Residential Renewable Energy Assessment Project

Calvin College 1876

January 23rd, 2018

ENGINEERING W84
Professor: Matthew Heun

Table of Contents

Table of Figures

Table of Tables

Executive Summary

Project Introduction

The students of the W84 Interim 2018 class were tasked to answer the question: *What would it take for Mr. Redfield to generate or save 20% of the electric energy requirements based on 2017's energy consumption?* This question was inspired by Mark Redfield's eagerness to volunteer his home to be part of the sustainable movement the world is being guided to. Challenged with the question, the class was divided in four taskforces: management, wind, solar and geothermal/efficiency. The report details the feasibility study and final design recommendations that the class endorses.

Procedure

To answer the question the class first planned a visit to the site to familiarize themselves with the property and the customer's needs. From there each team worked on collecting and analyzing the necessary data to predict the energy yield of various technologies. All these recommendations were filtered through the management team that consolidated the options into a single deliverable for Mr. Redfield.

Results

Figure 1. Capital Investment Summary

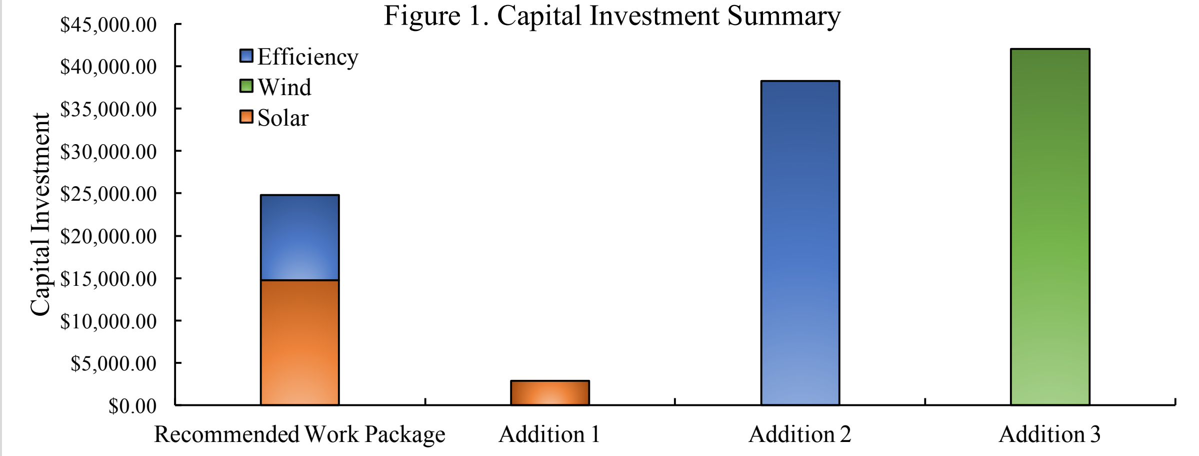


Figure 2. Project Potential

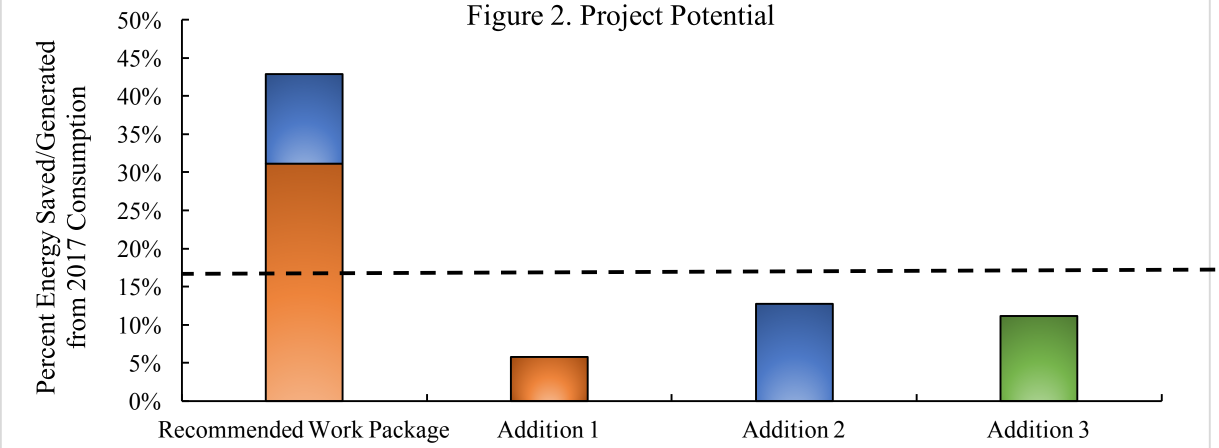


Table 1 Recommendations Details

	Recommended Work Package	Addition 1- Adding 8 Solar Panels	Addition 2- Updating Windows	Addition 3- WindSpot Turbine
Increase in Energy Generated (kWh/yr)	14585	1971	4342	3795.5
Energy Generated	42.9%	5.8%	12.8%	11.2%
Capital Investment	$25,393.00	$2,878.00	$38,255.00	$41,993.00
Monetary Payback Period (Yrs)	11.23	-0.10	11.88	14.01
Energy Payback Period (Yrs)	7.33	0.63	0.29	1.18

Recommendations

After analyzing the three options, the recommended work package was selected to be the best recommendation for the Redfield home. The option includes a 28-solar panel layout on the family's shed, purchasing a new geothermal heat pump, and additional door sealing. This option has the smallest capital investment, short monetary and energy payback time, and produces a significant portion of the Redfield's annual power. The other additions are also available if the family choses generate more energy. The base recommendation exceeds the 20% goal, with the potential to have more savings with further additions.

Conclusions

From analyzing solar, wind power, and efficiency options, the recommended base package was chosen to be the optimal design for the family. Solar power proved to be the best method of renewable energy based on monetary payback and energy generation. Wind and hydro power showed high capital cost with less energy generation. Replacing the Redfield's geothermal heater and sealing doors will have high energy generation with a short payback time. The combination of solar power and efficiency upgrades will provide the best energy results for the Redfield's.

Appendix A: Team Structure and Approach

Professor Heun – Calvin College
Engineering W84 – Sustainable Energy Systems
January 23, 2018

Team Structure

To efficiently divide the work of looking at different technologies, the class of 16 students was divided into 4 different teams. A summary of the team roles and members is presented below.

Team Solar

Members: Matt Boelens, Kirk Brink, Melanie Fox, and Hendrik Vermeulen

This team is responsible for understanding the solar resources in the property by researching the solar potential of the location and understanding the responsibility that a residential solar array carries. The team is also responsible for analyzing the cost of their recommendation and explaining the potential state and federal incentives that exist for solar residential installations.

Team Wind

Members: Laura Van Winkle, Josh Templeman, Richmond Amoh, Edwin Kpodzro

This team is responsible for understanding the wind resources in the property by researching the wind potential of the location and understanding the responsibility that a residential wind turbine carries. The team will analyze the cost of their recommendation and will explain the potential state and federal incentives that exist for residential wind installations.

Team Efficiency/Geothermal

Members: Abigail Berkompas, Nate DeHaan, Halley Press, and Jake Zandstra

Initially the Hydro/Geothermal team, this team is responsible for looking at energy efficiency in the house and calculating the potential savings of implementing these projects. Another of their responsibilities is looking at savings that can come from maintenance recommendations for the existing geothermal installation. The team will analyze the cost of their recommendations and will explain the potential utility and state incentives that exist for energy efficiency improvements in residential buildings.

