 4: Average 11:59am temperatures of each Group 2 logger over a 12 day time interval.

Urban logger 5, shown in Figure 4, exceeds the other loggers in daytime temperature throughout every 12 day time range. As temperatures steadily rose til mid April, ideal hybrid logger 2 and vegetative logger 14 continued to be the coolest differing from urban logger 5 by 4º.

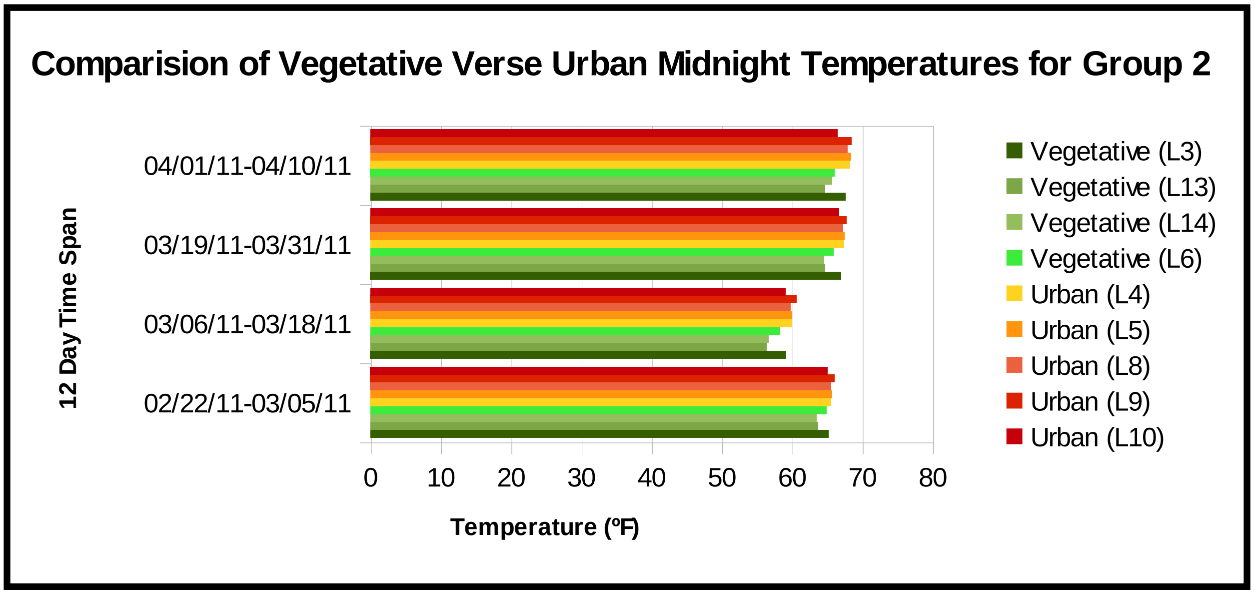


Figure 5: Average vegetative and urban temperature comparisons of group 2 between noon and midnight.

Figure 5 shows the overall results of urban and vegetative temperature comparisons. Hybrid loggers were classified as either or based on percent vegetative and ground cover type. Midnight temperatures for nearly all urban loggers uniformly show higher temperatures then that of vegetative with a maximum difference of 4º from 3/06/11-03/18/11.

In order to fully understand the benefits of natural cooling processes that plants contribute to lower temperatures, we measured relative humidity.

