Research on Mitigation Techniques for Heat Retention on Indiana University Southeast's Campus

Research In Sustainability SUST-S415

Indiana University Southeast

Department of Sustainability and Regeneration

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EXECUTIVE SUMMARY

This study examined how greenspaces and hardscapes contribute to the overall heat retention of Indiana University Southeast's campus. Our main areas that we focused on were forest, grass, building roofs, walking paths, parking lots/roads, and lake/water. Utilizing Google Earth Pro, we calculated the area of the areas in square meters. Subsequently, we calculated the albedo of each surface type. Other research conducted includes mitigation techniques such as tree types to employ, the transformation of the roof of the Life Sciences building into a green roof, and the installation of pavers. By making these campus improvements, we will ensure less trips to medical centers for students impacted by intense heat; we will lower greenhouse gas emissions to combat the climate crisis; we will increase habitat areas for pollinator species and other native organisms; we will ensure that our current and future students hold praise and a sense of belonging when thinking about our campus. It is our duty as informed students, faculty members, and stewards of this great planet to take action with the knowledge that we have amassed. The time has passed for us to continue with business as usual and hope for the best when pondering the future of our campus and our planet. The time to act is now. By making the adjustments and gathering the data found within this proposal, we are headed towards not only a healthier, more efficient campus but a more connected and stable world.

INTRODUCTION

The Kentuckiana area was found to be around 4.8 degrees F warmer than it should be in the summer (Urban Heat Island Project, 2019) due to a phenomenon known as the urban heat island effect. This condition is a byproduct of increasing asphalt and dark hard surfaces that accompany urban sprawl. As greenspaces disappear, there are fewer shading opportunities to keep temperatures optimal for buildings, parked automobiles, and students. This effect is amplified as the byproducts of natural gas (carbon dioxide, nitrogen oxides, and sulfur dioxide) contribute to global warming.

In an effort to combat anthropogenic degradation of our campus, improve the health of students and wildlife alike, and conserve campus funds, we conducted this study.

Our objectives are to:

1) Increase energy efficiency and maximize savings on energy expenditures

2) Reduce greenhouse gas emissions as a result of fossil-fuel generated heat

3) Lessen the effects of the urban heat island which threatens the health of students and campus wildlife

4) Allocate data that can be further utilized for future projects on campus

5) Mitigate stormwater run-off

METHODOLOGY AND RESULTS

Campus Albedo

We as a research class designated five types of areas we would be measuring both in area (meters squared) and in albedo (utilizing various sources and an albedo reference card for color matching). These six areas were as follows: forest, grass, buildings, paths, parking lots, and bodies of water (Figure 1). The albedos we calculated for each designated area are as follows: 0.70 for forest (accounts for shade of deciduous trees), 0.26 for short grass (cut by management), 0.27 for buildings (roof estimated coloration through albedo card Appendix 7), 0.40 for paths (closest color to gray cement), 0.02 for parking lots (median of various asphalts to account for diversity), and 0.50 for water (attempts to account for zenith angle). (See Appendices 1-7).

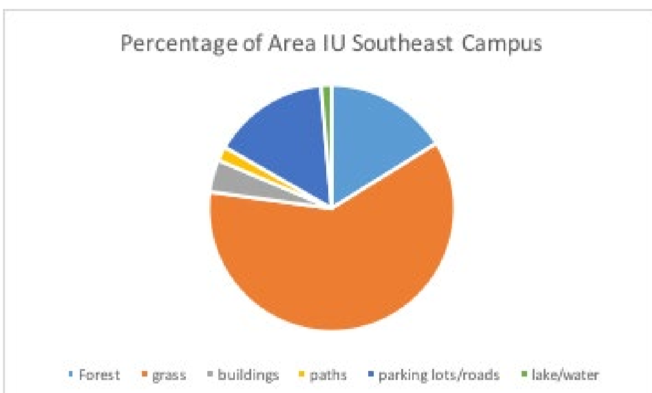

Figure 1. Total area of the campus was estimated at 758,022 m^2.