Team Infrastructure, Customer Relations and Management

Members: Jessica Bouma, Megan Anders, Elvin Vindel, Paul Bootsma

This team is responsible for contact with the customer, Mark Redfield. Additionally, the team is responsible for clear communication between the teams by standardizing approach and assumptions. Finally, the team is responsible for understanding existing energy consumption and consolidate the infrastructure integration of the recommendations presented by the other three teams.

Table 2 Team Options Summary

Project Name	Energy Generated (kWh/yr)	Monetary Payback Period (years)	Energy Payback Period (yrs)	Lifetime (yrs)	Capital Investment	% Total Energy Generated
Shed Mono Panel (20 panels)	6989	13.55	8.9	25	$11,763.00	20.6%
Shed Mono Panel (28 panels)	10590	12	8.2	25	$14,791.00	31.1%
Shed Mono Panel (36 panels)	12561	11.75	8.9	25	$17,669.00	36.9%
Aeolos 600W	738	364.8	57.39	20	$37,693.00	2.2%
WindSpot 1.5 kW	3795.5	79.09	13.06	25	$41,993.00	11.2%
WindSpot 3.5 kW	3516.27	87.33	13.64	25	$42,992.98	10.3%
Bergey Excel 6	6416	63.45	13.57	25	$56,992.98	18.9%
Window Replacement	4342	63	8.6	20	$38,255.00	12.8%
Sealing of Doors	345	0.51	0.08	20	$25.00	1.0%
Geothermal Pump	3650	10	5.48	20	$10,000.00	10.7%
Hydro Generator	555	156	37	25	$12,000.00	1.6%

Appendix B: Solar Power Analysis

Professor Heun – Calvin College
Engineering W84 – Sustainable Energy Systems
January 23, 2018

Introduction

The Solar Team was tasked with using solar energy to meet the energy goal of the class. Michigan has an average annual solar availability of around 3-4 kW-h/m2-day as seen in Figure 1. While this is lower than much of the country, it is still a sufficient source of energy for small scale operations. For this project, the team developed a plan to use photovoltaic (PV) solar panels to generate 20% of the Redfield's total energy demand.

Method

The team analyzed the creek, lake, and both the house and shed roofs as potential places for solar panel installation. Area, roof angle, and building orientation for these locations were estimated and used to approximate annual solar energy harvest. From this, it was found that only the shed was needed to meet the 20% electricity goal.

The team then moved to panel selection. Chuck Holwerda, Calvin College's electronics shop technician, recommended that the team use Canadian Solar panels because the company's products were used previously for other projects on the college's campus. Both monocrystalline and polycrystalline panels were considered and analyzed for power production and cost using the solar PV design website, Sunny Design. Cost to power output ratios were used to determine the viability of each panel option. Two similar panels were selected to use for final options, one monocrystalline and the other polycrystalline.

With accurate dimensions of the shed, the team designed panel configurations with aesthetics in mind. A SOLIDWORKS model of the roof and panels were built. These panel arrangements are shown in Figure 2. Previous calculations revealed that 20 panels were required to provide the power needed to meet the goal. These were arranged on the roof such that snow would easily slide off panels and for panel maintenance walkways. The team then sought the maximum number of panels that could fit on the roof with the same configuration objectives. This was done to fully utilize the space. This number of panels, however, required a second inverter and monitoring system. The team then maximized the number of panels that could be handled by one inverter and fit aesthetically on the roof. This and both the minimum and maximum number of panels were considered final options.

The team ended with five final design options combining the two panel types and the two panel configurations as well as the maximized inverter configuration with just monocrystalline panels. The qualities of the options were determined using the Sunny Design website.

Design Options

The solar PV design website, Sunny Design, was used to generate five different PV panel systems for the roof of Mr. Redfield's shed. Data for annual energy production, material cost, panel efficiency, panel model, and inverter model were gathered for each design.

The first thing the team looked at was designing a solar PV system to produce 20% of the electricity consumed by Mr. Redfield's house each year on average. Within this goal, the team first looked at a polycrystalline solar array. Through the analysis performed within Sunny Design, it was determined that 20 PV panels would be needed to meet the 20% electricity goal, which equates to generating 6,780 kWh/year. This first solar array design was labeled Option A, and all the Sunny Design data is displayed in Table 1.

The team produced a second solar array design option with the goal of generating 20% of Mr. Redfield's total electricity usage. This time, a monocrystalline solar array was investigated to produce Option B. The difference between monocrystalline and polycrystalline panels is that monocrystalline panels are created by growing one large crystal and slicing "wafers" off of its end. Monocrystalline panels typically consist of many non-square "wafers", shown in Figure 3. Polycrystalline panels are made by compacting many different crystals, similar to particle board plywood. A polycrystalline PV cell is shown in Figure 4. Polycrystalline PV cells are typically less efficient and slightly less expensive. The Sunny Design data for Option B is also shown in Table 1.

The team also generated two solar array designs that would utilize all of the available space on the roof. The roof could hold 36 panels. Option C was generated within Sunny Design utilizing the same polycrystalline panels as in Option A. Option D was created through Sunny Design utilizing the monocrystalline panels from Option B. Data for both Option C and D are shown below in Table 1.

A fifth design: Option E, was created to have the maximum number of panels for a single inverter. This would allow for the most energy output for a lower price per panel than a 36 panel arrangement. Monocrystalline panels are used for Option E. Only one panel type needed analysis because the panel types produced similar prices and power output in previous simulations. The annual energy output of each option on a monthly basis is shown in Figure 5. A graphical representation of each option to reach the class goal is shown in Figure 6.

Recommendation & Conclusion

The team recommends option E, using 28 monocrystalline panels. This will allow Mr. Redfield to maintain a lower equipment purchase cost while maximizing his power output from the shed. With this design, he will offset 31.2% of electricity currently purchased from consumers energy, obtaining a monetary payback period of only 10 years. Furthermore, space between rows of panels will allow for easy serviceability and installation. The total investment for this option is $14,791 after the 30% tax rebate is applied. For a side by side comparison of all the panel options see Table 3.

Figures

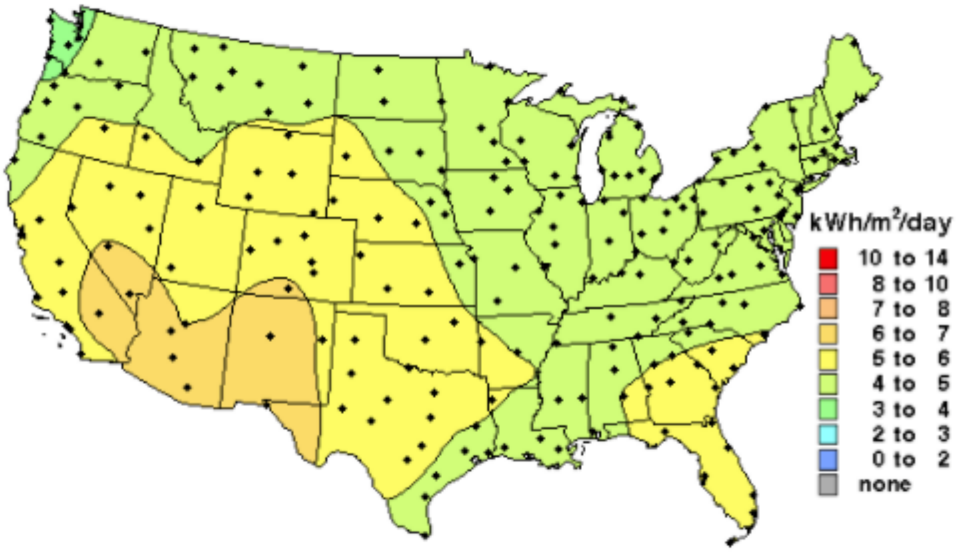


Figure 1 Average Annual Available Solar Energy Map.

