Feasibility of Combining Solar Panels and Green Roofs on the Activities and Recreation Center

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Kara Kessling, Abby Cohen, Jadon Jasso

EXECUTIVE SUMMARY

Installing solar panels or a green roof on top of a building are commonly treated as mutually exclusive. This project examines the feasibility of combining these two features on top of the Activities and Recreation Center (ARC) on the University of Illinois at Urbana-Champaign campus as a case study. The group found information on costs and benefits of both solar panels and green roofs, as well as the available ARC rooftop area, which was estimated to be 118,800 ft^2. Furthermore, the University's iCAP goals were examined to determine that the University wants to get more energy from on campus solar and produce energy from more renewable sources, making this project relevant to these goals. The main objective was to analyze if combining solar panels and a green roof would be more cost-effective and environmentally friendly than installing just one of the two sustainable options on top of a building. For the rooftop option of a combination of solar panels and a green roof, the calculations are based on the roof first being covered with greenery and then solar panels being placed about three feet above the greenery. This combination estimates that about ten percent of the area will be used for gravel pathways, meaning about ninety percent of the roof will be covered with both solar panels and a green roof.

The objectives were completed by performing a cost analysis of the three different sustainable rooftop options (solar panels and a green roof, just solar panels, or just a green roof) and discussing the environmental benefits of combining them. Through the cost analysis, the payback period of using just solar panels was calculated to be 13 years, the payback period of just a green roof was calculated to be approximately 73 years, and the payback period of the combination of the two was 13 years. Even though the initial cost of installing the combination of solar panels and a green roof was found to be the largest, the payback period was about the same as installing just solar panels. The environmental benefits of the combination include solar panels increasing the plant diversity of a green roof, a green roof decreasing maintenance needed for the solar panels, and green roofs providing a better climate and temperature for solar panels to function, among others. Finally, the group concluded that combining the two sustainable features on top of the ARC is feasible, even though the initial cost would be the greatest, because the payback period is one of the smallest, the environmental benefits of combining solar panels and green roofs are larger than when using just one of the options, and it helps the University reach iCAP goals.

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INTRODUCTION

Background on Technologies

Solar panels and green roofs are common sustainable options for environmentally friendly roofs. Solar panels, sometimes called photovoltaic (PV) systems, are more sustainable and better for the environment than energy produced by natural gas or coal because they have fewer greenhouse gas emissions (Qualitative Reasoning Group 2016; Tsoutsos et al. 2005). Green roofs are a layer of vegetation planted on top of a roof. There are three types: extensive, intensive, and semi-intensive. Extensive roofs are shallow with usually less than six inches of soil, limited plant diversity, and low watering requirements. Intensive roofs have more soil, sometimes several feet, and are more diverse. Semi-intensive green roofs are a mixture of the two, using a median amount of soil (Technical Preservation Services 2015). This project will be focusing on extensive green roofs to reduce the added weight to the building and because they traditionally have lower installation and maintenance costs. Green roofs are commonly used for reducing stormwater runoff, increasing energy savings, and improving thermal insulation in a building. Furthermore, shading from the plants on green roofs can reduce the temperature of a building and can also reduce surrounding temperature from the urban heat-island effect. This is when urban areas have higher temperatures than surrounding areas (Hui et al. 2011). Thus, both of these sustainable roof options have many environmental benefits when used independently.

Past Studies/Solutions

Solar panels and green roofs are traditionally used separately to maximize the benefits from each one. However, using them together so that a building can get the benefits of both is a new idea. In countries such as Germany and Switzerland, research shows that combining both solar panels and green roofs can provide many benefits (LivingRoofs 2017). For example, if the air temperature gets too warm or too cool, the solar panels can lose efficiency. It is clear that “one of the biggest and most significant performance parameters of photovoltaic panels is temperature” (Green 2013). The microclimate of the green roof can help fight the urban heat-island effect, but this will help the solar panels too. The green roof helps cool the surrounding air, providing a cooler temperature that allows the solar panels to perform more effectively (Environmental Protection Agency 2017). The company Green Roof Technology has created their own system for installing solar panels and a green roof together and has done extensive research on the benefits. An example of one of their roofs is seen in Figure 1. They found that green roofs can help reduce dust and air pollutants found on bare roofs, which can improve solar panel performance and reduce the maintenance needed (Green Roof Technology 2015).

Figure 1: Rooftop created by Green Roof Technology that combines solar panels with a green roof (Green Roof Technology 2015).

Furthermore, solar panels could also increase the diversity of flora and therefore fauna that inhabit the green roof. The solar panels do this by creating shaded areas beneath them. Rain runoff in the front of solar panels would create a more damp area, while the back would remain drier. This would establish a “habitat mosaic”, allowing a wider variety of flowers to flourish, thus attracting a variety of fauna (LivingRoofs 2017). The importance of this research is that it exhibits how solar panels and green roofs work well together. This shows that combining the two sustainable features can be more efficient and form a more diverse ecosystem in a small area.

The solar panel and green roof combination for this project will consist of about ninety percent of the 118,800 ft^2 available roof area of the ARC being covered first with greenery. Solar panels will then be placed above the greenery. The remaining ten percent of the rooftop area will be used for gravel pathways to allow for water drainage off of the solar panels, as well as maintenance paths for both the panels and the plants. Figure 2 was created to show an example of the layout.