To roughly convert the albedo to surface temperature we used empirical data (Figure 2) measured in Arizona (Cambridge Systematics 2005). We projected the fitted line to cover albedos up to 1.0. For each 0.1 increase in albedo results in decrease of about 7° C (12° F) in temperature. This allows modelling of changes in campuses albedo and the resulting changes in surface temperature (Appendix 8). E.g., changing ½ of the grass area to trees would change total campus albedo from 0.31 to 0.43 reducing drop average surface temperatures by about 8° C.

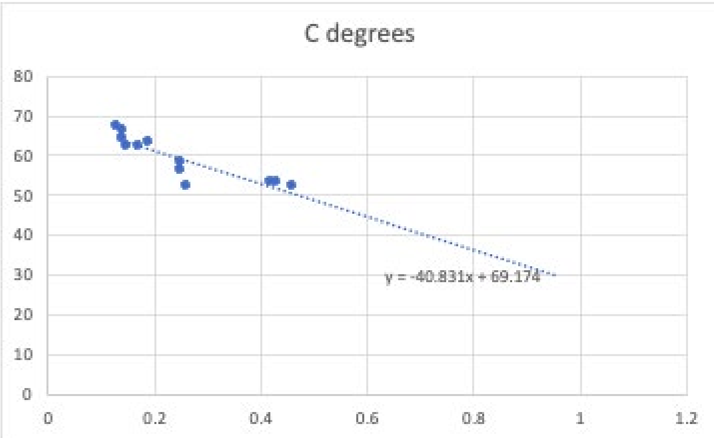

Figure 2. Linear relationship of albedo to degrees C based on data from Arizona (modified from Cambridge Systematics 2005). Weighted average of IUS albedo is .31.

Google Earth Pro Steps:

1. Campus Buildings (Appendix 7)
    a. We utilized the time machine tool on Google Earth to locate a clear satellite image so that we could calculate the area accurately. April 2017 and October 2018 were primarily utilized.
    b. The polygon tool was used to calculate the area in meters squared of each roof.
    c. The values from each campus building were compiled in an Excel spreadsheet and summed.
    d. The buildings on campus were split into three categories—residential, learning, and maintenance/others.
    e. Using an albedo reference card, we compared the color of the roofs to the corresponding colors on the card.
    f. The values for each building were compiled in the same Excel spreadsheet and summed to calculate total albedo
2. Forest, Grass and Water (Appendices 1, 3, 4)

a. We utilized the time machine tool on Google Earth to locate a clear satellite image so that we could calculate the area accurately. April 2017 and October 2018 were primarily utilized (especially to determine forest ponds).
b. The polygon tool was used to calculate the area in meters squared of each facet of forest on campus (four total determined), body of water, and grass covered space.
c. The values from each designated area were compiled in an Excel spreadsheet in their categories and summed.
d. The areas were separated into three different categories: forest (considered 50 percent or more inhabited by trees), significant bodies of water (three ponds including the lake), and grass (calculated by deducting all five decided categories of forest, buildings, paths, parking lots, and water).
e. Using data from various sources (along with an albedo reference card), we determined the albedo of forest as 0.70 (to account for shade of deciduous trees), 0.50 for water (attempts to account for constantly changing zenith angle), and 0.26 for grass (cut by management).

3. Walkways (Appendix 5)
   a. We measured all of the sidewalks and walkways on the Indiana University Southeast campus using the ruler tool on Google Earth Pro. (Figure 1) If the walkways crossed paths with parking lots or roads then this section was omitted.
   b. The total length of all walkways was 6,556.16 meters.
   c. That was then multiplied by 2.5 meters to get a total of 16,390.4 meters squared. (2.5 meters was estimated to be the average width of total walkways).
   d. According to the American Concrete Pavement Association, grey Portland cement has an albedo range of 0.35 – 0.40 when new and 0.20 – 0.30 when weathered. Because the sidewalks seem to be light in color, we used an albedo of 0.40.
4. Parking Lot/Roads (Appendix 6)
   a. We utilized the time machine tool on Google Earth to locate a clear satellite image so that we could calculate the area accurately. April 2017 and October 2018 were primarily utilized.
   b. The polygon tool was used to calculate the area in meters squared of each road and parking lot.