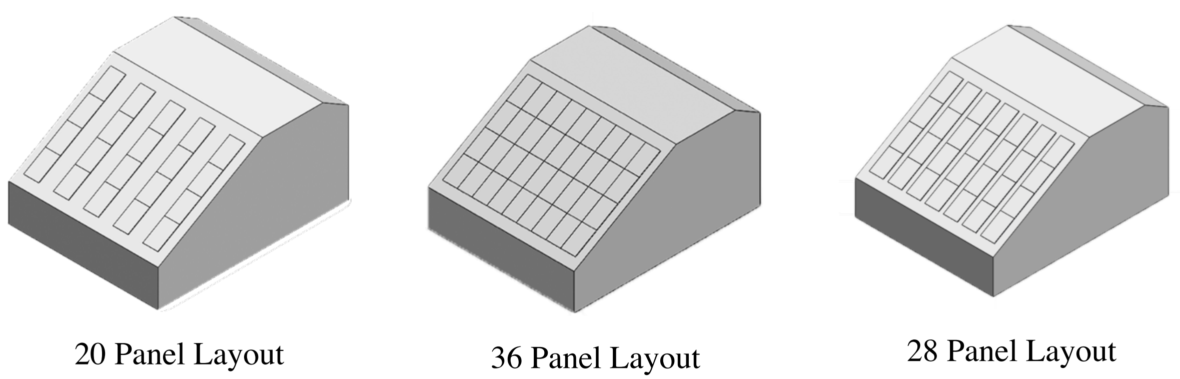


Figure 2 Panel Array Layouts

Table 3 Solar Array Design Alternatives

	Option A	Option B	Option C	Option D	Option E
Number of Panels	20	20	36	36	28
Panel Type	Polycrystalline	Mono-crystalline	Polycrystalline	Mono-crystalline	Mono-crystalline
Panel Model	CS3K-280P	CS6K-290MS	CS3K-280P	CS6K-290MS	CS6K-290MS
Inverter Model	SB 6.0-1SP-US-40 - 240V	SB 6.0-1SP-US-40 - 240V	2 x SB 6.0-1SP-US-40 - 240V	2 x SB 6.0-1SP-US-40 - 240V	SB 7.0-1SP-US-40-240V
Annual Production (kWh/yr)	6736	6989	12128	12561	10590
Percent of Total House Consumption	19.9%	20.6%	35.8%	37.1%	31.2%
Peak Power (kW)	5.60	5.80	10.08	10.44	7.98
Panel Efficiency	17.11%	17.72%	17.11%	17.72%	17.72%
PV, Inverter Cost*	$7,280	$7,540	$13,104	$13,572	$10,374
Mounting Rail Cost*	$2,765	$2,765	$3,030	$3,030	$3,030
Installation Labor Cost	$1,004	$1,030	$1,613	$1,660	$1,340
Total Cost**	$11,529	$11,763	$17,248	$17,669	$14,791
Monetary payback (Years)	11.45	11.25	9.39	9.28	9.28
Embodied Energy (kWh)	41173	62145	74112	111862	87004
Energy Payback (Years)	6.1	8.9	6.1	8.9	8.2
Panel Shipping Cost	$728	$754	$1,310	$1,357	$1,037

*30% Rebate not applied
**30% Rebate applied

Figure 3 Monocrystalline PV Cell Used (CS6K-290MS)

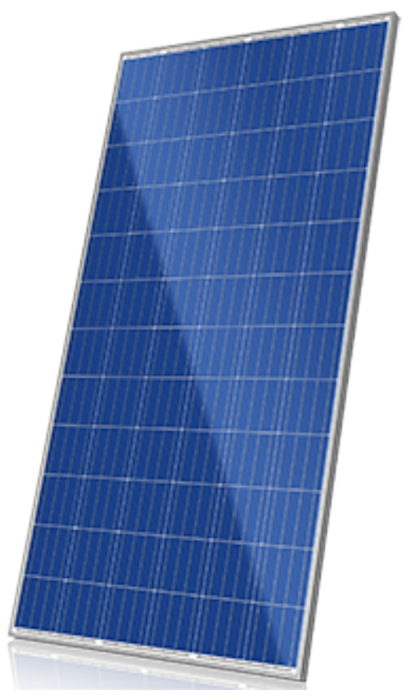


Figure 4 Polycrystalline PV Cell Used (CS3K-280P)