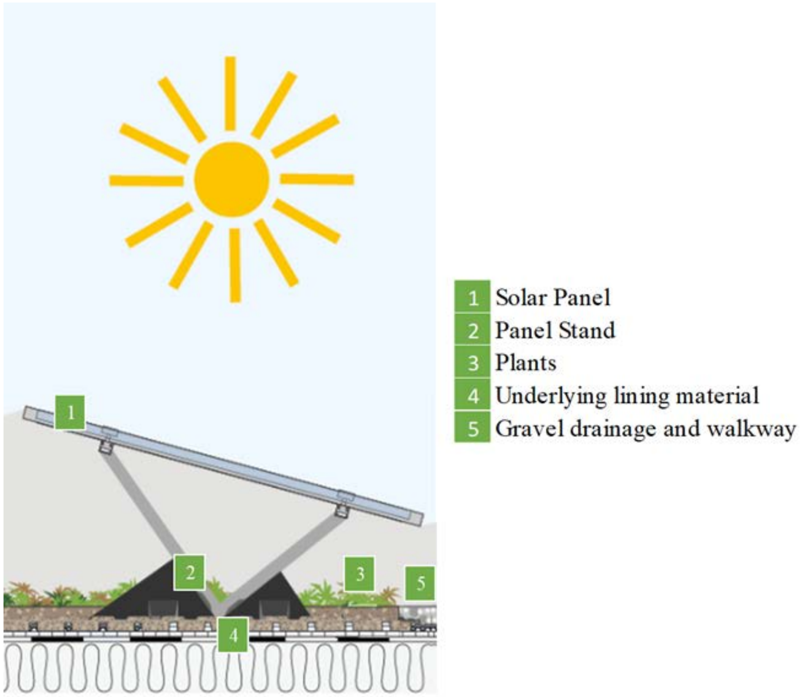

Figure 2: An example layout of a solar panel and green roof combination.

Background on the ARC and University iCAP Goals

The building this project is focused on is the Activities and Recreation Center (ARC). The ARC was chosen because it is on the list of buildings on campus that have the capability for rooftop solar, and was recommended as a good candidate for the objectives of our project (McDonnell 2015). Moreover, the Illinois Climate Action Plan (iCAP) from 2015 states that the University has a goal of producing 25,000 MWh of solar energy on campus property by the fiscal year of 2025, as well as goals to obtain energy from cleaner and renewable sources (Kishore 2017). An addition of solar panels on top of the ARC would help the University be much closer to its goal. Furthermore, it has around 118,800 ft^2 of no to minimum sloping rooftop area, see Figure 3, giving the potential to add both solar panels and a green roof (Kishore 2017). Another reason the ARC was chosen is because it is in public view, whether from Peabody drive or Memorial Stadium. In the school year of 2015 through 2016, it was recorded that over 41,000 different people had entered the ARC (Campus Recreation 2016). This could increase awareness for renewable energy and sustainable practices, as the solar panels and green roof could be seen from the stadium. All of these aspects of the Activities and Recreations Center make the building a good fit to research for the project.

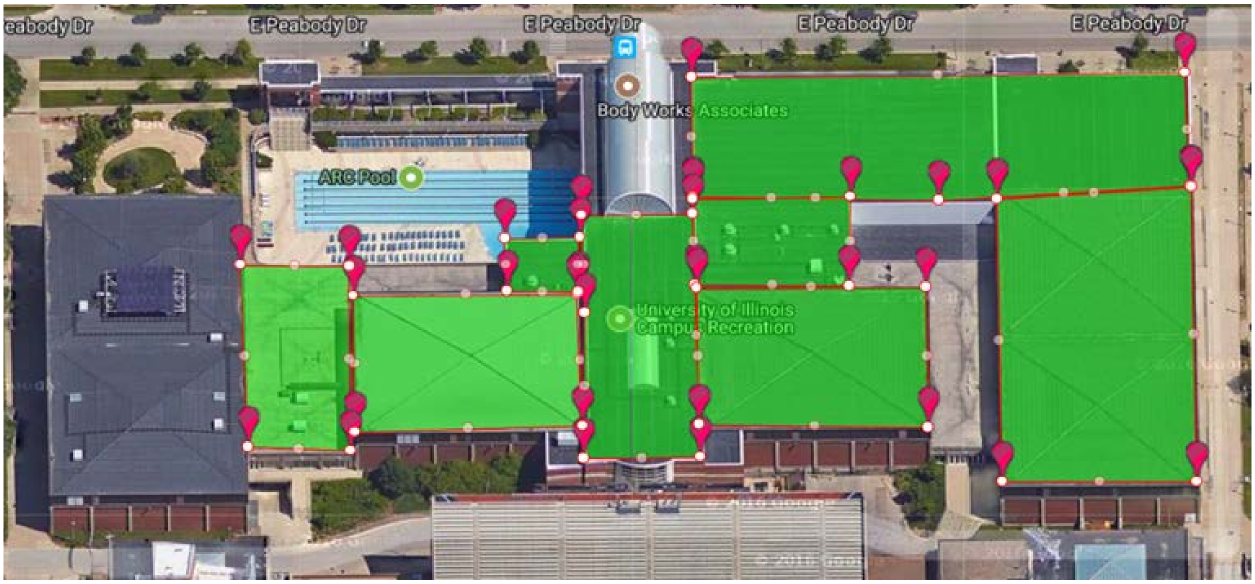

Figure 3: Potential area of the ARC to be covered with solar panels and greenery, about 118,800 ft^2 (Google Maps Area Calculator Tool 2017).

OBJECTIVES

The objective of this project is to determine the feasibility of combining solar panels and a green roof on top of a single building, compared to using just one of the options alone. This will be done by analyzing the economic costs and discussing environmental benefits of installing both sustainable features at the same time on the ARC located on the University of Illinois at Urbana-Champaign campus. The final deliverable will compare whether the combination of solar panels and a green roof is more cost-effective and environmentally sustainable than using only solar panels or only a green roof on top of the building. Using the research from the project, the University will be able to decide whether it is advantageous to pursue the combination of these features for the ARC or as a possibility for other campus buildings.

METHODOLOGY

Three tasks, spanning the length of the semester, were created to determine the feasibility and environmental benefits of adding solar panels and a green roof to the ARC.

<u>Task 1: Research information relevant to solar panels and green roofs</u>
The first task for the project was to complete the necessary research. This research included finding pertinent information about solar panels and about green roofs, and was therefore broken into two separate subtasks.

