Campus-Wide Photovoltaic Evaluation for Cornell University

Master of Engineering Report
Mechanical Engineering
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ABSTRACT

Over the past two semesters, Cornell University Sustainable Design (CUSD) has enlisted its Solar team to evaluate the potential for solar arrays to generate electricity on Cornell's Ithaca campus. More specifically, in Fall 2013 Solar began looking at the campus's solar photovoltaic (PV) potential primarily by assessing roof viability for PV to then prioritize the system integration.

Work in Fall 2013 began by building off of work done in Spring 2013; in Spring 2013, alumnus Dr. John Swanson donated 18 solar panels to the University in an effort to raise awareness of solar technology and to give back to his alma mater. A decision matrix had been created to weight different decision criteria and determine a single building on which to install the panels. 16 attributes were produced through discussion, weighted according to importance, and applied to buildings on the Engineering Quad. To quantify these attributes, several sources were used: data from the Cornell facilities' Roof Access Management program, input from our facilities stakeholders, and online resources such as Google maps to provide general building references. This decision matrix served as a baseline tool for subsequent semesters.

Moving forward in Fall 2013, the matrix was adjusted to better reflect new goals that arose from evaluating the entire Ithaca campus, a focus on power production rather than education and student access was established.

By the end of Fall 2013, we developed a preliminary recommendation for which buildings would be most appropriate for solar and we again relied on a decision matrix which consisted of 17 attributes of campus roof qualities. The evaluation at this time had high sensitivity, with only 54% of the weighted values fully graded. These graded weights were 4 of the first 5 highly weighted attributes. They were shading level, roof orientation, roof space and layout, and roof renovation dates. The fifth weight, roof material, was a very complex attribute with over 20 different materials on campus. For this reason, it required more time and attention to evaluate.

In order to communicate findings to stakeholders and the public, the tool ArcGIS was used to display which buildings were most appropriate for solar. These visuals displays were created to help team members learn new software as well as provide a professional and simple way to convey the results of a complex evaluation.

To accompany these mappings a compilation of the financial incentives and permitting procedures were produced to guide any implementation procedures. These was determined that they would be updated as a more accurate assessment of system size is reached.

In Spring 2014, it was decided to return to the decision matrix and make additional changes to weighting, such as decreasing weighting on hands-on educational opportunities. Also new to the decision-making process, primary filters were created to initially narrow down the daunting lists of over 700 buildings on campus.

The top 20 buildings were divided among team members and for each building, the Building Coordinator was contacted. Often, team members were successful in establishing in-person meetings that facilitated a better understanding of the building's characteristics and roof attributes. Rooftop visits were a highlight of this process.

With a goal of increasing visibility for CUSD and for solar technology in general, additional outreach goals were established. Solar decided to begin taking a more outward approach for our project by participating in Spring Fest, and beginning to brainstorm ways in which to display solar information more publicly on campus.

INFLUENCES

During the academic spring semester of 2013, Cornell University was provided with a donation of 18 photovoltaic solar panels by alumnus Dr. John A. Swanson. Dr. Swanson provided these panels with a vision that they would be an educational tool for student research groups on campus and provide open-source data to the public. CUSD's role in this donation was to decide where to place these panels. Solar developed a decision matrix that identified 16 building attributes which would affect the cost, operation, and safety of a system, as well as public interaction. The completion of this project resulted in the CUSD Solar team developing an excellent tool for evaluating campus buildings and determining their "Solar Potential" – a measure of ease for a PV installation.

The next step was to move beyond its decision in the Swanson project towards a campus-wide PV evaluation. Cornell's campus has 1,745,000 square feet of roof space. If all of this roof space were used for solar production, with a 20% mono-crystalline panel and an average annual insolation of 200 W/m^2, roughly a 6.5 MW would be available on campus. However, this figure assumes that solar panels are placed on every single available portion of the roofs.

Although placing panels everywhere wasn't determined feasible, there was still the possibility for a significant amount of solar production at Cornell. Therefore our goal for the Fall 2013 and Spring 2014 semesters was to start and complete an evaluation of this potential, including assessing the financial and permitting codes necessary to maintain its production. Because of uncertainty in where funding would be procured should the feasibility project become a reality, some of these considerations are taken to be rules of thumb.

FALL 2013

Matrix Development

Last semester the decision matrix was based on a relatively small part of Cornell to reflect Dr. Swanson's background: the Pew engineering quad. By expanding to the whole campus, the matrix design was re-evaluated and adjusted. Afterwards the tool was provided to a local consulting group, Finlo Solar in Ithaca, so that the team could receive professional feedback.

The result for Fall 2013 was an updated model incorporating three primary changes.

1) Re-weighting for feasibility vs. public interaction

2) Re-weighting safety and

3) An orientation attribute add-on.

The first change was a shift in the central goal of the project. Where the Swanson donation had a strong emphasis on public interaction and education – given 25% of the total weight (fig. 1) – Solar recognized that the campus-wide evaluation is geared towards power production. Therefore the changes placed a greater emphasis on implementation or feasibility attributes for our project, reducing education to 10% of the weight (fig. 2).

The second change also affected weights but was geared towards a set of specific attributes. With feedback from a Facilities contact and through the Finlo consultants, it was assured that safety concerns could be reduced because there was actually a low risk of harm to PV panels/equipment and there were campus insurance policies. Therefore safety considerations were lowered to a 10% weight, with the remaining 20% shifted the cost and operating attributes (fig. 2).

Lastly, the solar team deemed it necessary to provide an additional attribute under operating considerations. Given a larger pool of buildings it was understood that not every building on campus would be flat or generally south-facing, as in the engineering quad. To respond to this change an orientation attribute was established, which accounted for the buildings position in relation to the cardinal directions. A more detailed description is provided in our the matrix rationale (appendix 1), but, in short, the orientation measured the portions of the building which were facing South, East or West, and placed a greater weighting on those than roofs that were North facing.

The results of these developments were placed in a new matrix which can be viewed below (fig. 2), comparing to the first design (fig. 1).