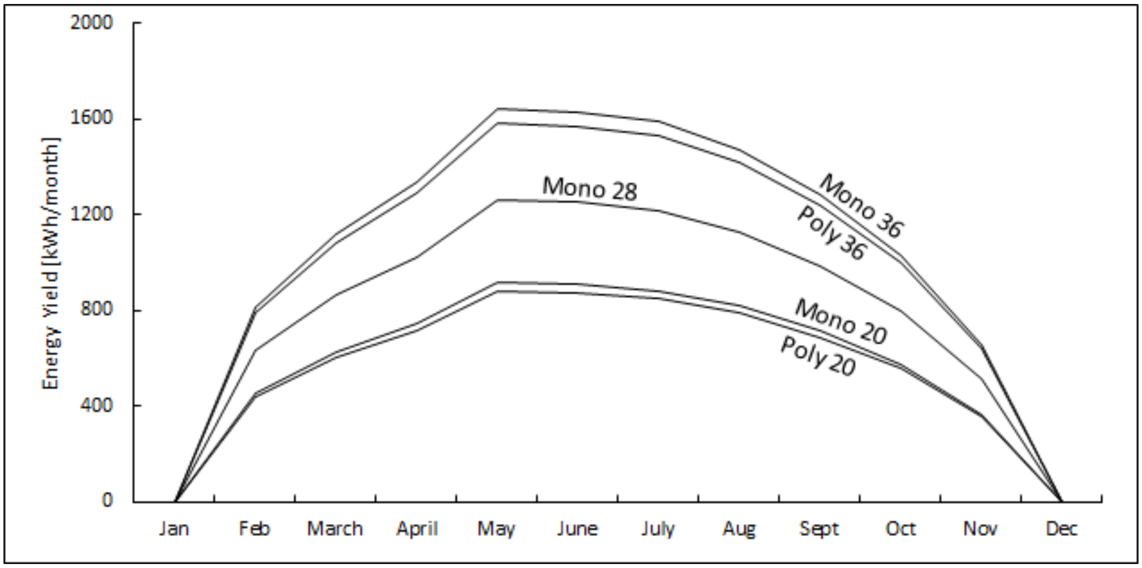


Figure 5 Monthly Energy Yield for Each Solar Array Option

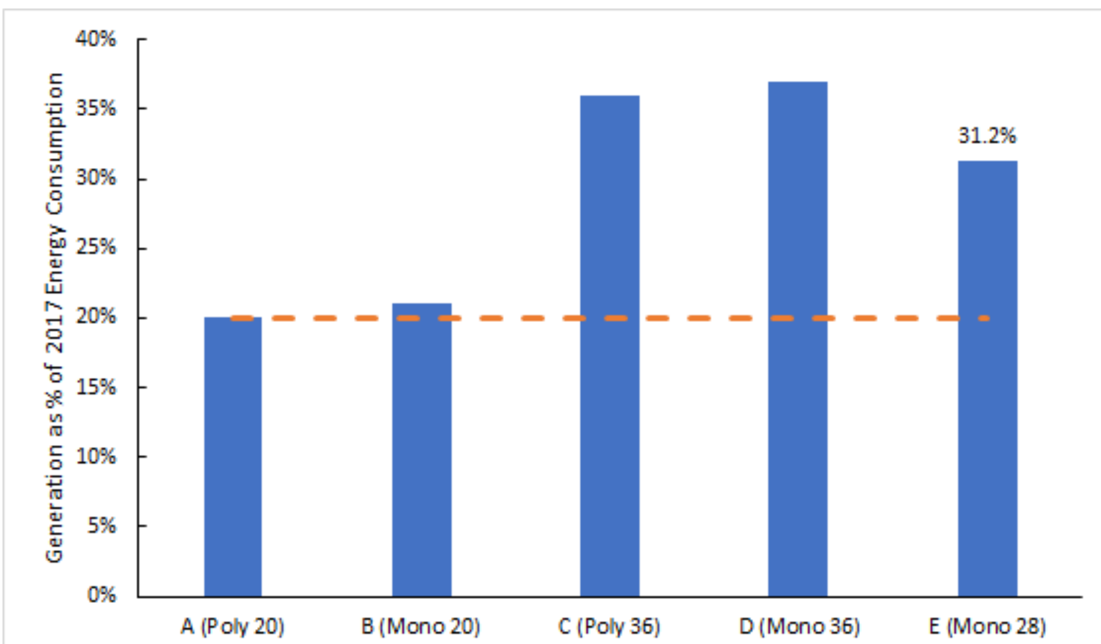


Figure 6 Summary of Energy Generated Annually for Each Option in Relation to the Class Goal

Appendix C: Wind Power Analysis

Professor Heun – Calvin College
Engineering W84 – Sustainable Energy Systems
January 23, 2018

Objective

The Wind team was responsible for understanding wind resources available to the customer and specifying wind energy machines that could be used to supplement the energy requirements of the Redfield property.

Analysis

The team started the project by considering five different wind turbines: Aeolos 600 W, Windspot 1.5kW, Skystream 3.7, Windspot 3.5kW, and Bergey Excel 6. The Calvin College Demonstration Wind Turbine was a Skystream 3.7; therefore, the team had collected data available to assess the actual performance of the turbine and compare it to the manufacturer's predicted power output. However, the Skystream 3.7 was ruled out as an option for the Redfield property because the production company is currently out of business. The team analyzed the monthly production capacity of each of the four remaining wind turbines using wind speed estimates from the Muskegon County Airport.

Windspot 1.5kW

The Windspot 1.5kW is a small-scale wind turbine with three blades capable of producing 12-20 kW daily at locations with average wind speed of 5 to 7 meters per second. It incorporates a variable pitch system which enables the turbine to maintain a constant peak output during times of higher wind. The Windspot 1.5kW is silent, efficient, and reliable, and can produce energy at wind speeds as low as 2.5 meters per second. Some characteristics of the wind turbine are:

Rotor Diameter	4.05	[m]
Cut in Speed	3	[m/s]
Rated Speed	12	[m/s]
Weight	155	[kg]
Yaw Control	Passive	
Transmission	Direct	
Acoustics	37 dB(A) from 60 m with a wind speed of 8 m/s	

At wind speeds of 5 to 7 meters per second, this turbine has an annual yield of approximately 2383 to 4850 kWh.

Figure 7 Windspot Turbine

Windspot 3.5kW

The Windspot 3.5kW Wind Turbine is slightly larger version of the aforementioned Windspot 1.5kW turbine. Manufactured by Sonkyo Energy, the Windspot 3.5kW turbine is a reliable and effective option for power generation given the appropriate environment. Incorporating the same variable pitch system as the 1.5kW model, the Windspot 3.5kW is designed to harness energy in any wind direction. The key features of the Windspot 3.5 kW turbine are as follows:

Rotor Diameter	4.05	[m]
Cut in Speed	3	[m/s]
Rated Speed	12	[m/s]
Weight	185	[kg]
Yaw Control	Passive	
Design	IEC61400-2	

According to the Sonkyo Energy, the Windspot 3.5kW will generate an annual energy yield in the vicinity of 5500 kwh to 11300 kwh provided that average wind speeds remain in a range between 5 to 7 meters per second (11 to 16 mph). Although this estimated yield is far higher than the estimated yield for the 1.5 kW model at the same 5 to 7 meter per second wind speed, the Windspot 3.5kW turbine will only outperform the 1.5 kW model for wind speeds greater than 6 meters per second. As shown in Figure [], the performance curve for the 1.5kW and 3.5kW models are seemingly inseparable for low wind speeds, and the larger production capacity of the 3.5kW model is only noticeable at higher wind speeds. Figure [] further exemplifies this behavior, and it is shown that the 1.5kW model presents higher power estimations at the low wind speeds which is assumed to be indicative of the wind performance at the Redfield Estate.