Task 1a: Research information about solar panels
The first subtask was to research information about solar panels. The first step in doing this was to look at previous case studies involving solar panels at the University of Illinois, such as "Powering Up E-14" (Klein et al. 2014), a case study about putting solar arrays over the parking lot next to the State Farm Center, and "Retrofitting the Campus with Rooftop Solar: A 2015 iCAP Objective," a study finding the highest solar energy producing buildings on campus

(Kishore 2017). This helped the group to learn what information had already been prepared, and provided some valuable sources in conducting more research. The next step was to find cost information relevant to solar panels. This included installation costs, like materials, fees, and labor, and maintenance costs, along with possible cost offsets, such as federal and local tax breaks or incentives. An example is the federal tax incentive, which provides 30% off of income tax with the installation of a solar system. However, the University does not pay income tax and therefore this did not apply to our project, but could be useful to know for future work. Other tax breaks were found from certain local energy providers, but again this does not apply to the University as they do not buy energy from these providers. No other tax incentives were found. Another step that was completed was finding out the benefits that solar panels provide. Many benefits were found, including the energy produced from the system and the savings from this, the reduction in emissions compared to alternative uses at the University, and that when combined with a green roof, a more diverse rooftop environment results.

Task 1b: Research information about green roofs

The second subtask under conducting research was to obtain information about green roofs. Information was first gathered from previous case studies that involved green roofs or greenery on buildings at the University, to help the group gain knowledge on what has already been prepared. The report "Feasibility Study of Green Walls at the University of Illinois" was helpful in providing information about the different types of greenery systems, as well as a specific application of one to the University, including costs and savings (Mathew and Salot 2014). Relevant cost information pertaining to green roofs was found, such as plant, soil, and bedding costs, labor, installation fees, maintenance, and costs of any water irrigation systems that might need to be added, along with any cost offsets, such as decreased stormwater runoff incentives. All of the costs that were obtained were rough estimates and averages. The environmental benefits of using greenery on the ARC was researched. Benefits such as reductions in CO_2 emissions, insulation benefits, which decreased heating and cooling costs, and decreases in the urban heating effect were found. Other benefits such as increased aesthetic appeal, increased awareness of environmental concerns and solutions, and the possibility that moods of onlookers could be increased were also noted. We contacted Ryan Pankau, a horticulture educator at the University, to help us determine which plants would be most beneficial, in the environment at the University, to use on the green roof and to guide us in finding more accurate installation and maintenance costs. We also contacted Timothy Prunkard for cost information about the green roof on top of the Yeh Center.

<u>Task 2: Conduct a cost analysis</u>

The second task created for this project was to conduct a cost analysis to determine the financial impacts of this project. This was broken into three subtasks, one each for the options of just solar panels, just a green roof, or a solar panels and a green roof combined.

Task 2a: Complete a cost analysis for the ARC roof being covered in just solar panels

The first subtask was to complete a cost analysis for the roof of the ARC full of solar panels. This option uses ninety percent of the available ARC rooftop area, to leave about ten percent for gravel pathways. The cost analysis included the researched information about solar system costs, installation fees, yearly maintenance cost, yearly energy savings converted to dollars, and would have included tax incentives if any had been found that applied to the University. Please refer to the results and discussion section for solar panel cost and benefit information.

Task 2b: Complete a cost analysis for the ARC roof being covered with just plants
The second subtask was to complete a cost analysis for the roof of the ARC being entirely a green roof. This option uses one hundred percent of the available ARC rooftop area. The cost analysis included the researched information about initial plant, soil, and installation costs, as well as a yearly maintenance cost, and possible offset costs, such as reduction in stormwater runoff fees, and reductions in heating and cooling costs from increased insulation. Please refer to the results and discussion section for green roof cost and benefit information.

Task 2c: Complete a cost analysis for the ARC roof being covered with solar panels and plants
The third subtask was to conduct a cost analysis on the combination of solar panels and green roofs. This option also uses ninety percent of the available ARC rooftop area, and leaves ten percent for gravel pathways. This cost analysis combined the information from the two previous subtasks, but differed slightly based on overlapping costs and new benefits resulting from the combination of solar panels and green roofs. Please refer to the results and discussion section for this analysis.

Task 3: Compare options and present work
The third task was to take the results obtained from the cost analysis, along with the qualitative environmental benefits, and compare these between the three options of using just solar panels, using just a green roof, and combining solar panels and a green roof together. Work was presented in two different milestone reports throughout the semester, to ensure that the project was continuing on track. A presentation of the project to University faculty, staff, and students was presented on December 12th. This final report, documenting the project objective, tasks, analysis, results and problems encountered was submitted to the University on December 15th.

RESULTS AND DISCUSSION

Economic Analysis
Three numbers first had to be calculated for the cost analyses: the square footage to be used, the cost of electricity, and the potential solar generation. The total square footage to be used on the roof of the ARC is 118,800 ft^2, obtained from a report conducted in May (Kishore 2017), and confirmed using the area calculator feature of Google Maps. This will be used for the option of installing just a green roof. As previously mentioned, the design of the rooftop area for solar panels and the combined solar panels and green roof will only use about 90% of this, or 106,900 ft^2, leaving 10% for walkways that double as drainage paths. According to the Illini Energy Dashboard, the ARC used about 3,000 MWh of electricity last year, and they associated this with a cost of about $257,600 (University of Illinois). Dividing the total cost by the total electricity produced, gave the cost of electricity specifically for the ARC, about $0.09/kWh. Using the online PVWatts Calculator, with a 106,900 ft^2 area, we found that the solar panel and green roof combination could generate about 1,880 MWh of electricity in the first year, compared to the option of just solar panels generating only about 1,860 MWh of electricity in the first year. These values are about half of the consumption of energy the ARC uses, and could meet about 7% of the iCap goal of producing 25,000 MWh from solar. This was because the green roof can help

keep foreign particles off of the solar panels, slightly decreasing system losses. The calculator also showed that for each year the solar panels aged there was about a 1% increase in system losses, and therefore about a 1% decrease in electricity production per year. Details of the input information to the PVWatts Calculator can be found in Appendix A.

After these numbers were found, the cost of installing solar panels was calculated using the following equation.