IMPLEMENTATION 75%										EDUCATION AND INTERACTION 25%					
COST 20%					OPERATING 50%			SAFETY 30%		PUBLIC INTERACTION 70%				SUPPORT SYSTEMS 30%	
STRUCTURAL 80%			ELECTRICAL 20%												
Roof Material 80%	Need for Fences/ Parapets 15%	Load Capacity 5%	Proximity to Elec. Room 60%	Existing Space & Power Cnxns 40%	Shading 50%	Roof Layout and Avail. Space 30%	Next Roof Renov. 20%	Vandalism Risk to Panels 75%	Vandalism Risk to Equip. 25%	Student Access to Monitor Equip. 35%	Student Access to Panels 30%	Panel Visibility 25%	Area Traffic 10%	Existing Info. Cnxns. 90%	LEED Credit Pot. 10%

Figure 1: Spring 2013 Attribute Weightings

Feasibility (90%)														Education and Interaction (10%)					
Cost (30%)					Operating (60%)				Safety (10%)		Public Interaction (70%)				Support Systems	
Structural (80%)			Electrical(20%)													
Roof Material	Current Existence of Parapets	Structural Design	Proximity to Electrical Room	Existing Space and Power Connections	Level of Shading	Roof Layout and Available Space	Orientation	Next Expected Date of Roof Renovation	Vandalism Risk to Panels	Vandalism Risk to Monitoring Equipment	Student Access to Roof	Student Access to Monitoring Equipment	Panel Visibility	Panel Traffic	Preexisting Information Connections	Potential for LEED Credits
(80%)	(15%)	(5%)	(60%)	(40%)	(40%)	(20%)	(20%)	(20%)	(75%)	(25%)	(30%)	(35%)	(25%)	(10%)	(90%)	(10%)
17.28%	3.24%	1.08%	3.24%	2.16%	21.60%	10.80%	10.80%	10.80%	6.75%	2.25%	2.10%	2.45%	1.75%	0.70%	2.70%	0.30%

Figure 2: Fall 2013 Attribute Weightings

Evaluation Process & Sensitivity for Fall 2013

The overall evaluation process can be represented with a systems engineering tool, an IDEF0. The first level, shown below, gives an overview.

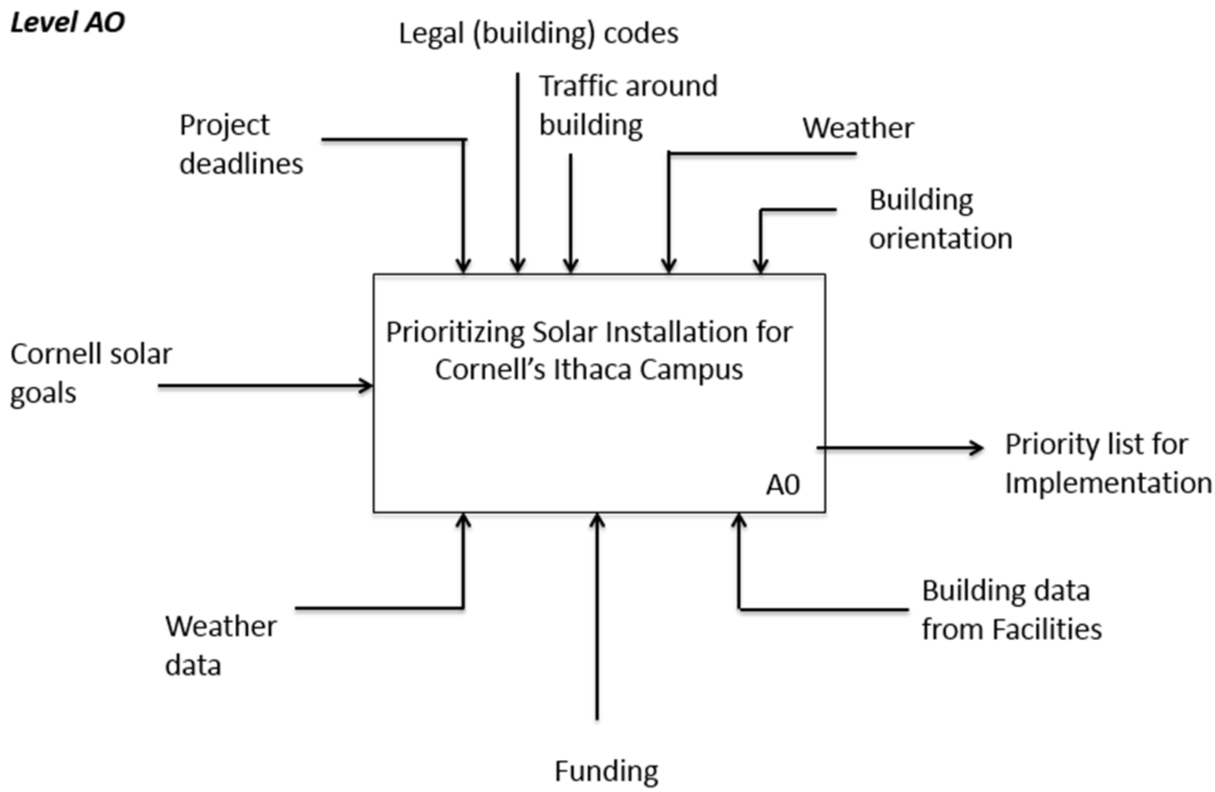


Figure 3: IDEF0

With more than 700 registered "roofs" in Cornell's Roof Access management program it was necessary to quickly filter those the most potential for being strong PV sites. The first method of filtering was "rational basis" test. In this step, we removed all roofs that were simply not feasible, i.e. buildings that were not a building such as sheds, historical markers (Source 1), and buildings that lacked a vast quantity of data. The number of buildings still under evaluation at this point was reduced to roughly 100 roofs.

The second filtering method was to evaluate the remaining buildings based on the most important attributes first. This was done because of time limitations in the semester. The top 5 attributes according to highest weight were:

1. Level of shading
2. Roof material

3. Roof layout
4. Available space, orientation
5. Next expected date of roof renovation

Together these attributes made-up 70% of the grading weights. However, due to complexity of data and time constraints, we evaluated only 4 excluding roof material. The 4 attributes that are current evaluated made up 54% of the weighting (Fig. 3).