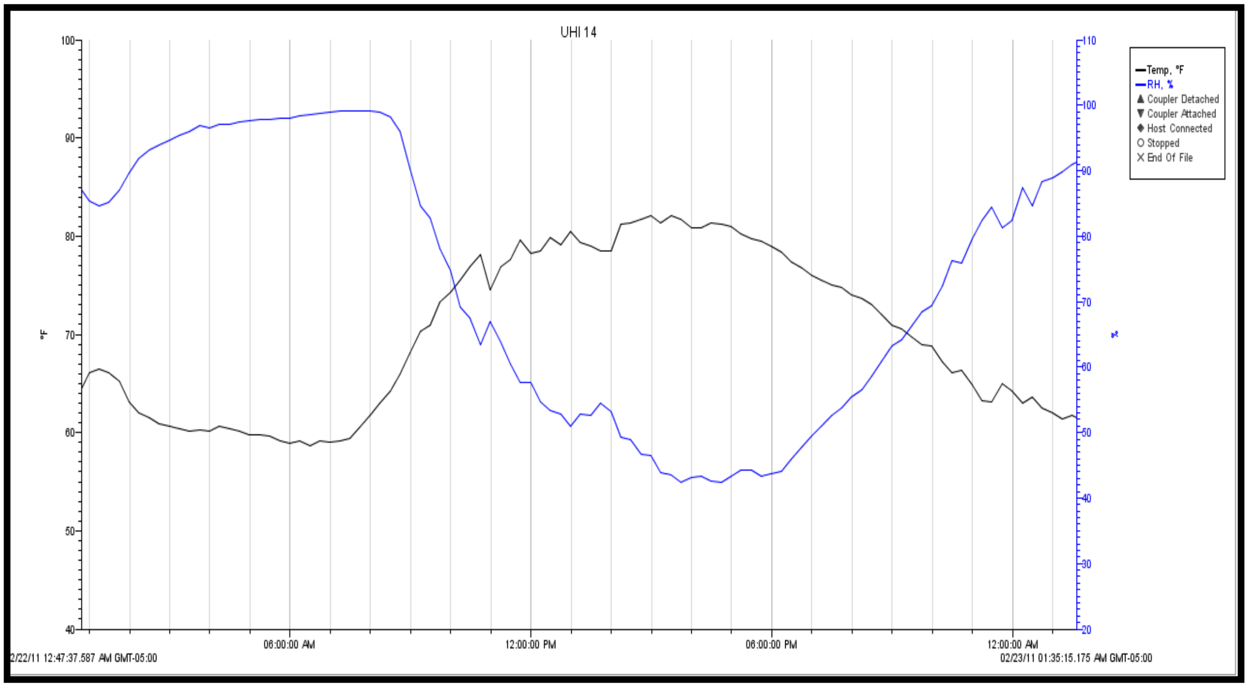


Figure 6: Temperature and humidity comparison during February 22, 2011 of vegetative logger 14.

Figure 6 displays the inverse trend of high humidity and low temperature for vegetative areas. In contrast to urban settings that absorb heat during the day, plants use evaporation cooling processes that release heat consistently day and night contributing to higher humidity and lower temperatures. The highest relative humidity level took place at 6am at 99% and corresponded to the lowest temperature of logger 14 that day at 58º. In comparison, urban logger 9 at 6am had a RH of 68% with a temperature of 63F (Figure 7).