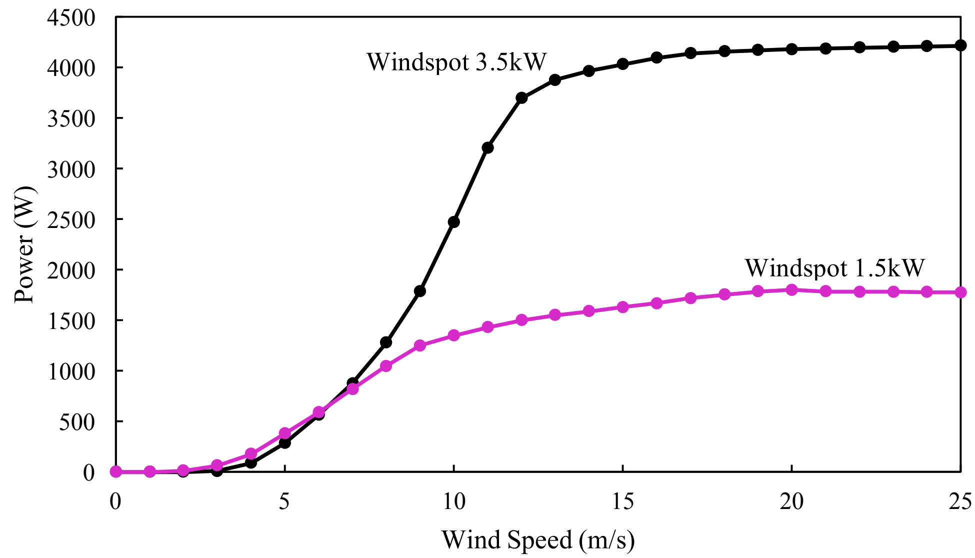


Figure 8 Performance Curve

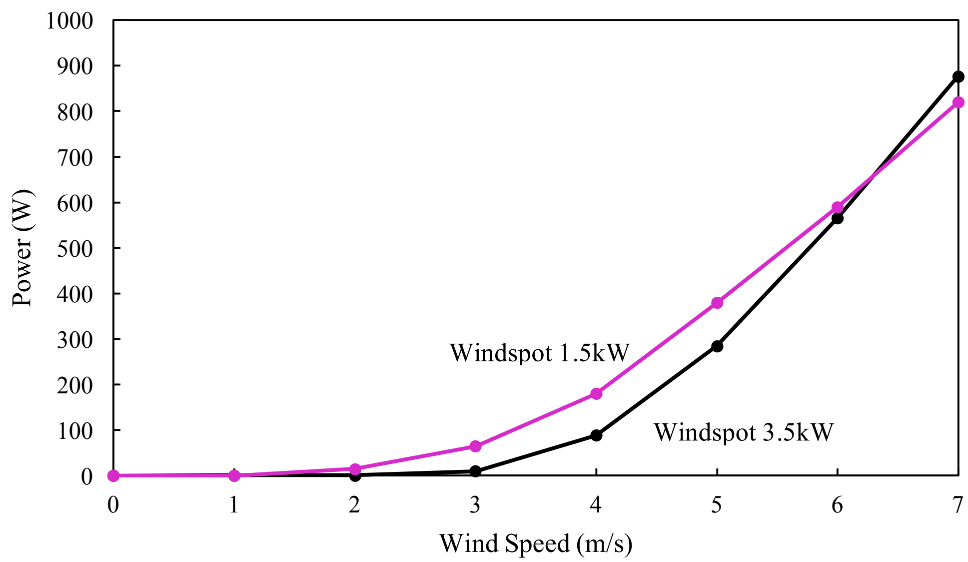


Figure 9 Performance Curve for Low Wind Speed

The performance curves as predicted by Sonkyo Energy imply that the Windspot 3.5kW turbine is not a favorable option for wind speeds below 6 m/s. Given the wind speeds at the Redfield Estate are not believed to exceed this 6 m/s threshold, the full performance potential of the 3.5kW model will not be realized at the Redfield Estate.

In addition to being potentially outperformed by the lower rated 1.5kW model, the 3.5 kW model is more costly in regards to both energy and monetary means. The price of a Windspot 3.5kW Turbine is $8,000. When installation and tower costs are factored in, however, the total cost of this system is roughly $43,000. Furthermore, the energy required to produce this turbine and its components is estimated to be 173,000 MJ. Provided the production rate given by Sonkyo Energy hold true, the fiscal payback of the turbine is projected to be in the vicinity of 100 years while the energy payback of the turbine is projected to be in the vicinity of 15 years. Hence, the Windspot 3.5kW is considered to be an undesirable option in comparison to alternative small turbines and solar generation methods.

Bergey Excel 6

The Bergey Excel 6 wind turbine is the largest turbine to be evaluated for the Redfield property. The turbine is manufactured by Bergey WindPower, the oldest residential wind turbine manufacturer. The turbine produces 240 VAC single phase electricity, and the turbine has the ability to connect to the grid. The key features of the Excel 6kW turbine are as follows.

Rotor Diameter	6.2	[m]
Cut in Speed	2.5	[m/s]
Rated Speed	11	[m/s]
Weight	350	[kg]
Yaw Control	Passive	
Design	IEC 61400-2	
Thrust Load	1850 lb	

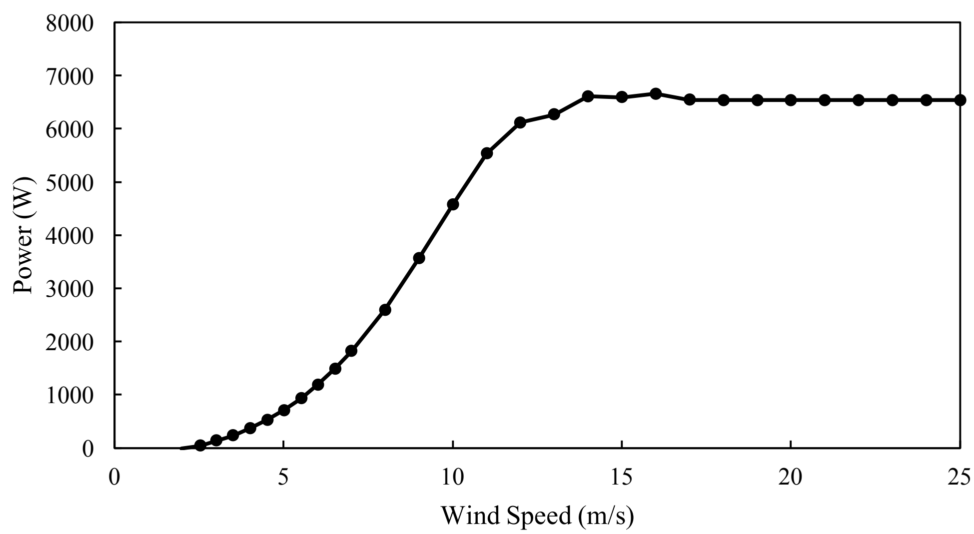


Figure 10 Bergey Power Curve

Using the predicted wind speeds of the Redfield property, the annual yield of the Windspot turbine is estimated to be 6400 kWh. The estimated installation cost for the Excel 6kW model is $57,000 and this leads a monetary payback period of 65 years. Additionally, the embodied energy of the Excel 6 is estimated to be 87,000 kWh leading to an energy payback period of 14 years. While the monetary and energy payback periods estimated for the Excel 6kW turbine are comparable to the smaller Windspot models, implications involved with installing such a large system make the Excel 6kW turbine and unfavorable option.

The size of the Bergey turbine requires a large tower which must be supported with anchored support cables. The radius of these support cables must be at least 60 percent of the tower height, meaning a far larger portion of the wooded area must be cleared in order to make room for the system. Furthermore, the Bergey system has a larger rotor radius and therefore must be stationed higher. Additionally, it may be difficult to conduct a wind study at the height required for the Bergey system. When all of these factors are considered, a turbine of this size is not an attractive option candidate for the Redfield property.