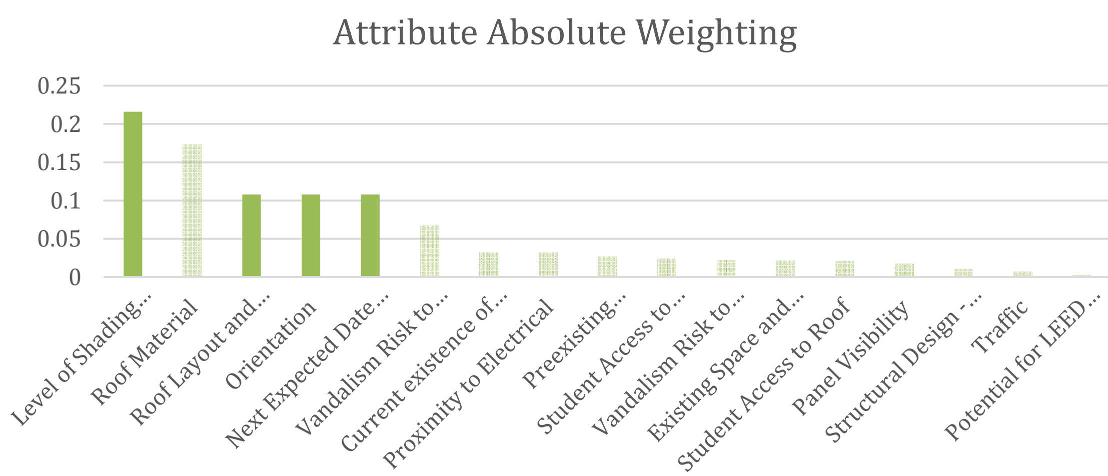


Figure 4: Matrix Absolute Weighting

After creating these filters and completing the first grading approximation we arrived at our “top ten buildings”:

1. Ives Hall Faculty Wing
2. Sheldon Court
3. Barton Hall
4. Ives Hall East
5. Ives Hall West
6. Savage Hall
7. Carpenter Hall
8. CHESS Lab

9. Uris Hall and
10. The Cornell Store

At this point a question arose: “how viable are the results?” Unfortunately, the building scores were highly sensitive. With only 54% of the weights graded there was a strong likelihood that in accounting for our fifth primary attribute Roof Material, there will be a significant shift in the results. For example, Carpenter Hall, a contender in the top ten, will likely be removed because of its roof material—it fared poorly in the spring 2013 solar evaluation. However, once roof material is solidified in our rationale it is highly likely that our sensitivity will decrease greatly. The 4 attributes graded vary significantly from building to building, and a small change in any of them can significantly impact the overall score – similarly true for roof material. Meaning that once these numbers are graded, the high variance weights are stable. Additionally the remaining 12 attributes are not very sensitive (i.e. less variance), as we expect the values to be consistent amongst the buildings, e.g. vandalism risk amongst all buildings should be minimal. Therefore even without our 12 smaller attributes (consisting of 30 %) we expect the results to also remain consistent with minute shifting.

ArcGIS representation

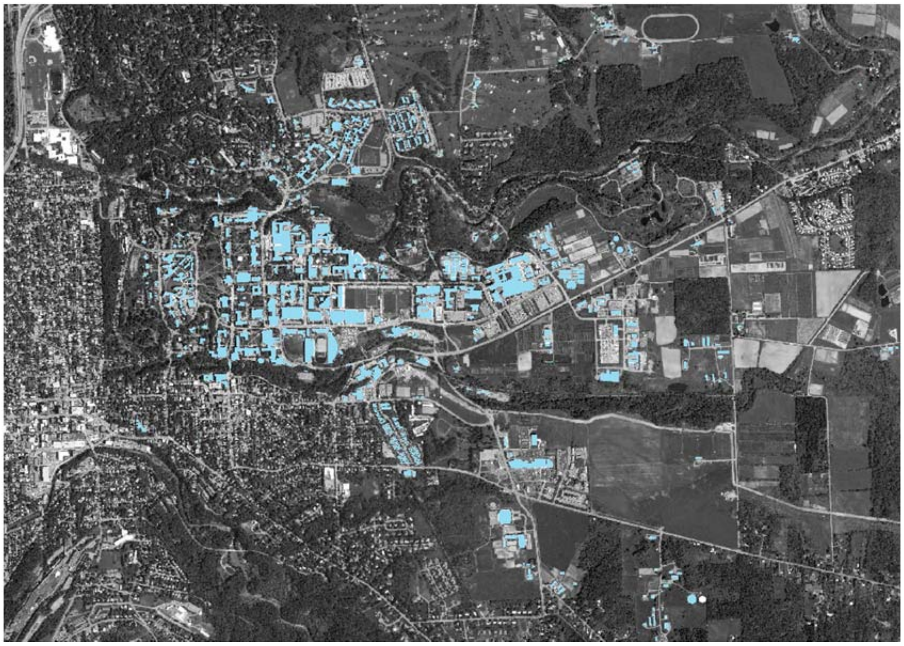
A primary aspect of this project was to present the findings to Cornell Facilities and make a recommendation about the potential of solar power for Cornell’s Ithaca campus. It was imperative that the information from the decision matrix could be easily understood for all who would need it. It was decided that a Geographic Information System (GIS) would fulfill this need. Specifically, ArcGIS software was appropriate for mapping the output of our decision matrix in layers.

ArcGIS is a platform which relates geographic information with a multitude of data types and purposes. For this project, thematic maps—one of the software’s more basic features—were applied to communicate the matrix output. Thematic maps assign a color to each geographic object based on its value relative to all other values of the objects. The “theme” of the map is the type of value used, e.g. roof shading, remaining useful life of the roof, or overall potential for a photovoltaic installation. This scaling by color allows the data to be a simple visual representation.

To begin mapping, a map, or shape file, of Cornell's campus with outlines and coordinates for all of the buildings was first obtained through Courtney Koelbel – a Cornell facilities intern and CUSD representative. The map contained everything from buildings, sheds, bridges, and many other elements that are not candidates for solar installations. Satellite images of the campus were also included, which could later be used to provide context for the shape file. Taking the data behind the shape file's buildings and importing it into Excel showed that there were nearly 700 elements. After eliminating the elements that were not feasible candidates for solar, the list of buildings was reduced down to about 200. Before true grading occurred, the team created a template map that could later have real data added to it. Each building was assigned a random variable representing PV rating between 0 and 1. These data acted as temporary placeholders for the numbers that would be generated from the decision matrix. It was then possible to create an effective visual representation of this data, confirming the proposition that GIS was a good tool. The PV rating represents how beneficial it would be to integrate a solar system on this building. The template map shows the most optimal buildings in green, and the least optimal in red. Since the building's ratings rest on a gradient, so do the colors of the buildings on the ArcGIS map. Thus, merging the two tools was simple and yet highly useful.