c. The values from all the roads and parking lots were compiled in an Excel spreadsheet and then summed.
d. The islands that are in the parking lots were measured as well and then deducted from the overall total measured meters squared of the parking lots and roads.
e. Using different albedo resources, we compared the color of different pavements to the corresponding colors on the site. Since there have been updates to certain areas that have been paved, we then took the two different albedos and calculated them therefore finding the median albedo. We found that for the median albedo was 0.02 for the roads and parking lots.

<u>Life Sciences Green Roof</u>

To get a basis of what we needed to examine, we first analyzed literature pieces concerning albedo, green roofs, the urban heat island effect, and retrofitting. With an idea of what to measure in mind, we took to the program Google Earth Pro to measure area and albedo.

<u>Life Sciences Green Roof Calculations</u>

Information pulled from the EPA as well as other scientific literature (Thering, 2017) were utilized to determine information about implementing a green roof on the Life Sciences building. From those sources, we gathered information about minimal vs. extensive green roofs as well as another alternative—cool roofs.

Costs	**Minimal Green Roof**	**Extensive Green Roof**	**Cool Roof**
Implementation	$272,780	$681,950	$20,458.5 to $81,834
Maintenance (annual)	$20,459	$40,917	$351 to $1,381
TOTAL	$293,239	$722,867	$20,809.5 to $83,215

Table 1. The costs as of green and cool roofs for Life Science based on Thering, 2017.

Tree Selection for Parking Lots and Islands

There are many benefits to choosing the right trees for urban settings such as providing energy conservation, stormwater runoff reduction, helping with carbon sequestration, reducing air pollution and providing habitats for pollinators. We decided that we would focus on native trees that are non-invasive. Looking at different soils that each type of tree needed, as well as management styles, resistance to pests and disease, how tall they get at maturity, the growth rate for each year and how much space the roots need to grow, we chose two trees that would be most fitting for around the parking lots and in the islands within parking lots. We decided on the Black Gum (*Nyssa sylvatica*; "Black Tupelo") and Red Maple (*Acer rubrum*) as the trees that we commend to plant on the campus. They are aesthetically pleasing and fit the above-mentioned criteria.

Tree Type	Height	Growth per yr.	Soil Conditions	Roots	Maintenance Level	Pest/Disease
Red Maple	avg. 40-50 ft.	36 inches	wet/dry	roots grow close to surface and can cause surfaces to buckle.	Low	minor
Shumard Oak	40-60 ft/up to 115 ft.	13-24 inches	well-drained soils/prefers norm moisture		low	minor /oaktree wilt
Quaking Aspen	50 ft.	Fast	adaptable/prefers dry		?	many/dogwood borer
Flowering Dogwood	15 ft.	Slow	evenly moist, well-drained, fertile, deep		?	many
White Oak	50-80 ft	12-24 in/med	acidic/neutral, deep, moist well-drained	needs plenty of room		wood borers
Black Gum	30-50ft	slow-moderate	widely adaptable	long taproots	low	minor

Table 2. Top 6 recommended trees and their characteristics.

Benefits of Tree Shading

By simply adding more trees to the campus the ambient heat can be decreased in that area significantly. Along with the decrease in heat, the psychological wellbeing of campus residents can be enhanced in the process. For the trees to have the most desirable effect, deciduous trees should be placed along buildings. The deciduous nature of the trees will prevent solar radiation from hitting the buildings during the spring and summer months, when the air conditioning is running, but during the fall and winter months, when the heat is running, the sunlight will be allowed through due to the trees shedding their leaves. This same design principle can be used around walkways and parking lots as well.