Total Installation Cost = Average Cost of Installation (\$/W)* Potential Solar Generation (Wh/year) ÷ Hours of Sunlight (h*year)

The average cost of installation for solar panels was found as \$3.16/W (Matasci 2017). Therefore, the solar generation needed to be converted to Watts instead of Watt-hours, so the hours of sunlight that would be used to produce the energy needed to be found. For simplicity, this was taken as 8 hours per day times 365 days per year, although it is known that the number of hours of sunlight will vary per day, based on many factors including season, weather, and peak hours. The average cost of installation is based on Watts and the number of Watts for the option of just solar panels versus solar panels and a green roof won't vary due to the same rooftop area being used and therefore the same number of solar panels being used. Thus, the potential solar generation of using just solar panels was used, creating a rough installation cost of \$2,015,000 for both options.

The average cost of installing an extensive green roof is in the range of \$1.03/ft^2 to \$1.66/ft^2 (U.S. EPA 2008). For the option of installing just a green roof multiplying the average of these costs times the 118,800 ft^2 of available area gives a cost of \$159,800. For the solar panel and green roof combination, multiplying the average costs times the 106,900 ft^2 available area gives an installation cost of around \$143,800.

For the combined option of solar panels and green roofs, which used the cost data for the 106,900 ft^2 available area, 5% was taken off of the installation cost. This was due to the fact that some of the materials that need to be purchased to first protect and prepare the roof were accounted for in the cost of installing solar panels and in the cost of installing a green roof. This means that the \$2,015,000 solar panel installation and \$143,800 green roof installation, totaling \$2,158,800 were reduced to 95% of this, or \$2,051,000.

Yearly maintenance costs for green roofs, given by Ryan and Timothy, are around \$500. For yearly maintenance costs of solar panels, the group estimated it would be \$1,000. This was based on the fact that the solar panels should not need much maintenance each year, but the value should be at least doubled that of green roof maintenance. But once again the option of using solar panels and green roofs gives the added benefit of less foreign material on the solar panels, and the group estimated that this could save about 5% on maintenance costs. This gave \$950 as the yearly maintenance cost for the combined option.

After finding the costs of the different options, savings were needed to complete the three cost analyses. One of these savings is in electricity costs from the solar production by the panels. Multiplying the solar generation per year times the \$.09/kWh cost of electricity for the ARC gave the electricity savings per year. So for example, the first year electricity savings due to the energy provided by just the solar panel option was \$160,000; the electricity savings for the first year of the combined option was $162,000, due to the increased solar production from increased efficiency that the green roof helps provide.

Green roofs provide two savings that were quantified: electricity savings from added insulation and decreased stormwater runoff fees. The electricity savings were found with the help of Arizona State University's online Green Roof Energy Calculator. Plugging in the available rooftop area of the ARC, produced an estimated electricity consumption of the building and an estimated electricity savings of the building. However, the electricity consumption that was estimated was not what the Illini Energy Dashboard said the ARC consumed, so the ratio of the electricity consumption to savings was taken. To calculate the total savings from the added insulation of the green roof the following equation was then used.

$$\text{Savings from Electricity} = \text{Electricity Consumption of ARC (kWh)} \div \text{Ratio of Consumption to Savings} * \text{Cost of Electricty (\$/kWh)}$$

The ratio for using just a green roof was found as 164, producing a savings of about $1,600. The ratio found for combining solar panels and a green roof, which used less of the available rooftop area, was 182, producing a savings of about $1,400 per year.

The yearly stormwater fee reduction was found using the impervious area of ARC, 187,000 ft^2, and equating that to an equivalent residential unit (ERU), which are the units used to determine the stormwater service charge. One ERU is equivalent to 3,478 square feet, thus the ARC has approximately 54 ERU's. There is a charge of $5.24 per ERU per month, costing the University over $280 a month, or $3,360 a year for the ARC alone. However, adding a green roof will give a credit of 40% on these monthly stormwater utility fees (City of Champaign). Multiplying this by the monthly charge of the ARC gave savings of about $110 per month. Yearly this comes out to savings of $1,300.

To compare the yearly costs and savings and initial installation costs a payback period was calculated for each option. This was simply done by graphing the costs and savings in Excel, varying it year by year, using the trendline tool to find the equations of the lines, and then equating the cost line to the combined savings line, and solving for the year. Figures 4, 5, and 6 are the graphs showing the payback period for retrofitting the ARC with the different options of just solar panels, just a green roof, and solar panels and a green roof combined, respectively.