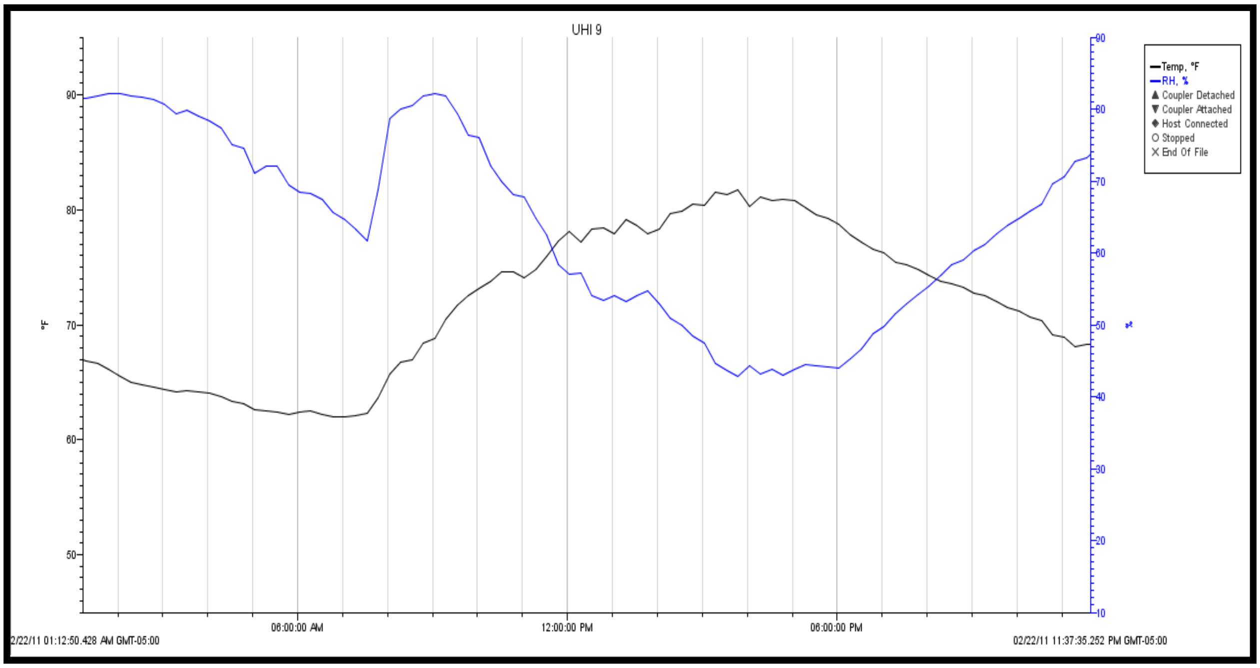


Figure 7: Temperature and humidity comparison during February 22, 2011 of urban logger 9.

The temperature and humidity flux for logger 9 is far less drastic than seen with logger 14. With little to no vegetation, humidity gradients will demonstrate less dramatic behavior causing a fairly stable inverse relationship. Without humidity fluxes during the evening, urban areas show higher temperatures during the night.