Degradation of asphalt and pavement will occur much more quickly when exposed to direct sunlight throughout the entirety of the day when compared to asphalt and pavement that is shaded (Yamaguchi, 2005). Depending on latitude and color of asphalt, the surface temperature difference between shaded and unshaded portions of asphalt can be as high as 20° C during the summertime. In the wintertime when the solar radiation is less intense and the leaves have fallen from the tree, the surface temperature difference in shaded and unshaded areas of the asphalt or pavement is only 3° C (Massetti, 2019). Vehicles can also benefit from being shaded during the hotter months. A study has been done in obtaining the temperature differences of the inside of vehicles parked in the shade and the inside of vehicles parked in direct sunlight and it found that vehicles parked in the shade were 25°C cooler than vehicles parked in direct sunlight (Scott, 1999).

A study was done by Akbari et al. (1997)in California, Japan, and China and they measured the peak power output along with the A/C cost savings associated with the shade that trees produce and white surfaces in Sacramento, California and they found that the shade that trees provided resulted in a peak cooling energy savings of 27% - 42% and a 30% A/C energy savings.

Further attention must be given to the placement of trees along the buildings. Studies have shown that trees have the most significant cooling effect when placed along the West and Southwest sides of the building (Akbari, 1997). It is also beneficial for trees to be planted along the East and South facing walls but since the sun is lower in the sky during the wintertime it is desirable to not have the trunk of the tree directly in front of South facing windows. Doing so could prevent the desirable solar radiation in the wintertime from reaching the windows, which would negate the decrease in heating costs. Trees can also be planted to the North of the building which could help lower heating costs in the winter by blocking cold winds and creating a microclimate in between the building and the tree.

The amount of shade hitting the building also makes a difference in how much A/C energy costs can be saved. Air conditioning electric costs can be decreased by 9.3% with just 19.3% dense shade coverage while 50% shade coverage can lower the cost by 14% (Pandit, 2010). This study was done on multiple, identical houses with the only difference being that some houses had trees planted near them and others did not. Overall, it is estimated that the U.S. urban/community forest is estimated to save approximately $7.8 billion per year by reducing electricity use by 38.8 million MWh and heating needs by 246 million MMBtus (Nowak et al., 2019).

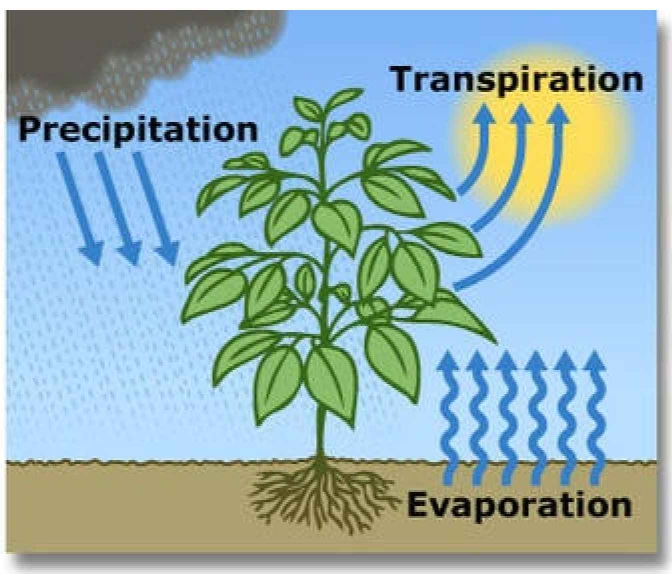

Figure 3. Plants role in evapotranspiration, plants reduce temperature both through shade and transpiration (from Trees-Energy-Conservation, 2019).