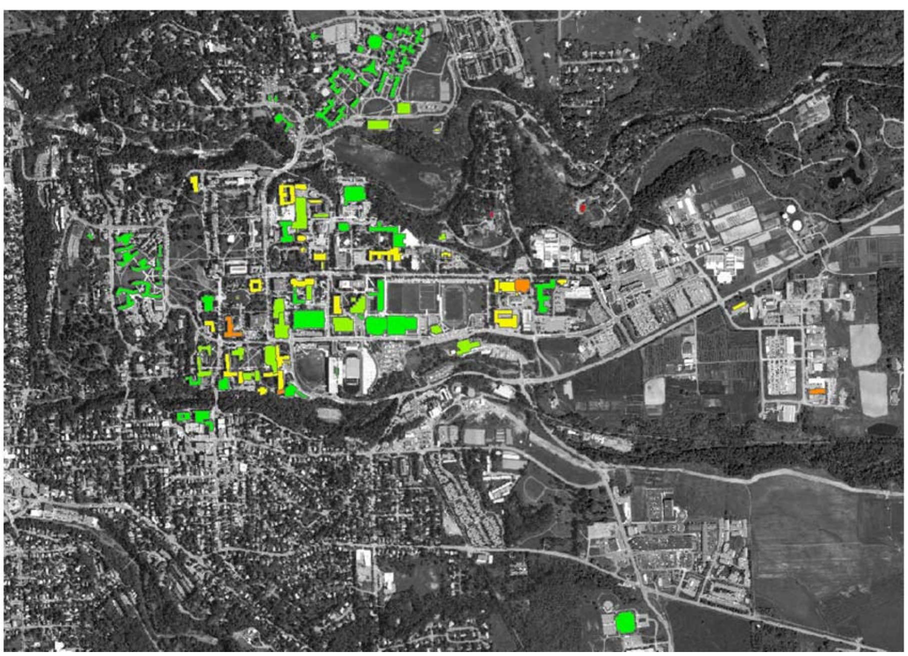
The final maps generated during the Fall 2013 semester followed the same pattern as the template map. Once each of the four primary attributes were graded, GIS maps were created for each separate variable as well as the final total rating based on the graded values from the decision matrix. This final rating was generally referred to as the total weighting of the building or total solar potential. As with the decision matrix, a building with a high total weighting was a good building for solar—and colored in green—while a low total weighting implied a building was bad for solar and was colored in red on the map. The following were the representation of maps completed in Fall 2013.

All Buildings: This map shows the buildings that remained after eliminating the elements that were not feasible candidates for solar



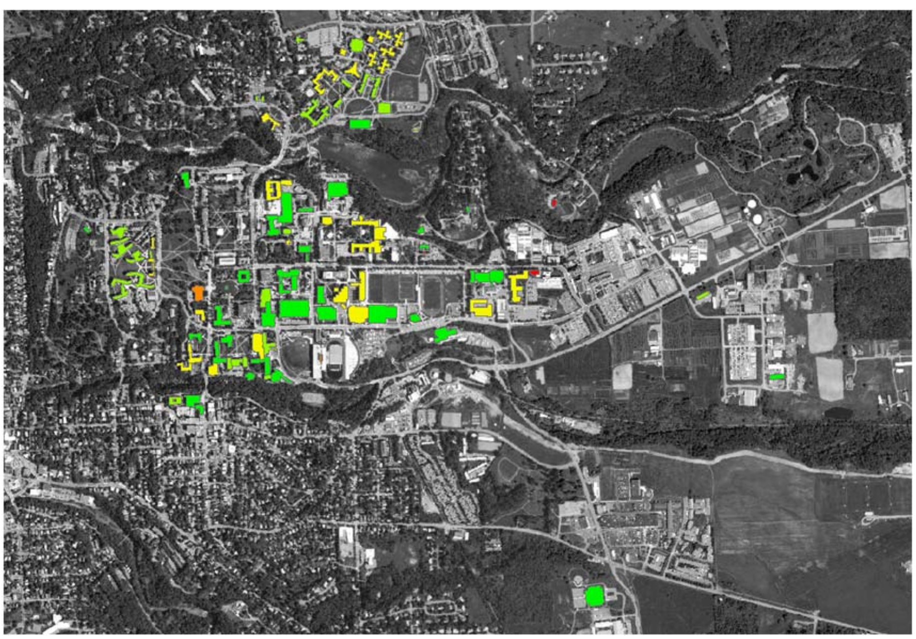
Shading: The buildings in green are buildings that have little to no shading, and the buildings in red are those that have obstructions that cause shading on the rooftop.

Renovation Date: The buildings in green are those that have either renovation dates that are very soon, or beyond the lifespan of the solar panels. Buildings in red are those that have renovation dates that fall between.



Orientation: Buildings in green have roofs that are primarily south facing, or flat, due to these orientations providing the most access to direct sunlight, and roofs marked in red have a lower possibility for optimal sun exposure.

Layout: The roofs in green have few to no obstructions on the roof that would limit the placement of solar arrays, and those in red have many.



Tax incentives & Rebates

In order to better assess the economic feasibility of implementing solar PV on Cornell's campus, it was necessary to research ways to reduce overall cost. Financial assistance from the government was an important consideration, and two main channels were identified: incentives and tax breaks.

There were three programs to keep in mind moving forward. Because programs vary year to year, these programs were identified to only serve as rough models or ideas for the kinds of programs to look for when the time comes to actually apply. When the time arises to find a contractor and apply to these programs, the two most important factors will be system size (power generation), and location. As the evaluation continues, a more focused idea regarding size and location will arise, and the team can tailor the programs to match these two.

NYSERDA, the New York State Energy Research and Development Authority, is described as a "public benefit corporation" that provides monetary incentives for energy projects including solar. There are three to keep in mind for the future project. A summary of these are seen in figure below.

Incentives							
Index	Incentive	Description and Status	Agency	System Size	Money award	Timeline	Important Notes
I.1	PON 2112	Solar PV Program (current)	NYSERDA	200 kW or less for commerical; sysem can't exceed 110% of consumption	25-35% of installed cost after tax credits, or $170,000	Applications accepted through Dec. 31, 2015	Incentive award can't be more than 40% of total system cost
							Must involve Eligible Installer/Contractor who signs agreement
I.2*	PON 2860	New York Sun Competitive PV Program (current)	NYSERDA	Larger than 200 kW	Maximum is $3M/project if not in Strategic location; Maximum is $6M/applicant if not in Strategic location	Must be operational by April 30, 2015	Based on bid of $/kWh
I.3	PON 2844	ETAC-CI: Demonstrations of Underused Technologies and Innovative Strategies (upcoming)	NYSERDA	Not stated	Not stated	Due January and June 2014	We could qualify for supporting demonstration of innovative tools and strategies for energy savings in institutional facilities
*Note: does not include our zone (Zone C). So look for similar PONs in the future that include Zone C.							