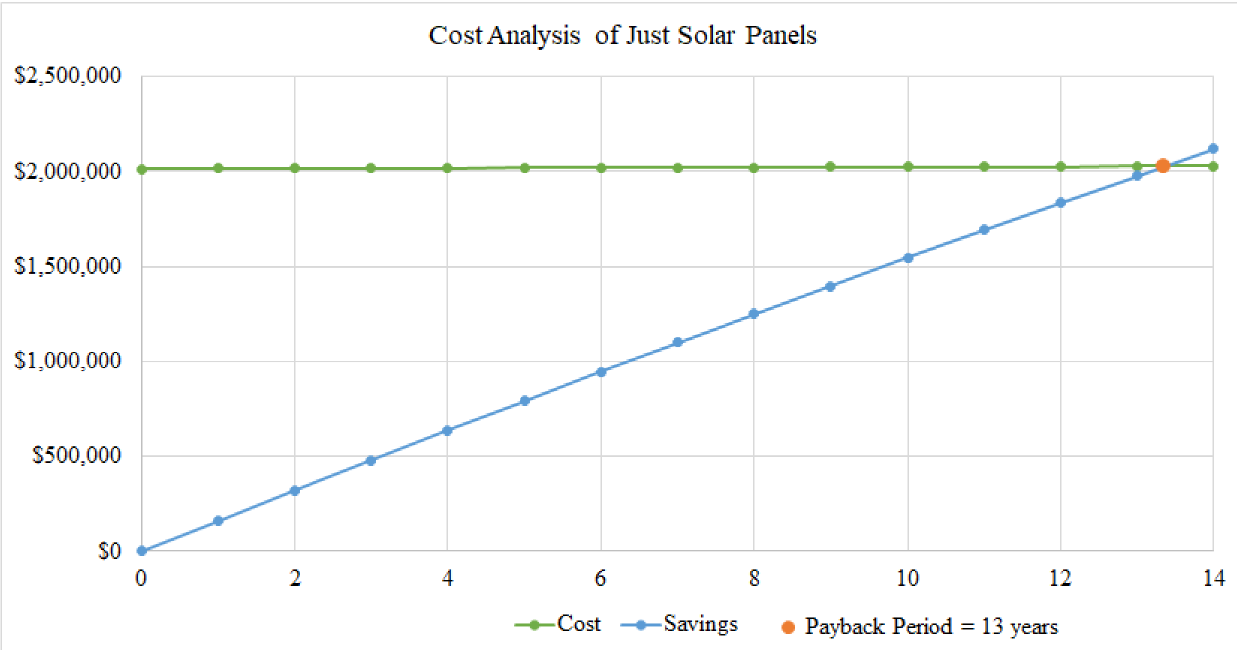

Figure 4: Graph showing the costs, savings, and payback period for retrofitting the ARC with just solar panels.

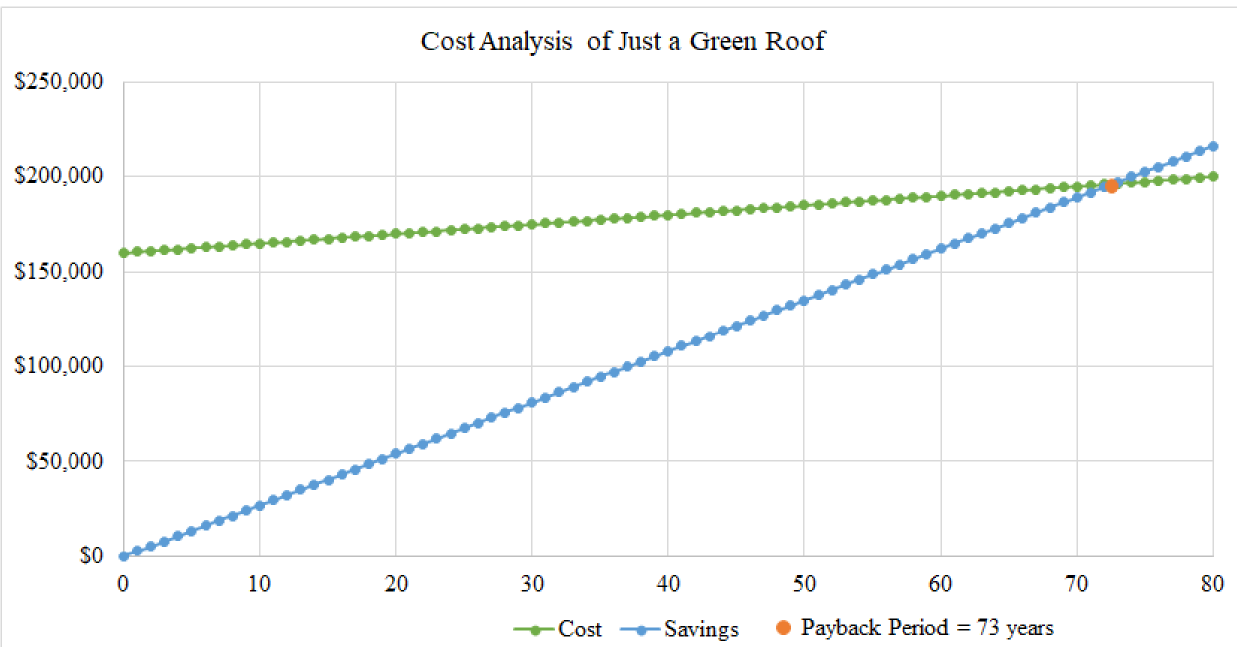

Figure 5: Graph showing the costs, savings, and payback period for retrofitting the ARC with just a green roof.

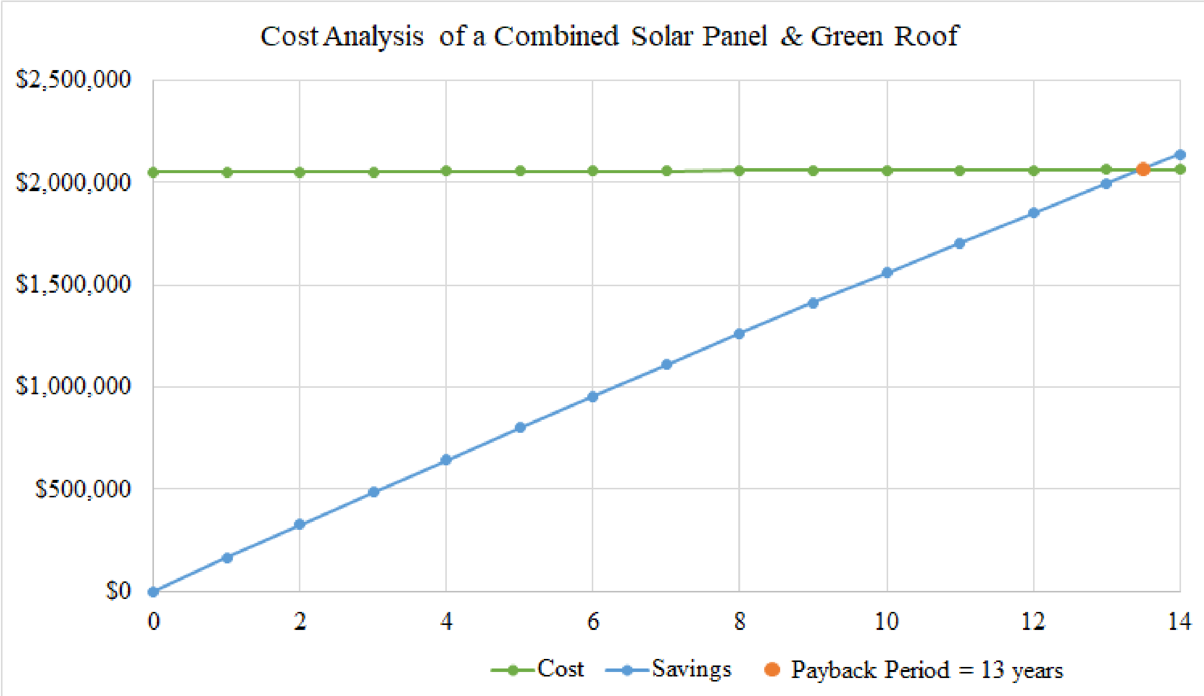

Figure 6: Graph showing the costs, savings, and payback period for retrofitting the ARC with solar panels and a green roof together.