Along with shade, trees also reduce the ambient temperature in the immediate area by a process known as evapotranspiration (Figure 3). Evapotranspiration is the process of plants taking up water through their roots. The water is then transported up and out of the leaves. The process of water transforming from a liquid to water vapor cools the surrounding area. (Trees-Energy-Conservation, 2019)

Pavers

The initial installation costs of permeable pavers are probably the biggest downside, considering materials and labor compared to cheaper concrete and easier installation (Pavements, n.d.). When comparing 120 square feet of land, concrete was estimated to cost between $865 and $1,085 compared to pavers ranging from $1,310 and $1,770 purely related to installation costs. This means replacing all of IU Southeast's walkways with pavers could cost from $1,925,700 and $2,601,900.

Cost	Concrete Slabs	Permeable Pavers
Implementation	$66,294,158 (median)	$2,263,800 (median)
Maintenance (annual)	$73,433,529 (estimated repair)	$16,573,539
Total	$139,727,687	$18,837,339

Table 3. Comparative costs of concrete slab sidewalks to permeable pavers.

Maintenance costs are lower for pavers considering replacement occurs on an individual basis compared to replacing an entire concrete slab and since the permeability decreases water wear and tear and consequently decreasing runoff. The benefit comes later with pavers with potential heat reduction due to evapotranspiration and mitigation for stormwater management (chemical filtering provided as well though aggregate), an adverse issue across our valley of a campus (Environmental Protection Agency, 2020). "The permeable modular pavement (PMP) underdrain water quality had consistent total suspended solids (TSS), zinc, and copper event mean concentrations that were statistically less than the reference asphalt runoff…Combined with data from the literature, it is recommended that permeable pavements, in general, be given strong consideration for effective source treatment of urban storm-water runoff" (Fassman and Blackbourn, 2011).Permeable concrete pavers can be utilized for both walkways and potentially roadways considering they have four times the weight capacity before cracking compared to the traditional concrete. This is pertinent to our campus layout considering motor vehicles especially of physical plant management typically utilize walkways to commute from location to location as necessary. Potential external costs associated with permeable pavers that allow vegetation could include other maintenance such as additional mowing unless specific groundcovers are utilized such as clover or creeping thyme.

Figure 4. Selected permeable pavers will increase evapotranspiration while remediating water filtration and absorption. (Nicolock Turfstone Pavers, 2020)

RECOMMENDATIONS FOR CAMPUS

1. When redoing the expiring Life Sciences roof, implement either a cool roof or green roof to maximize energy savings and enhance campus sustainability.
    a. Opportunity to elevate AASHE STARS score
2. Increase the tree population on campus which will increase total albedo, along with having positive social, economic, and environmental benefits
3. Shade tree types that were recommended were Red Maple for large trees and Black Gum for smaller trees as they are local and a good size.
4. Replace various impervious urban surfaces (asphalt, concrete paths) with more environmentally sustainable alternatives like pavers which allow increased vegetation along with evapotranspiration and also aid in stormwater mitigation.

ASSESSMENTS AND METHODOLOGY FOR THE FUTURE

<u>Why Utilize the Proposed Adjustments?</u>

Greater health for all

We cherish the ability for our students to feel safe in case of a medical emergency on campus. For students with respiratory conditions, the increasingly intense heat of summer time can sometimes mean a trip to the hospital and missed class days. By making shading and cooling improvements, we make students feel safeguarded and provide relief for all.

Aesthetics

A positive byproduct of making shading and cooling adjustments is that it will most likely be accompanied by increased green areas on campus. This means the return of previously extinguished pollinator species and beautiful flora that capture the hearts of prospective students. If we increase the visual appeal of our campus, we are solidifying our commitment to the natural world and campus upkeep.

Energy savings

According to the United States Green Building Council, buildings account for 24-50% of energy use and 38% of carbon dioxide emissions. Our goal is to optimize energy use intensity (get the most out of a unit of energy) in an effort to lower those figures. In this endeavor, we are ensuring campus savings which could be better utilized for other campus energy projects such as on-site renewable energy generation or other improvements. Allocate data for future urban planning projects. The research can aid in making heating efficiency adjustments in the future and further our progress towards achieving success in various rating systems such as AASHE STARS and the United States Green Building Council's LEED Green Building Rating System (LEED).