Figure 5: NYSERDA Incentives

PON 2112, the Solar PV Program, awarded 25-35% of the installed cost after tax credits, or $170,000. Applications are accepted through the end of 2015, so although it is unlikely the team will apply for this particular PON, it is more likely that a similar PON will arise in the future. Another is PON 2860, the New York Stat Sun Competitive PV Program, which would award up to $3 million. Unfortunately, Cornell is in a NYISO zone (zone C) that doesn't qualify for this program, but the team should be alert for a similar PON in the future. The final one is PON 2844, which could be applied to because we may be able to "qualify for supporting demonstration of innovative tools and strategies for energy savings in institutional facilities", where the institutional facility could be perhaps defined as "Cornell University". Unlike the previous two PONs, it was not current but rather upcoming—depending on the time scale of the project, the team may be able to apply and qualify for this program or a similar one when it is live.

In addition to these initiatives, the government provides tax exemptions and credits that should be taken advantage of. Once again, changes to these policies must be tracked, as rates may change or new policies may be added or discontinued. A summary is seen below.

Tax Exemptions and Rebates				
Index	Description	Gov. Level	Timeline	Important Notes
T.1	Property Tax Exemption	NY State	100% for 15 years	100% for 15 years
			Ends 12/31/2014 so check to see if it is renewed	Local opt-out option but Ithaca is still participating
T.2	Sales Tax Exemption	NY State	100% for sales and installation	City of Ithaca does not provide local sales and use tax exemption
T.3	Solar Investment Tax Credit	Federal	Through Dec. 31, 2016	30% credit on expenditures, no limit

Figure 6: Tax Incentives

In New York State, a property tax exemption of 100% for 15 years may be received. This exemption ends at the end of 2014, so its possible renewal should be monitored. New York State also gives a 100% tax exemption for the sales and installation of solar. As long as Ithaca continues to participate, the team can take advantage of this break as well. At the federal level, the United States government gives a 30% solar investment tax credit. This is only valid through the end of 2016, when it is likely to decrease.

It is very important not only to understand what financial incentives there are today, but also to monitor the changes that may occur as the energy market evolves as solar implementation recommendations continue. It is the team's hope that at the time of implementation, there will remain enough incentives to make our project economically feasible. In addition to these financial considerations, it is necessary to consider legal processes such as permitting and building code compliance.

Permitting Case Studies

There are two main legal processes for installing solar panels on Ithaca's campus. The first is applying for building and electrical permits with the Town of Ithaca or the City of Ithaca, depending on which municipality the building resides in. There is a map that shows the divide between the two, and they have different forms so it is important to know which one a building falls in. The forms cannot be filled out until an actual plan for the panels is built. This is usually an AutoCAD drawing showing electrical connections and location of the panels on the roof, along with drawings for the structure of the racking and their height above the roof. Therefore, we will need to have spoken with a solar contractor or someone experienced with solar installations who can construct these drawings and electrical plan sets prior to submitting the permit applications. Timeline for these permits can be a few weeks up to a few months, depending on the efficiency of the local municipality and how backed up they are on applications. Once the permits are approved and construction has begun, a licensed electrical inspector must also inspect the panels prior to interconnection. Interconnection is a whole different process that involves the local utility and the solar contractor we use. I can do more research into that, but it is a longer-term implication. However, it would be important if we want to know how much of our campus's energy usage the panels could offset. Links for the applications are below.

The second legal process for installing solar panels is getting approval from Cornell Facilities. We need to submit a Project Approval Request (PAR), which is a somewhat complicated process. However, this only applies to projects that are valued at over $100,000, so it would only be relevant if we wanted to group all the solar panels across campus as one project. It first requires approval and endorsement from a multitude of people within facilities. Then it needs to be pre-authorized by the CFPC (Capital Funding and Priorities Committee), which only meets once a month, so if it is rejected we have to wait a whole month to re-appeal. Once it is approved by the CFPC, it needs to go to the Treasurer's office if it requires Cornell funding, and a man named Tom Cole decides final project funding approval. Last, the PAR Administrator needs to review the final application. Once he/she approves the project, it can begin. This whole process is outlined in a flowchart that is also linked below.

Compiled Pertinent Forms:

1) City of Ithaca Building Permit Application: http://www.egovlink.com/public_documents300/ithaca/published_documents/Building_Department/Permits/Bldg%20Permit.pdf
2) City of Ithaca Electrical Permit Application: http://www.egovlink.com/public_documents300/ithaca/published_documents/Building_Department/Electrical/Elec%20Permit%202010.pdf
3) Town of Ithaca Building and Electrical Applications: http://www.town.ithaca.ny.us/home/forms
4) Flow Chart of Project Approval Request (PAR) Form http://www.fs.cornell.edu/fs/ir/PARProcess.pdf

Findings and Future Work at the End of Fall 2013

At the end of the Fall 2013 semester, Cornell Tech Solar finished a first evaluation of roughly 100 buildings on campus.

At the end of the Spring 2014 semester, we have re-evaluated the buildings on Cornell's Ithaca campus and produced a list of the top 10 buildings that we recommend be priority for solar installations. After the completion of this grading scheme we will have a much greater understanding of the capacity available to Cornell facilities for PV production. We will then compare this capacity to our compiled permitting and incentives to develop a holistic Cornell PV plan for facilities. This comparison will act as the final component to next semester's goals and will require an extensive look – past compilation – into the incentives and codes required for a chosen set of high potential buildings and system sizes.

SPRING 2014

Matrix Re-Development

The background for this semester's work stemmed from a need to refine last semester's work. Last semester, as mentioned, we produced a preliminary recommendation for the best buildings.

This recommendation, however, was based on the attributes that contributed to the majority of the weighting, but not on all of the attributes.

Continuing our work, we decided to completely re-review the top buildings in order to provide a more reliable recommendation. We wanted to consider all of criteria contained in the decision matrix and collect more data in person. If this was not possible with our top buildings, we moved down the list and collected data for those so that we could score enough to determine a top 10.