Figure 11 Bergey Wind Turbine

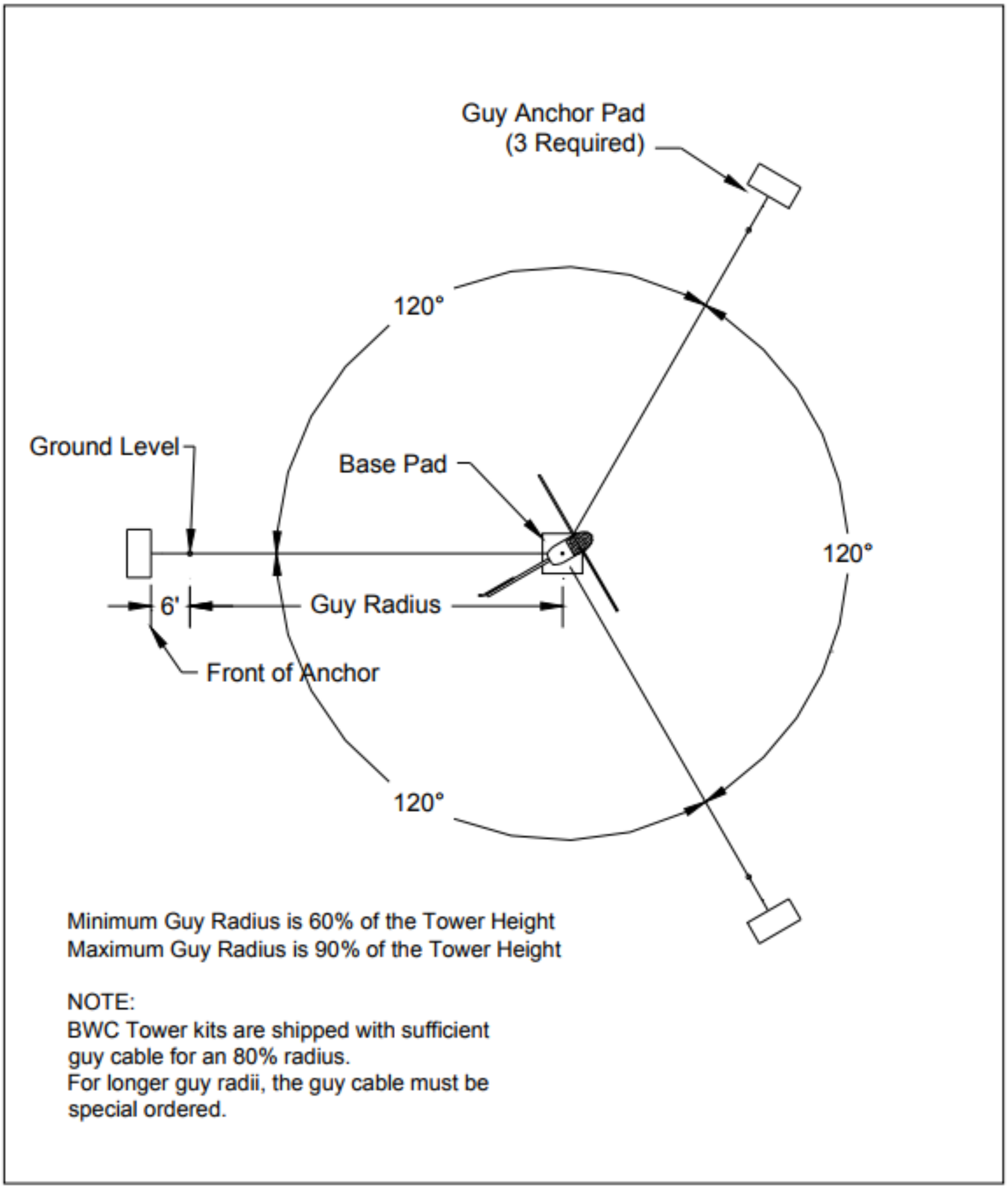


Figure 12 Bergey Tower Specifications

Aeolos 600W

The Aeolos 600W is a small vertical axis wind turbine capable of producing 100-800W at wind speeds from 5 m/s to 13 m/s. This wind turbine is reliable power generation sources that outperforms the larger turbines at low wind speeds. The benefits of having a vertical axis wind turbine include easier maintenance because the generator can be mounted on the ground, they do not need to point into the wind to start up, at high winds they are more durable, because they don't need as much wind they are able to be mounted closer to turbulent wind, and they are quieter than the traditional horizontal wind turbines.

Figure 13 Aeolos 600 W

Additional information about the Aeolos 600W can be found below:

Rotor Height	2.0	[m]
Rotor Diameter	1.6	[m]
Cut in Speed	1.5	[m/s]
Rated Speed	10	[m/s]
Weight	18	[kg]
Transmission	Direct	

The manufacturer for the Aeolos 600W vertical axis turbine is The Aeolos Wind Turbine company is based out of Denmark with products in the United States, Canada, the United Kingdom, and more than 65 countries and regions. The turbine has a 5 year warranty and a 20 year expected life. Once the wind data has been collected on the Redfield property the actual power generation can be determined. If the average wind speed over the year is at 5 m/s, which is predicted by the National Renewable Energy Laboratory, the Aeolos 600W would produce about 876 kWh a year. The Power curve can be seen in Figure 13.

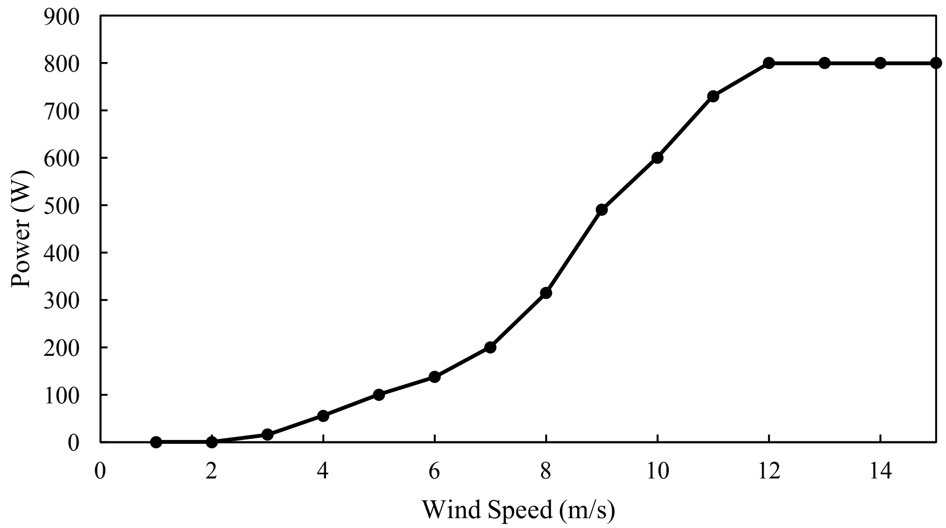


Figure 14 Aeolos Power Curve

Anemometers

The Wind team considered two main types of anemometers per the installation of a wind turbine. The anemometers differ in the sense that one is AC powered while the other is solar powered. The AC powered unit comes with internal batteries which would enable it to operate for approximately 30 days in the event of a power failure. On the other hand, the 10 watt solar panel will run the data logger almost indefinitely and thus is perfect for remote areas lacking access to AC power. The devices are both manufactured by APRS World LLC and their features are summarized in

Table 4 below.

Table 4 Comparison of AC and Solar Powered Anemometers

Solar Powered Wind Data logger Package	AC Powered Wind Data logger Package
Pelican 1300 Case	Pelican 1200 Case
Anemometer with boot	Anemometer with boot
Wind data logger module	Wind data logger module
10 Watt Solar panel	Universal AC power Supply (90 to 264 VAC, 125-370 VDC, 47-63 Hz)
7 amp/hour sealed AGM battery	8 D Cell Alkaline Batteries (for backup)
Solar charge controller	-
Weatherproof Cable feedthrough	Weatherproof Cable feedthrough
512 megabyte SD Card (-40°C to 85°C)	512 megabyte SD Card (-40°C to 85°C)
Temperature sensor (10ft)	Temperature sensor (10ft)
Price of $913	Price of $625

Installation

In addition to performing a year long wind data collection, there are other factors that should be considered in order to achieve optimum performance from the wind turbine. These include:

Site & Space: For the Windspot 1.5kW, it is recommended that the tower be installed 10 meters higher than the tallest obstacle around and at a distance more than twice the height of the obstacle. The Aelos, however, has a recommendation of being installed 7 meters higher than the tallest obstacle while being 15 times its rotor diameter away from this obstacle.

Predominant Winds: It is necessary to determine the direction of the strongest and frequent winds in order to ensure that the area is free of all obstacles such as trees and other structures that might impede wind flow.

Cable Connections: Two methods were proposed for the wiring of the wind turbine to the house's electrical system. These methods are namely directional boring and ditch witching. In directional boring cables are installed underground in a shallow arc along a prescribed path and the process is carried out with little impact on the surrounding area. In ditch witching however, a mechanized compact trencher is used for laying underground pipes and cables.