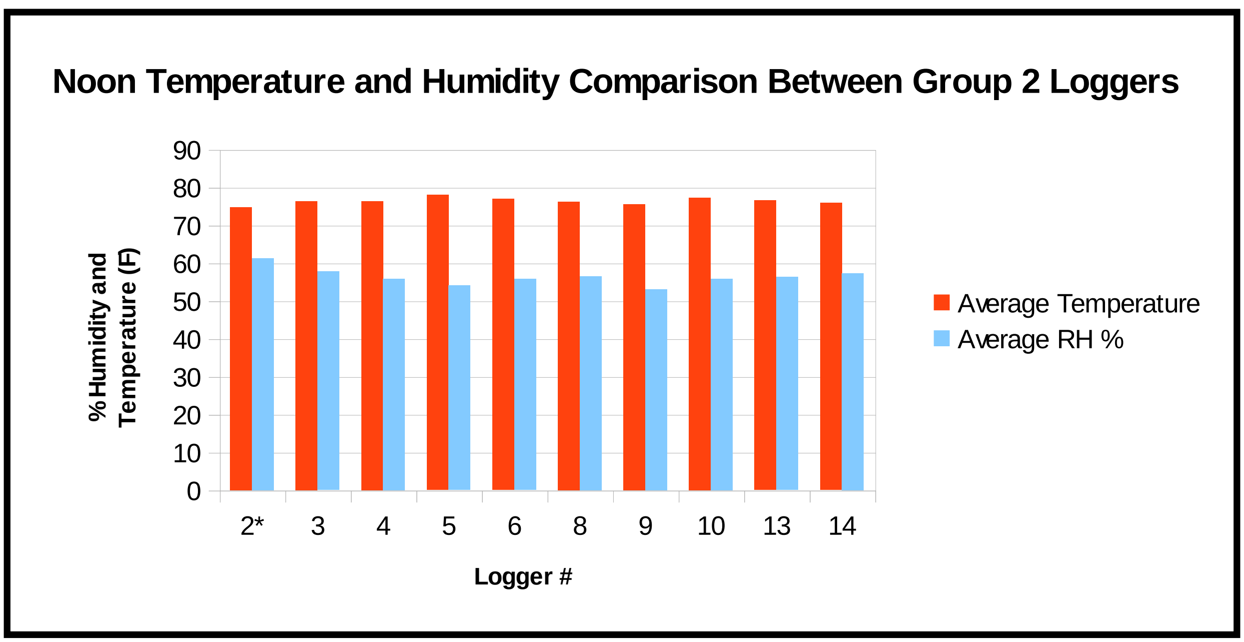


Figure 8: Average temperature and humidity comparisons from February to April of group 2 loggers.

Urban logger 5, located in a heavily trafficked parking lot with no vegetation, shows the greatest temperature and the lowest humidity (Figure 8). We can also see that ideal hybrid logger 2, located in a fairly urban setting with large patches of vegetation, shows some of the coolest temperatures and the greatest amount of humidity. The results demonstrated by logger 2 amplify potential benefits of urban areas including appropriate vegetation in there landscape.

Discussion:

Our data is conclusive in demonstrating the association between low temperatures and vegetated locations. It is clear plants serve a fundimental purpose to maintaining our climate. Our research was intended to explore how and why vegetation could null the effects of urban heat storage.

Although we analyzed two, three month time periods with 4 fewer loggers compared to the intended one span with all 15, our results accurately represented the important aspects of vegetation for urban cooling. We can reject our null hypothesis and accept our alternative that vegetated locations produce higher humidity yielding cooler temperatures. The ability to see results over both time spans allowed us to be confident in the effects of the urban heat island effect at the University of Central Florida and also have the ability to pick and choose data with the least amount of weather and construction interferences. Group 2 loggers, including data from February to April, were free of disturbances and therefore were the main subject of our study.

A predominant barrier encountered included our extraction technique using the Hobo Shuttle. This lead to split time spans and was a direct result from difficulties relaunching each logger. Thoroughly checking each logger for the first 3 days might be the solution to managing logging status and assuring the correct time period is logged.

Logger 12's malfunction also presented itself as a barrier. Regardless of the several launch trials by the Hobo Shuttle, the sensor was corrupted and unable to record any data. This prevented us from gaining temperature and humidity information from a prime urban location. Vegetative logger 11 experienced similar issues. The sensor only included data for a 5 day period independent of the number of times launched. To overcome these obstacles, we eliminated both loggers from our data sets and included results over a larger time spectrum.

Exploring the effects of the UHIE at a small scale allowed us to realize the importance of budgeting and designing appropriate vegetative landscapes to urban interfaces. Dr. Urban, author of “Up by Roots”, highlights key soil and site location assessments of urban areas for planners, architects, and engineers. Most importantly, he describes that the process of implementing landscape design to promote healthy trees can lead to improvement in the overall quality of where people live, work and play (Urban 2008). For city planners, the benefits can be endless. In the United States, Urban says, 'trees add legally definable value to a property'. For example, “a mature willow oak on a site with good soil conditions in a residential area is worth $24,300 compared to a newly planted one at $840” (Urban 2008). Property value enhancement from trees can initiate community say in city plannings and give rise to tree plots around infrastructure. By giving city planners incentive, the effects of urban warming could be stalled.

The outcomes of our experiment are meant to encourage allocating urban landscaping for local urban areas, such as the University of Central Florida. If put to action, we will see significant savings in energy and even greater public appeal. Urbanized warming is a growing concern for our planet as populations rise and cities expand. It leads to energy expenditure, abundant greenhouse as emissions, and pollution. Vegetation designed in specific locations around urban settings have the potential to curve the crucial consequences of the UHI phenomenon.

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