Here we see the final decision matrix for this semester.

11.52%	2.16%	0.72%	1.80%	1.80%	18.00%	18.00%	9.00%	20.25%	6.75%	3.50%	3.00%	2.50%	1.00%
Implementation (90%)										Education and Interaction (10%)			
Cost (30%)					Operating (60%)			Safety (10%)					
Structural (80%)			Electrical (20%)										
Roof Material	Parapets	Load Capacity	Proximity to Electrical Room	Existing Space and Power Connections	Shading	Viable Space	Next Renovation Date	Vandalism Risk to Panels	Vandalism Risk to Electrical Equipment	Student Access to Monitoring Equipment	Student Access to Panels	Panel Visibility	Existing Information Connections
80%	15%	5%	50%	50%	40%	40%	20%	75%	25%	35%	30%	25%	10%
17.28%	3.24%	1.08%	2.70%	2.70%	21.60%	21.60%	10.80%	6.75%	2.25%	3.50%	3.00%	2.50%	1.00%

Figure 7: Spring 2014 Attribute Weightings

The most important change for the matrix was combining roof layout and orientation into one variable: viable space. The two categories seemed to inadequately incorporate the effect of roof size. For example, a roof that is southern facing and clear of obtrusions would have received scores of 5 in both categories; however, if this roof was very small (say, 40m^2), then in practicality this roof could not support a very worthwhile solar array. Therefore, this roof should receive a very poor viable space score. Comparatively, a very large roof (let's say 1000m^2) of western facing roof clear of obtrusions has far more potential than the small roof. Even though it is facing west, this large roof could generate large amounts of power. Previously, the smaller roof would have been ranked higher in the combined ranking when it should not be.

To remedy this error, the two categories of viable space and orientation were combined into one, more encompassing "Viable Space" category. The scoring for this new category is based on an *effective area*. The effective area is determined by first using PV Watts software to trace the usable, obtrusion-free roof space. From this PV Watts area, the orientation is factored in using $Area_{Effective} = (Area_{South}) + .85(Area_{East/West})$. Therefore, effective area finds the area of usable roof (free of obtrusions) while also incorporating the reduced efficiency of East/West facing roofs. This final effective area that is calculated is then given an integer score of 1-5.

Effective areas below 200m^2 receive a score of 1. Effective areas above 200m^2 and below 400m^2 receive a score of 2. Effective areas above 400m^2 and below 600m^2 receive a score of 3. Effective areas above 600m^2 and below 800m^2 receive a score of 4. Effective areas above 800m^2 receive a score of 5.

Limitations of the adjusted matrix should be acknowledged--expert knowledge of what truly makes a site "good" for solar is still not known completely by our team. Our research is still ongoing as we learn what classifies as ideal and what classifies as poor for solar. For example, we are not completely confident in what type of roof material is ideal and what type is poor. There are many different roof types that we have encountered in the top 25 buildings alone. We need to speak with more experts on the subject in order to solidify our grading scheme for the roof material. Other categories that similarly could use more expertise knowledge include available space in electrical room and existing power connections. Currently, we use rough estimations for these categories without truly knowing what exact space a system needs in an electrical room, and what exact existing electrical power connections are needed for a solar array.

Evaluation Process

Last semester, a comprehensive list of Cornell University's buildings was gathered in order to rank the buildings on solar photovoltaic (PV) potential. Each building was analyzed using a decision matrix that utilized 17 pertinent attributes. Due to data and time constraints, only 54% of the decision matrix was completed for each building. From this 54%, a ranking of the top buildings was created. This semester, one goal was to complete 100% of the decision matrix for the top 25 buildings established from last semester's ranking. Information had been gathered previously using the Roof Asset Management (RAM) system, where we had used data provided to us on spreadsheet. It was decided that on-site visits could likely be the way to gather this information, and in order to do this and complete the matrix, site visits for the top 25 buildings were carried out. Since site visits are very time-intensive, it was decided that completing the matrix for only the top 25 buildings was the best use of time.

To move forward, we directly contacted Building Coordinators to obtain the information we needed to complete the decision matrix. We began by contacting the coordinators via email, explaining our project and asking to meet in person if possible to gain more information. Four outcomes occurred as the result of these emails.

Some coordinators did not respond in a timely manner, and some did not respond at all. Although disappointing, we acknowledge that not all coordinators may be interested in the project, may be very busy, or may have simply forgot to contact us back.

Some coordinators opted to answer some of our questions via email. While reasonable considering the amount of work and projects that the coordinators deal with, it does introduce more variability in the grading process because a team member was not physically present to evaluate the variables.

For many buildings, we were able to meet with the coordinators and visit the building itself. At each site visit, attributes such as “Proximity to Electricity Room,” “Existing Space and Power Connections,” “Viable Space,” and “Visibility of Panels” could be completed. These attributes are among several that are best determined through site visits, and therefore require a more time intensive data-gathering period. Small protrusions on the roof and visibility issues are particularly hard to gather from other sources, such as Google Earth, yet are very easy to gather in an on-site visit.

An additional benefit of interacting with the coordinators was that we could gage the interest and support (or not) of the coordinators toward our project and solar on Cornell’s buildings in general. This may work to our advantage if this project is put into action in the future.

Results

After collecting the building data and calculating a final score with the Spring 2014 attribute weights, a list of the top ten buildings for solar was determined and is seen below.

1. Barton Hall
2. Reis Tennis Center
3. Ives Hall Faculty Wing
4. Wilson Synchrotron Lab
5. Phillips Hall
6. Rhodes Hall
7. Ives Hall
8. Stocking Hall
9. Johnson Museum
10. Morrison Hall

An ArcGIS representation is seen below.