Results

The effectiveness of the wind turbine is dependent on the winds in the area that can be determined in a yearlong wind study using an anemometer.

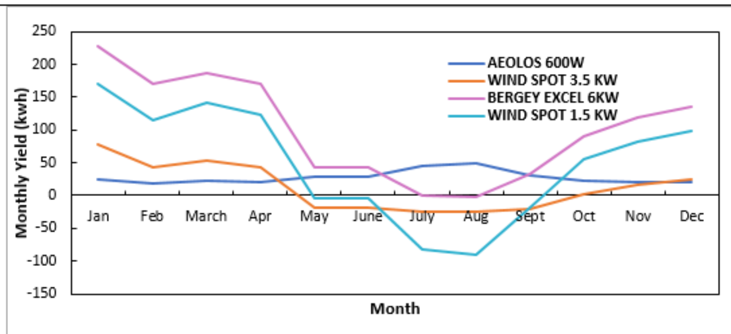
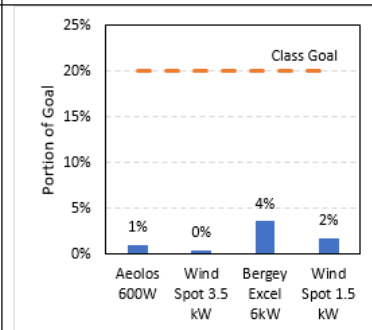
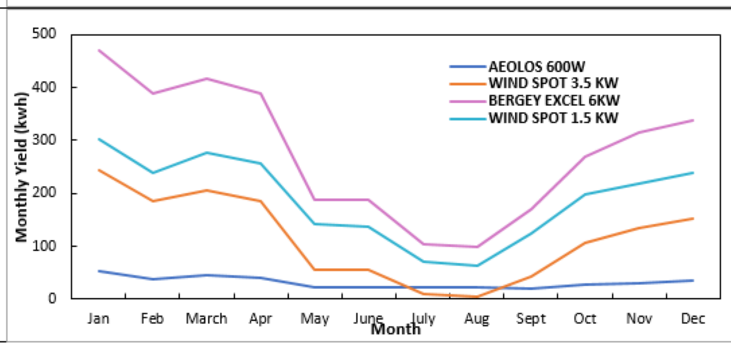
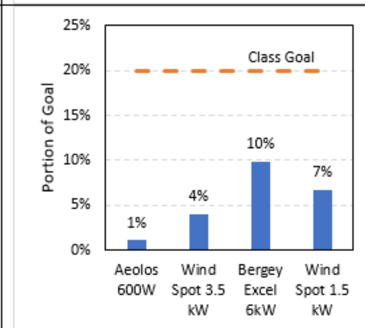
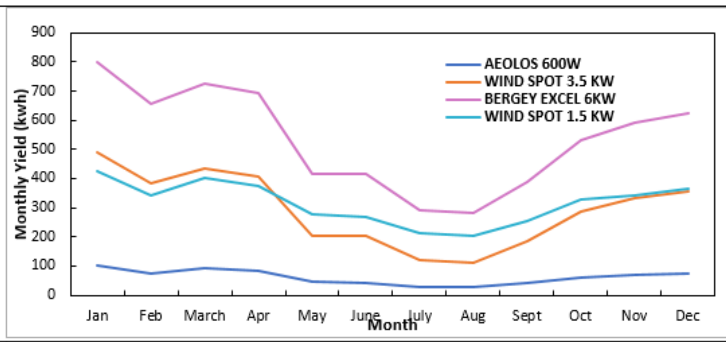
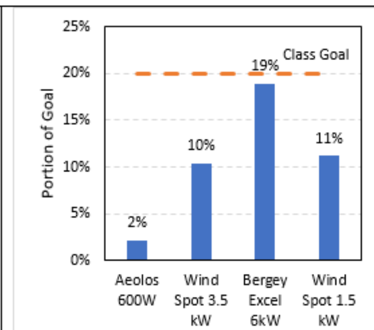
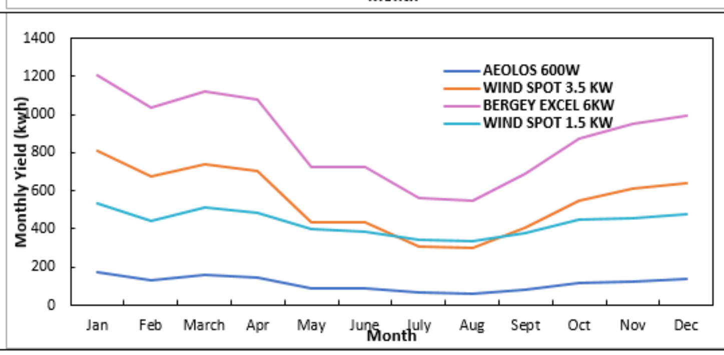
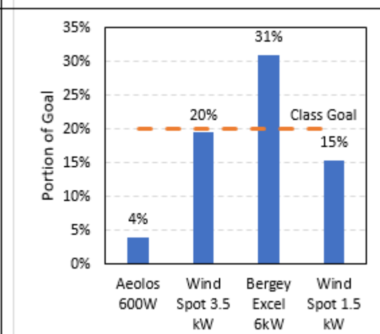
Assuming that the wind has an average wind speed of 5m/s, or 16.5ft/s, **Error! Reference source not found.** has the results for the four wind turbines considered.

Table 5 Wind Turbine Specifications

Turbine	Aeolos 600W	Windspot 1.5kW	Windspot 3.5kW	Bergey Excel 6kW
Power Generation [kWh]	738	3790	3520	6420
Monetary Savings [$/yr]	103	531	492	898
Monetary Payback [yrs]	364.8	79.1	87.3	63.5
Energy Payback [yrs]	57.4	13.1	13.6	13.6

At different wind speeds the power generated by the four turbines is different. In the following **Error! Reference source not found.** the average wind speed is indicated, but it varies on a month by month basis similar to the varying wind at the Muskegon Airport.

Table 6 Power Generation with Varying Wind Speeds

Average Wind speed [m/s]	Monthly Output	Percent of Total Predicted Energy Consumption by Each Turbine
3		
4		
5		
6		

As seen above, at low wind speeds, which is predicted at the Redfield residence, the smaller turbines generate more or very similar amounts of power as compared to the larger wind turbines.

Conclusion

Taking into account the economic and energy analysis, the team recommends implementing the Windspot 1.5kW wind turbine, if a wind turbine is desired. At low speeds, the Windspot 1.5kW performs better than the Windspot 3.5kW. Although the Bergey Excel 6 has the best energy return on investment, it has a high upfront cost and operates better at higher speeds. At an average wind speed of 5 m/s, the Windspot 1.5kW has a reasonable monetary and energy return on investment (approximately 190 and 21 years respectively). It is also built to perform better in areas with low wind speeds like the location of the Redfield property.