<u>Discussion of Environmental Benefits</u>

The discussion of the environmental benefits includes qualitative information, because quantitative data and calculations are beyond the scope of the project. This discussion complements the economic analysis to help determine which rooftop option is best beyond just the costs. Furthermore, this discussion is much more general and the benefits could be applied to buildings other than the ARC. Table A below briefly discusses the benefits and organizes them into categories. This table is provided for reference for the rest of this discussion.

Table A: Summary of Environmental Benefits

Just Solar Panels	Just a Green Roof
• Cleaner energy compared to traditional methods of supplying energy to a building • Doesn't release gas or liquid pollutants	• Neutralize the acid rain effect • Increase aesthetic appeal • Reduce sewer system overflows • Improve insulation of building and reduce energy cost
Solar Panel & Green Roof Combination	
• Green roofs reduce the urban heat-island effect produced by solar panels • Green roofs improve performance of solar panels and decrease maintenance needs by reducing the dust and air pollutants surrounding the roof • Solar panels can increase the plant diversity of a green roof • Green roofs can create a better climate and temperature for solar panels • All benefits of other two columns apply to this column as well	

First of all, solar panels have many benefits just on their own. Solar panels derive clean energy from the sun. Installing solar panels can help combat greenhouse gas emissions, as well as reduce the collective use of fossil fuels. The heating of buildings is traditionally done by either coal or natural gas, both of which are finite and harmful to the environment. Solar panels do not release gaseous or liquid pollutants into the environment, thus making them a much cleaner alternative to methods that release fossil fuels (Tsoutsos 2005). In general, solar panels are better for the environment than common sources used for heating (Solar City 2014).

Green roofs are beneficial in numerous ways. Overall, green roofs can positively impact the community, the building owner, and perhaps most importantly, the environment. Green roofs can remove nitrogen pollution from rain, as well as neutralizing the acid rain effect. Green roofs are permeable surfaces, which allows them to decrease stormwater runoff. As a result, green roofs help reduce sewer system overflows. They also provide a home for various wildlife, allowing for a bit more diverse fauna in an area (Green Roof Technology 2015). Furthermore, green roofs can reduce the temperature of a building to improve insulation and reduce energy cost. One study found that on average they reduce indoor building temperature by 2 degrees Celsius in the summer and can therefore reduce energy costs of a building (Jaffal et al. 2012).

The benefits to installing just solar panels or just a green roof also apply when combining the two, but using them together yields more unique benefits. Green roofs can reduce the urban heat-island effect produced by solar panels. They can also improve performance of solar panels and decrease maintenance needs by reducing the dust and air pollutants surrounding the roof (Green Roof Technology 2015). The solar panels can increase the diversity of a green roof by creating shade underneath the panels and water runoff at the bottom of the panels. This allows different types of plants to flourish that would not grow without the solar panels. Furthermore, Figure 7 (below) exemplifies how combining solar panels and a green roof can combine the separate benefits of the two in a positive way. For example, the individual benefit from a green roof of decreasing stormwater runoff and decreasing the roof temperature can help solar panels have a better climate to function in. Solar panels traditionally function better in a cooler temperature, so a green roof can provide this. Thus, solar panels and green roofs have many environmental benefits that can help the other operate better than average. Overall, the combination of the two has the most environmental benefits because it utilizes all of the stand alone benefits of solar panels and green roofs as well as has unique benefits that only apply to the combination.

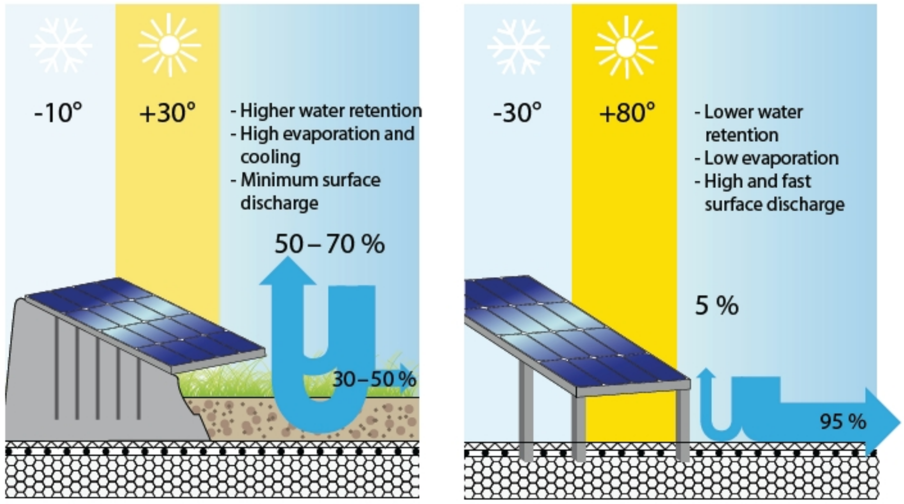

Figure 7: General benefits of combining solar panels and green roofs (Green Roof Technology 2015).