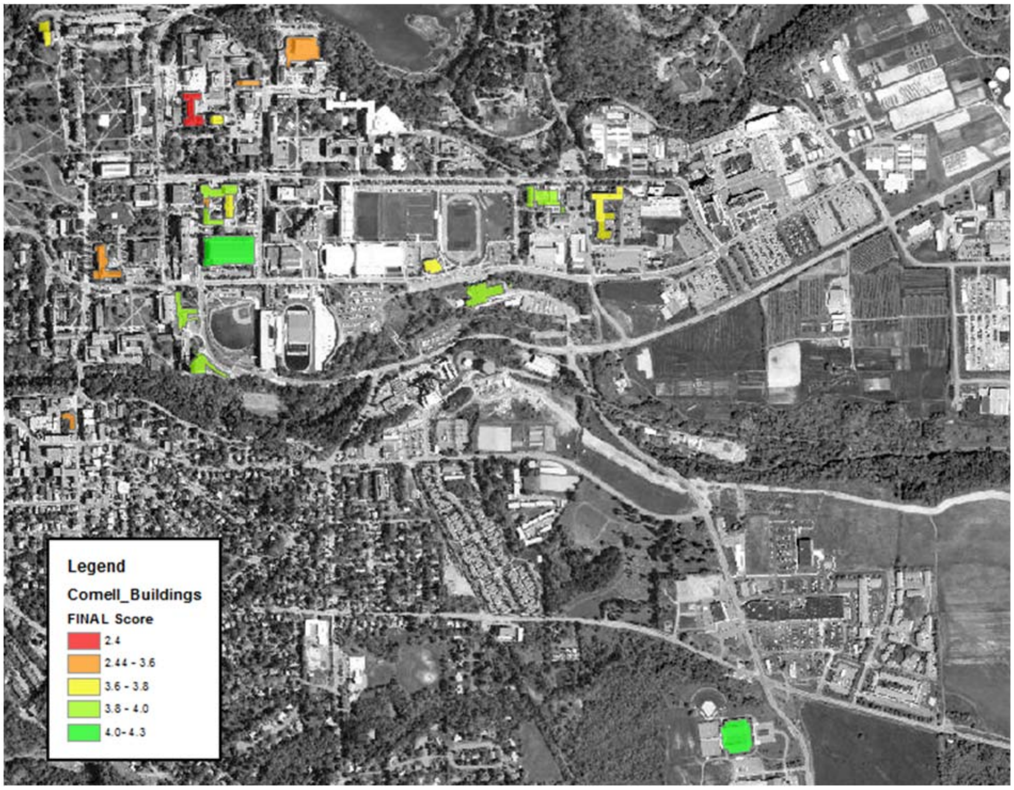


Figure 8: ArcGIS map of building scores

Outreach

In previous semesters, the focus of Solar was to work toward a recommendation for facilities. The spring 2014 semester was the first semester when we considered adding to this mission. We began to seriously consider making education and outreach one of the team's goals. While CUSD Solar does not have a significant global influence, the students of Cornell University are the future homeowners, business owners, and leaders of the world. With this in mind, we decided to first reach out to the Cornell Community, who are closest to us and whose members are likely to be interested in renewable energy.

We succeeded in establishing a booth at SpringFest, a celebration held at Cornell around the time of Earth Day. Our strategy for catching the attention of students was to have interesting solar-powered demonstrations at our booth. We primarily utilized small solar powered vehicles and a poster that outlined our main points.The poster was set up to take students through the role of solar energy on a national level, local level, and personal level. On a national level, our main goal was to demonstrate the incredible solar potential that most of the continental United States possesses contrasted with the meager amount that solar currently contributes to our annual national energy consumption. On a local level, we explained Cornell's large energy demands, and showed the current solar energy that we are producing on Snee Hall, Day Hall, and the Cornell Store. Finally, on a personal level, we used the Swanson Effect to explain that the price of solar energy continues to drop as the price of other forms of energy continues to rise, and therefore will be very desirable in the near future for most homes and businesses. The feedback we received was generally positive, and Solar hopes to continue outreach efforts in the future.

CONCLUSION

In conclusion, the campus-wide solar photovoltaic study during the Fall 2103 and Spring 2014 semesters produced a list of the top ten buildings for which solar panels would be most feasible. Next steps include presenting the findings to Cornell University Facilities and perhaps working with them to explore funding options. It also may be necessary to re-evaluate some buildings for which there was incomplete data. It is hopeful that Cornell may be able to use this study to begin more solar initiatives on campus.

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APPENDIX

Fall 2013 Solar Matrix Rationale

Level 1 [90%]: Implementation

Addresses the logistics of system installation and operation; factors critical to the system development. This category represents the bulk of the decision as it controls the systems' cost, output, and flexibility. Ultimately, this category answers the question: how well will a given location act as a support for the solar system?

Level 2 [20%]: Cost

Factors dictating the installation cost of the system. Some modifications to given sites may be necessary, thus incurring additional costs. This category considers both structural and electrical costs, which are further broken down as follows.

Level 2B [80%]: Structural

Any structural modifications required for a given site present significant modifications in the system installation cost. The roof material presents the greatest contribution to this cost, as certain materials require considerable modification to ensure adequate support for the system. The existence of parapets on buildings, or fences if the panels are on the ground, represents a critical safety measure necessary for panel installation, and is thus expected to also contribute on a smaller scale to the cost. Load capacity represents a small additional cost; this cost is expected to be low as expected modifications would likely only entail installation of a weight distribution system made of plywood planks – a low cost system.

Level 3 [80%]: Roof Material

Indication of the roof material integrity as it affects system installation.

Some materials require additional support systems to prevent penetration of the mounting system. Scoring: 1: EPDM (polymer material; thin and fragile, requiring additional material layered on top); 3: green (ground); 5: MBF (modified Bitumen), or pavement/concrete

Level 3 [15%]: Need for Parapets/Fences

Addresses the necessity to have the panels protected by fences if installed on the ground (to prevent public access), or parapets (low walls) on a roof for roof-mount systems. Necessary for safety concerns. Scoring: 0: lacks parapets (building), or fences (ground); 5: already has parapets or fences.

Level 3 [5%]: Load Capacity

Indication of the roof's structure as it affects load capacity. Potential problems can be mitigated with a simple modification, e.g. installation of plywood panels.

Scoring: 1: steel framework; 3: slab, green-space; 5: cast-in concrete

Level 2B [20%]: Electrical

The electrical components also contribute to system cost. We anticipate that proximity to the electrical room will slightly dictate the overall electrical costs, given restrictions in running wires from the panels to the electrical rooms in the event of electrical rooms that are not located on the top floor of the building.