Allocate data for future urban planning projects

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Water Mitigation

Various solutions we have provided for mitigation of heat retention in the urban setting of Indiana University Southeast focuses on reducing impervious surfaces including asphalt, concrete walkways, traditional building roofing, and limited canopy cover (large grass coverage which is not the most helpful reducing heat retention or for water mitigation). The solutions we have provided through our research including further integration of trees throughout campus, a potential high albedo or green roof for replacement of Life Science's roof, and permeable pavers all also have the potential to contribute to stormwater mitigation and absorption through various methods. The increase in vegetation on campus will increase water retention including in flood conditions common in our valley through roots (especially of trees) and permeable sidewalks which will decrease runoff (Environmental Protection Agency 2020).

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APPENDICES

Appendix 1. Google Earth Pro image of IUS campus (total shaded).

Appendix 2. Excel Spreadsheet of measured areas and selected albedos

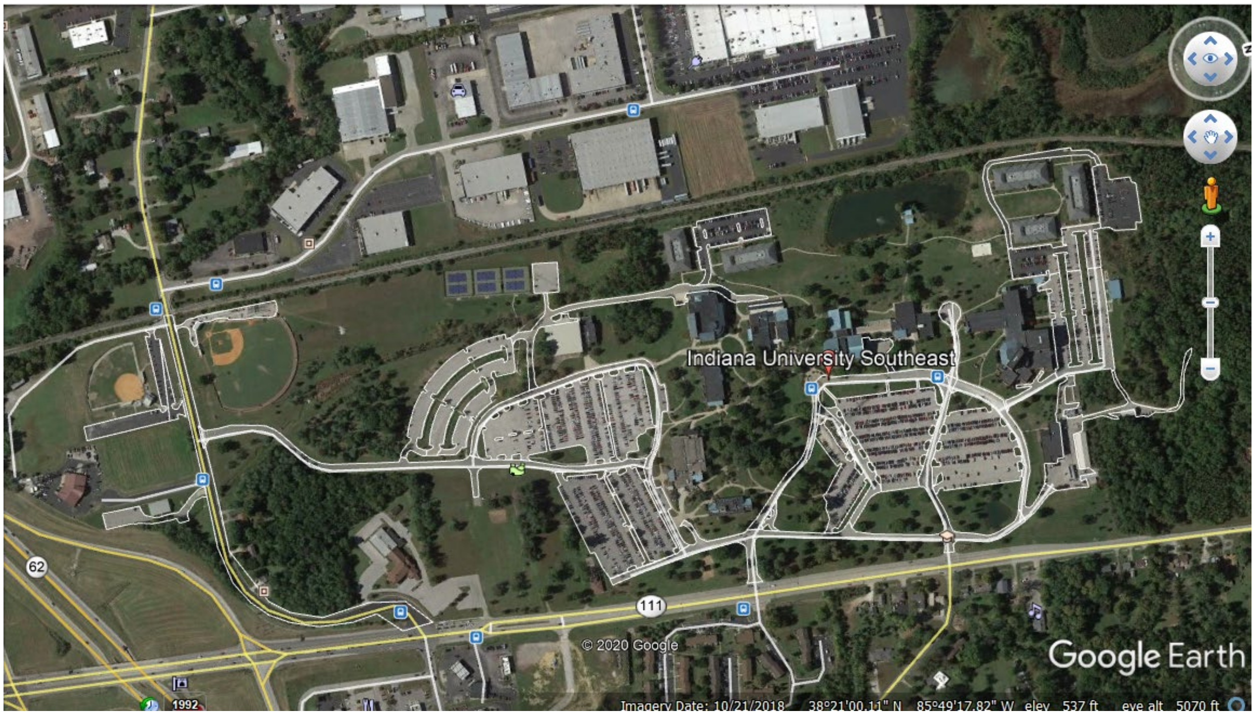
	Area m2	acres	albedo	Reference
total	758022	189.5055	0.31	
Forest	141617	35.40425	0.70	Accounts for shade by deciduous trees (numbers based on shade produced by clouds)
Grass	534339	133.5848	0.26	Most grass short due to management practices (mowing)
Buildings	37305	9.31375	0.27	see image below (sourced from https://acescentral.com/t/acescg-for-animation-feature-and-further-questions/1545/41)
Paths	16390	4.05	0.40	see image below (sourced from https://acescentral.com/t/acescg-for-animation-feature-and-further-questions/1545/41)
Parking lots/roads	134380	33.20602	0.02	https://www.fhwa.dot.gov/pavement/sustainability/articles/pavement_thermal.cfm
Lake/water	12110	3.0275	0.50	Attempts to account for constantly changing zenith angle