<u>Considerations for the Future</u>

There is much more that must be considered when exploring the option of combining solar panels and green roofs on one building. Structural capabilities of a building are one of the more crucial factors for feasibility. The ARC has also already been proven to have the structural capacity for the retrofitting of solar panels (McDonnell 2015). However, the average weight for solar panels including their mounting equipment and hardware is 3-4 pounds per square foot (Energy Sage 2017). An extensive green roof weighs about 20-25 pounds per square foot on average (Arch Tool Box 2016). Thus, the total added weight for a combination system of solar panels on top of a green roof would be about 23-29 pounds per square foot. If the University chooses to install the combination of solar panels and green roofs on top of the ARC, they should determine if the building can handle this added weight first. If the University was going to apply this research to other buildings, several precautions would need to be taken into consideration. Primarily, in order to obtain accurate information, they would need to scale our costs to the square footing of the other building. Afterwards, the University would need to perform a structural analysis of the building to see if it could handle the weight calculated. For any new buildings to be constructed in the future, they could be fitted with appropriate structural members to handle the weight of both solar panels and a green roof, provided that the University chooses to use this sustainability method. The costs would also change for new buildings adding solar panels or a green roof instead of a regular roof, because the building isn't being retrofitted but installed from the start. The University would also want to look at the lifetime of traditional roofs versus one of these options to see if any savings result from not needing to replace the shingles or other material every so many years. The solar panels would need to be replaced, but according to the payback period found in the cost analysis they could pay for themselves.

The group also determined a couple of recommendations for how and when a solar panel and green roof combination should be installed. By interviewing Ryan Panku, a horticulture educator, it was determined that one way to help the green roof plants grow and survive would be to let the green roof be installed before the solar panels. This would not require a permanent irrigation system, and would let the plant life become established before the solar panels are introduced to the environment. This could be done by installing the green roof in March and then the solar panels in late summer. Therefore, both the structural capability of a building and the installation time frame must be considered should solar panels and a green roof be installed together.

CONCLUSIONS

Solar panels and green roofs are often considered as mutually exclusive. The objective of this project was to determine the feasibility of combining solar panels and green roofs on one building, using the ARC as a case study. Through the completion of the objectives of this project, the group concluded that the combination of solar panels and green roofs is feasible for the ARC. This conclusion was made based on the solar panel and green roof combination maximizing the environmental benefits while minimizing the costs.

The economic analysis that was completed resulted in initial costs and payback periods for each of the three rooftop options. Many cost and savings parameters were considered in this analysis, including installation costs, maintenance costs, and electricity savings. The payback period was found to be 13 years for just solar panels, 73 years for just a green roof, and 13 years for the combination of the two. While the initial cost is greatest for the option of combining the two features compared to just having one sustainable feature, the payback period is 13 years, which is the same for solar panels and much less time than green roofs. This was due to some potential savings in installation and maintenance costs, along with fully utilizing the savings from the other two options.

The discussion of the environmental benefits resulted in significant benefits for all three different rooftop options. The combination of green roofs and solar panels includes the individual benefits of just solar panels and just a green roof as well as its own unique benefits. These unique benefits include green roofs creating a better temperature for solar panels to function in and solar panels increasing the biodiversity of a green roof, among others. Thus, the group concluded that the combination of combining both is the rooftop option that would best maximize the environmental benefits. However, the discussion only includes qualitative information and research collected, so further calculations and data can be collected in a quantitative sense as a future project.

There were a couple of shortcomings that the group experienced when executing this project. Initially, there was a bit too much in mind for the scope and the group had to make the discussion of environmental benefits only a qualitative analysis instead of a quantitative analysis, to account for the time and difficulty that a quantitative analysis would have entailed. The group also had some difficulty collecting data from contacts, but eventually all data that was needed was collected and used for the final report. Finally, structural capacity of a building must be considered should the combination of solar panels and green roofs be utilized on top of the ARC. This was a complicated analysis that the group was not able to include in the scope of this project, but it is an important step for future work on this project.

Therefore, the group concluded that the combination of solar panels and a green roof is very feasible on the ARC and that the University should consider this option. According to the iCAP report, the University wants to produce 25,000 MWh of solar energy by 2025 and get energy from more renewable sources, and the combination of solar panels and green roofs on the ARC can help achieve those iCAP goals. It would do this by producing over half of the energy consumed by the ARC, and accounting for about 7% of solar production goal. Overall, the report presents the University with information about the three options, and suggests that the combination of the two is economically cost-effective and has a large amount of environmental benefits.

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APPENDIX A

The online PVWatts Calculator was used to obtain the potential yearly solar generation that the solar panels could produce. The following information is the input, so that if any future work is done, they have this information to know exactly how our numbers were obtained. For further information or descriptions of any of the input values and what they mean, one can simply access the PVWatts Calculator, and click on the the different buttons for help (See Figure 8 for clarification).

The first thing that the PVWatts Calculator asks for is the address of the building; the ARC's address was entered, 201 E. Peabody Dr., Champaign, IL 61820. Using the address of the building location the calculator pulls up nearest TMY2 solar database, which in this case is located in Springfield. TMY2 means that the data was collected between 1961 and 1990. However, there was an option to choose a more updated database, 1991-2010 information. One was actually located at the University, with latitude/longitude coordinate of 40.060, -88.370, and this one was used.

The next screen the user will see looks like Figure 8. As explained in the help dialogue boxes, the system size is simply the following equation.

$$\text{Size (kW)} = \text{Array Area (m}^2) \times 1\ \text{kW/m}^2 \times \text{Module Efficiency (\%)}$$

Using 90% of the 118,800 ft^2 roof area of the ARC and a standard 15% efficiency gave a size of 1,490 kW. The defaults of standard module type and fixed open rack array type were selected. The system losses are explained in the next paragraph. The tilt of the solar panels was changed until an optimal angle of 30^o was found. The azimuth angle, or the angle clockwise from true north that the solar array will face, was left at the default of 180^o, because the array will face south. The other input information on the calculator, which is not shown in Figure 8, was left at the default values, because it was not used for our calculations.