Level 3 [50%]: Proximity to Electrical Room

The proximity of the solar panels to the electrical room will determine the cost required to set-up necessary equipment and wirings to connect the solar panels to the electricity source of the building. It is estimated that the cost of installing electrical wiring for the Ithaca area is $200 for every 3 meters. If the solar panels and electrical room are located far apart, the cost of installing the electrical wiring will be high, increasing the overall installation cost. Scoring: 1: electrical room more than three floors away, or in separate building (for ground mount systems); 3: electrical room between 1 and three floors away; 5: electrical room on roof

Level 3 [50%]: Existing Space & Power Connections

The existing space and power connections in a building will determine the cost required to connect the solar panels to the power system of the building. It is estimated that each additional power connections installed will cost approximated $250 in the area of Ithaca. If there is no or few existing space and power connections available to connect the solar panels, a large amount of additional cost is required to install them. Scoring: 1: sites with no existing space and power connections for the solar panels; 3: sites with existing space and power connections but insufficient space; 5: sites with sufficient space and power connections

Level 2 [50%]: Operating

Covers logistics involved with the installation and subsequent operation of the solar system. To determine the scoring we visited potential sites and took notes on the layout.

This analysis was then supplemented with roof diagrams from the building's constructio n and/or latest renovation. We also then used Google Earth to consider additional sources of shading. Shading is considered the largest concern (hence the greater weighting), as it will greatly hinder output as well as any experiments, as the presence of any shading will likely unequally affect the system. The next priority is the available space, given that this also limits the range of experiments able to be performed on the panels. – generation potential, how efficiently will the panels given the site, power output determining factors

Level 3 [40%]: Shading

Indication of the amount of direct sunlight blocked from the panels due to buildings, trees, and additional obstructions. Scoring: 1-5 in integer values; 1: consistent shading; 3: some shading during early and late parts of the day; 5: no shading

Level 3 [20%]: Viable Space

Amount of free space, taking into account building protrusions (vents, drains, pipes, etc) which may limit system layout. Scoring: 1-5 in integer values; 1: scattered and restricted system layout required to fit panels; 3: some minor building protrusions limiting system layout; 5: excess available space with no building obtrusions.

Level 3[20%]: Orientation

%"North-South-East-West" of viable roof space, proposed equation 5*(%S + %EW*.85) rationale for .85 is based on Swanson Data and efficiency loss from losing direct sunlight. 5 for flat roof, orientation is then based on the user.

Level 3 [20%]: Next Roof Renovation

Date (year) of next expected roof renovation, which may affect (delay) system installations. This information was obtained from Cornell Facilities renovation schedule. Scoring: 1: 2012 (overdue); 3: 2013-2018; 4: 2019-2024; 5: 2025-2030

Level 2 [30%]: Safety

Covers the safety of the investment; it should be noted that the safety of the students and community are required to meet a minimum standard, as dictated by the presence of parapets/fences (in the cost category above), and in part of the education and interaction category (which follows). The risk of vandalism to the panels is perceived to be greater than that to the electrical equipment, as the panels will be outdoors and more exposed to the public, while the electrical equipment will be housed separately indoors and thus less accessible.

Level 3 [75%]: Vandalism Risk to Panels

Entails the potential vandalism risk to the panel system. Scoring: 1: ground-mount system with fence; 2: roof with public roof access; 5: roof with secured & private access 1: ground-mount system with a fence; this system is easily vandalized because students can climb over a fence and access the panels without much difficult; 2: roof with public access - better than a ground-mount because roofs are less accessible, but it is given a low rating because a public roof can still be accessed by anyone; 5: private roof with no public access – the highest rating because a private roof is locked and only accessible by building maintenance

Level 3 [25%]: Vandalism Risk to Electrical Equipment

Entails the potential risk of vandalism to system electrical equipment. Scoring: 1: location with no on-site locked electrical room; 3: on-site locked electrical room

Level 1 [10%]: Education and Interaction

Addresses the learning and student involvement side of the project; in short, how well will the location cater towards education and public interaction?

Level 2 [70%]: Public Interaction

Public interaction falls under the education and interaction category. It comprises 70% of the category, with support systems accounting for the other 30%. Public interaction is made up of the following categories: student access to roof, student access to monitoring equipment, panel visibility, and area traffic. Student access to monitoring equipment and the panels is of first priority, as this will affect student ability to gather data and run experiments. We predict that access to the monitoring equipment will be more crucial as it will need to be performed more frequently. Panel visibility follows shortly thereafter, as it is a good way to raise public awareness and interest. Area traffic represents a small contribution to the decision, as this may change in relation to the system being developed.

Level 3 [35%]: Student Access to Monitoring Equipment.

Denotes the level to which students are able to access the monitoring equipment measuring the power output and other characteristics of the solar panels.

Scoring: 1: no access to the equipment; 3: supervised access only; 5: unsupervised visual access (supervised physical access only)

Level 3 [30%]: Student Access to Panels

An evaluation of whether students will be able to get on the roof to examine and study the panels with and without supervision Scoring: 1: no access; 3: supervised physical access; 5: unsupervised visual access with supervised physical access. Supervised physical access means students only have access to the panels when a professor or other university official is with them. Unsupervised visual access with supervised physical access means the students can view the panels at a close distance without an official, and therefore offers more interaction.

Level 3 [25%]: Panel Visibility

As part of this project is about increasing awareness of renewable energies, panel visibility is an important factor in the placement of the solar panels. We want the panels to be visible to the public, but out of the way and not an eyesore. Scoring: integer values from 1-5; 1: no visibility from buildings; 3: no visibility from the ground, but visible from buildings; 5: visible from both the ground and buildings.

Level 3 [10%]: Area Traffic

A measure of how many people walk through the area the panels would be visible from and therefore a measure of how many people would likely see the panels. Scoring: integer values from 1-5; 1: minimal traffic; 3: moderate traffic; 5: very high traffic

Level 2 [30%]: Support Systems

This category covers the auxiliary supporting measures for the system. The existing information connections category is more heavily weighted as compared to LEED credit potential since the application of the system for LEED credit is a secondary concern, as compared to the desire to provide online tracking of the system performance.

Level 3 [90%]: Existing Information Connections

Measure of whether or not a network is already in place to transfer data from the monitoring equipment to a campus server for online tracking. Scoring: 0: no existing connection currently at location; 5: existing connection at location.

Level 3 [10%]: LEED Credit Potential

Buildings undergoing significant renovation (as defined by LEED) may be eligible to apply for LEED certification if the building pursues relevant changes. This system could offer a small contribution toward achieving that goal; thus, the odds of this pursuit for LEED certification are considered. Scoring: 0: not part of a structure that may qualify for LEED accreditation; 1: part of a structure that may qualify for LEED accreditation.