Appendix 3. Google Earth Pro image highlighting facets of forests (4) measured.

Appendix 4. Google Earth Pro image highlighting bodies of water (3) measured.

Appendix 5. Measured walkways across IU Southeast Campus.

Appendix 6. Outline measurements of parking lots and roads at Indiana University Southeast using google earth.



Appendix 7. Raw data concerning building measurements and their calculated albedos

Building	Roof Area (meters squared)	Albedo
Amphitheater	328	0.43
Athletic Department	2,285	0.38
Children's Center	525	0.2
Crestview	1,336	0.18
Forest Lodge	1,552	0.22
Grove Lodge	1,544	0.22
Hausfeldt	451	0.7
Hillside Hall	2,400	0.18
House 1	252	0.26
House 2	155	0.31
House 3	148	0.36
Knobview Hall	6,231	0.18
Knobview Storage	84	0.43
Library	2,540	0.3
Life Sciences	2,534	0.21
Meadow Lodge	1,959	0.22
Men Baseball Field 1	56	0.43
Men Baseball Field 2	40	0.43
Men Baseball Field 3	31	0.43
Observatory	17	0.7
Observatory Building 2	18	0.8
Orchard Lodge	1,998	0.22
Physical Sciences	1,143	0.2
Picnic 1	58	0.43
Picnic 2	58	0.43
Service Building	1,202	0.18
Service 1	138	0.36
Service 2	687	0.58
Service 3	181	0.36
Service 4	280	0.12
Service 5	50	0.36
University Center	4,829	0.3
Women Baseball Field 1	57	0.43
Women Baseball Field 2	129	0.43
Women Baseball Field 3	49	0.43
Woodland Lodge	1,960	0.22
TOTAL	37305	

Building Categories	Area (meters squared)	Total Area of All Buildings (meters squared)	Average Albedo #	Total Albedo	
Residential	9,568	37305	0.25375	0.065082	0.0651
Learning	21,013	37305	0.221428571	0.124727	0.1247
Maintenance/others	6,674	37305	0.43047619	0.077008	0.077
					0.2668

Color Roof	SRI
Green	36
Blue	33
Wash Black	27
Dark Grey	41
Light Grey	55
Beige	76
Light Brown	54

Appendix 8. Model showing albedo versus temperature. (Spreadsheet model available on request to dwtaylo2@ius.edu)

	area m2	acres	% area	Albedo	Wt Average	Temperature difference from asphalt parking lots
Forest	141617	35.40425	18.6824393	0.7	0.13077708	-27.638504
grass	416220	104.055	54.9086966	0.26	0.14276261	-9.6728639
buildings	37305	9.32625	4.92136112	0.2668	0.01313019	-9.9505147
paths	16390	4.0975	2.16220637	0.4	0.00864883	-15.389204
parking lots/roads	134380	33.595	17.7277177	0.0231	0.0040951	0
lake/water	12110	3.0275	1.59757896	0.5	0.00798789	-19.472304
Total Sum 3-8	758022	189.5055	100		0.3074017	
Total measure	758022	189.5055				
Green roof mitigation (see Gaffin et al, 2006)				0.77		
Parking lot trees 100				0.7		
Pavers (see EPA Reducing Urban Heat Island)				0.75