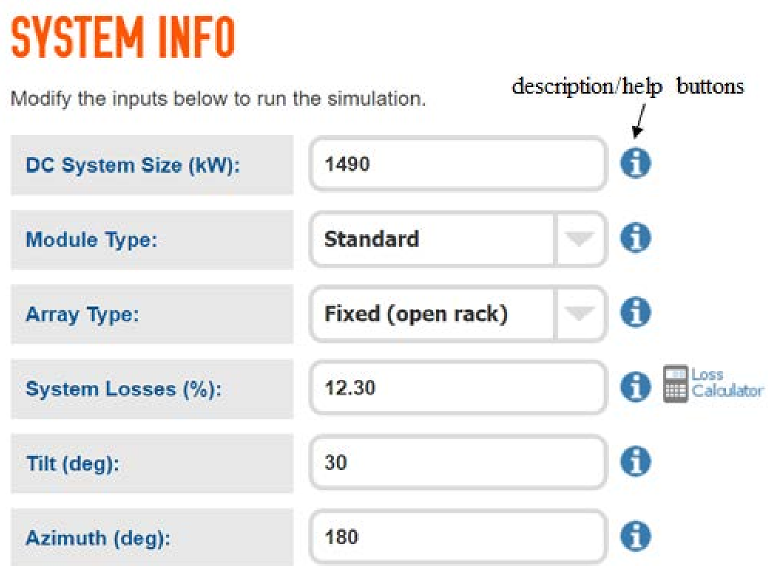

Figure 8: Input screen of the PVWatts Calculator, showing the input values of the combined solar panels and green roof option (PVWatts Calculator).

Returning to the system losses input information, there is a parameter feature, the loss calculator, to calculate these losses based on different inputs shown in Figures 9 and 10. The parameters that were modified for this case study were soiling, shading, snow, and age; the other values were left at the defaults. Soiling has a default value of 2, and this was left as is for the option of using just solar panels, shown in Figure 10. Figure 9 shows that the soiling value for the combined option was changed to 1, and this is because the green roof can help reduce the amount of foreign material on the panels. Shading has a default value of 3. However, there are no buildings, trees, or other objects around the ARC that could block the solar panels from receiving the sun, so the value was changed to 1. Snow was changed from a default value of 0 to 1, to err on the side of caution, because Illinois tends to receive fair amount of snow. To calculate the effect that aging had on the system losses, 1 through 10, 15, and 20 were put in place of the default value of 0 in the age parameter. This showed that the losses per year due to aging would be about 1%.

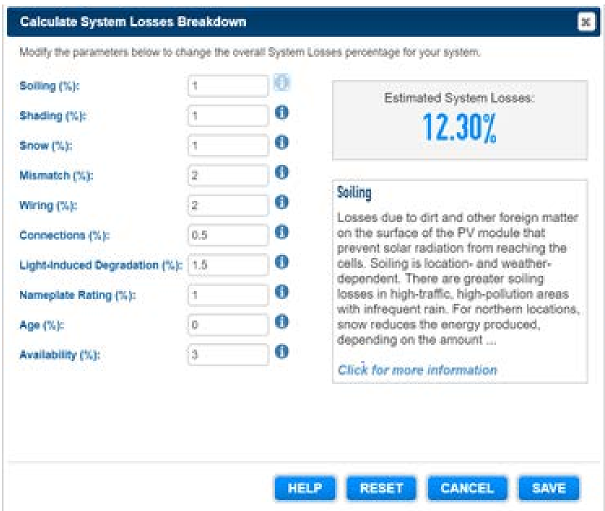

Figure 9: Parameter values for solar system losses of the combined option (PVWatts Calculator).

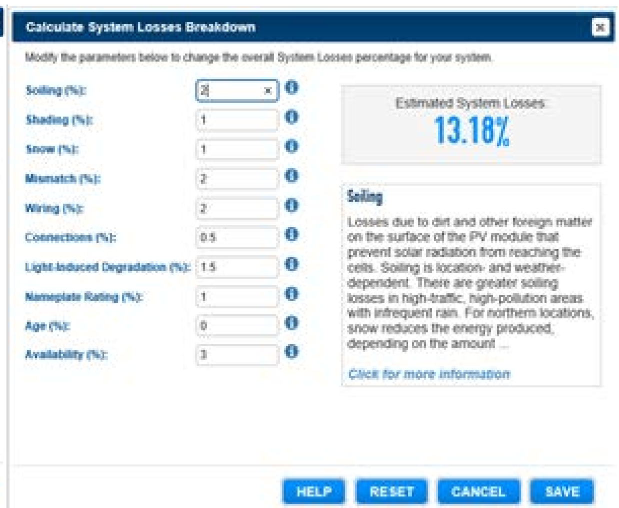

Figure 10: Parameter values for solar system losses of the just solar panel option (PVWatts Calculator).

GROUP REFLECTIONS

Over the course of this semester, our group gained a lot of practical knowledge and experience that will help to guide us in our future careers as civil and environmental engineers. This project has been a great experience for learning and growing as researchers, writers, and presenters. Our group significantly benefited from taking this class and completing a project that was interesting and created by us. However, looking back over the semester, there are a couple of things we would have done differently.

When we started the project, we had too much in mind for our scope. Limiting and refining this scope from the beginning could have helped us to complete things more efficiently and in a more organized fashion. Furthermore, we would have more clearly stated all of the information we needed to research and obtain, so that this could have been completed at an earlier date. This also would have applied to contacting sources. As it took some sources longer to get back to us than others, it would have helped to contact them right away and know exactly what we needed from them. If we had contacted some sources much earlier or known of the other people we needed information from earlier, we could have completed key calculations ahead of time. This was a skill we better developed as the project progressed, and that will be helpful to know in our professional lives.

If we had more time, we would do even more research to get more accurate and detailed cost values for solar panels and green roofs, instead of some of the averages obtained. It would have helped us to have even more primary sources and contacts from people on campus who could give us concrete data. Another thing we would do differently is that we would schedule more times to meet or discuss the project on a regular basis. While we had plenty of meetings and good communication among the group, we could have set up a regular meeting time to give consistency to the project and more updates on what needed to be done.

We gained a lot of valuable knowledge and experience from this project. Our research and technical writing skills have grown immensely. This class also gave us experience creating and finishing our own project. Learning how to brainstorm a scope, create a schedule, do calculations, and let go of aspects that could not be completed efficiently are real world applications that can help us in internships and in our future careers. We also expanded our ability to work as a team and combine our individual skills, which will greatly benefit us as engineers both in and outside of college. We are very grateful for all we have learned and are very proud of the project we completed.