Table 7 Cost Break Down of Windspot 1.5 kW

Spent		
	2007 $	2018 Price
WindSpot 1.5 kW	-	$7,000.00
Leonard DeRooy PE Structrual Design Time	$348.00	$481.71
Remote wireless interface	$156.73	$216.95
USB converter	$79.00	$109.35
Gin Pole Kit	$286.00	$395.89
Hinge Plate Kit	$253.00	$350.21
Turbine Shipping	$136.20	$188.53
1200 feet of 1 1/2 inch schedule 40 conduit	$921.80	$1,275.99
200 feet of 1 1/2 ich schedule 40 conduit and 2 man holes	$564.71	$781.69
Conduit	$33.18	$45.93
4 elbows 90 degree and 4 female adapters	$34.86	$48.25
General Duty Safety Switch	$41.18	$57.00
Galvaized Unistuct with spring nuts	$29.03	$40.18
750 foot power/comm bore	$5,270.00	$7,294.91
Zoning Application Cost	$100.00	$138.42
Electrical Permit	$142.00	$196.56
Building Permit	$94.00	$130.12
Consumers Energy Interconnect Application	$100.00	$138.42
Generator Interconnection & Operating Agreement meters	$477.00	$660.28
Surveyor	$200.00	$276.85
Turbine Site Field Trip	$42.68	$59.08
NI Compact Field Point and related modules	$2,755.79	$3,814.66

NI Compact Field Point DIN Rail	$14.03	$19.42
IP Camera	$1,002.80	$1,388.11
Tower Foundation - Cement	$540.50	$748.18
Re-Rod	$93.88	$129.95
1.8 by 3/4 100 Straps	$45.60	$63.12
Mat Bolt Kit	$357.05	$494.24
Fiber Optic Cable - 600 feet Use ST Connectors MultiPode 6 Fibers Underground	No Cost	$0.00
Fiber Optic Termination Point at Consession Stand	$279.55	$386.96
Ethernet to Fiber Converter	$336.00	$465.10
Lighting Protection	$116.00	$160.57
COMM Cabinet - Hoffman U-U1008030	$930.42	$1,287.92
Soil Sample Borings	$900.00	$1,245.81
Fence and Gate	$1,750.69	$2,423.36
Davis Instruments Wireless Vantage Pro Plus (6162)	$326.92	$452.53
Davis Instruments weatherlink serial (6510SER)	$490.38	$678.80
2" x 2" Finger Duct	$51.96	$71.92
1 13/16 wrench and 1 1/4 cutting die	$135.20	$187.15
10 IN SONO Tube 8 Feet Length	$13.60	$18.83
Din Rail Mounting Clips	$23.40	$32.39
3 Din Rail Mountable 115 VAC outlets	$49.61	$68.67
1 1/2 Green Heat Shrink Tubing	$20.90	$28.93
Cabinet heater	$227.50	$314.91
Mile Marker PE8000 Electric Winch with Roller Fairlead	$389.99	$539.84
Mile Marker Detachable Mount MM60-06495	$199.87	$276.67
Miscellaneous Hardware	$39.90	$55.23
Miscellaneous Hardware - Returns	($8.48)	$11.74
Stainless Steal nuts - 19 1 1/4	$66.50	$92.05
Grounding Rods	$39.71	$54.97
SOOW Cord	$40.93	$56.66
Cement Form rentals	$93.88	$129.95
Circuit Breaker - Din Rail mountable	$154.22	$213.48
Thermostat	$31.85	$44.09
Silicon Grease	$14.95	$20.69

Din Block Jumpers	$11.36	$15.72
2" IMC Conduit (10 each)	$22.44	$31.06
Square D Circuit Breaker and Load Center	$86.51	$119.75
Fuse reducers	$21.18	$29.32
DUCT, Cover 2"	$18.84	$26.08
Hofman Enclosure and PVC Fittings	$113.13	$156.60
Nema Disconnect Switch 60 Amp 240 V	$190.60	$263.83
Lock Nut Sealant	$10.70	$14.81
Terminal Gnd Bar	$15.44	$21.37
CH Circuit Breaker	$11.20	$15.50
10/4 SJOOW Black Power Cord for tower internal run	$52.03	$72.02
650 Feet of #8 THHN Green Gnd Wire	$207.45	$287.16
2 Large Wrinches 1 and 13/16 "	$39.90	$55.23
Labor for wire pull at turbine	$105.00	$145.34
9330 Siemens Meter	$417.65	$578.13
ethernet switch - Phoneix Contactor	$513.76	$711.16
1 Din Rail 1 Meter	$7.32	$10.13
Din Block material and Fuse	$40.34	$55.84
2 Hoyt current transformers @201.20 each	$414.40	$573.63
3x650 Reels of #2 THHN	$2,128.99	$2,947.02
total		$41,992.98

Appendix D: Efficiency and Geothermal Analysis

Professor Heun – Calvin College
Engineering W84 – Sustainable Energy Systems
January 23, 2018

Objective

The objective of this group was to find ways to decrease the total energy usage of the home and of the geothermal systems. This was done by analyzing the windows and doors in the home to find the the energy savings if replacements are made for either. Research on the geothermal systems were made to find any improvements and average life cycles for all three models in the house. The ideas recommended by the group include: replacement of windows with higher U value windows, replacement of doors with better seals, and replacement of the oldest geothermal furnace.

The group was first tasked with looking into potential hydro generation and found that the energy and monetary payment periods were far too great to make a hydro generator worth the cost. The amount of energy that could be obtained from the small waterfall located on the property would be a maximum of 555kWhyr. This amount is less than 10% of the total amount of energy needed to be saved and is accompanied by an energy payback of 37 years.

The group from the beginning also looked into the geothermal systems that Mr. Redfield has to heat his home. When analyzing the furnaces used, it was noted that one furnace, the oldest furnace, had the potential of being replaced to greatly increase efficiency. The other two furnaces were determined to have insignificant change when replacing; therefore, only that furnace was studied. In addition, maintenance of all three furnaces was studied for potential increase in efficiency.

Once the team determined that the hydro based projects would not be viable, the team switched focus and began analyzing the house for ways to make it more energy efficient. Specifically, the team first analyzed the windows to see if heat loss could be reduced through improvements. In addition, the group also researched any rebates that went along with replacing windows to be more energy efficient.

Another project the team tackled when switching to efficiency was sealing the doors. Since various doors had gaps that allowed heat loss in the cooler seasons and heat gain in the warmer seasons. Since this makes for excess energy usage to keep the home at a set temperature, the team studied door sealants to reduce this heat flow.

Analysis

Micro hydro Generator

Potential energy over the waterfall on the Redfield property was analyzed using the equation:

$$E = Pt = \rho \dot{V} g h$$

In this equation, the potential energy of water over the waterfall was calculated as a product of the water density, flow rate, acceleration due to gravity, and height of the waterfall.

Once the potential energy was calculated, giving the power over the waterfall, power produced by the generator was calculated, assuming an efficiency of 50%.

Geothermal System

After obtaining technical data for each of the current installed geothermal heat pumps, the sole source of heating and cooling in the house, the data was analyzed to determine potential cost savings. The two ideas for savings were maintenance on current systems and the replacement of the oldest pump, a system with a COP (coefficient of performance) of only 3.2 and an EER (energy efficiency ratio) of 13.

The most recommended maintenance operation was to check and replace the air filter 1 to 2 times per year. These are the most common hindrance of pump efficiency. Annual inspection of the systems is another way to ensure that they are running properly.

The highest efficiency ENERGY STAR® rated geothermal heat pumps were evaluated that had similar heating and cooling outputs to the oldest pump and averaged to analyze potential savings.

The possible rebates for geothermal heat pump installation were considered.

Tier 1 Ground Source Heat Pump 17.0 EER-18.99 EER

(*Replacement Only) $200

Tier 2 Ground Source Heat Pump 19.0 SEER or higher

(*Replacement Only) $300

Window Replacement

Calculations were done according to the equation:

$$Q=UA\Delta T$$

where Q represents the heat transfer through the windows, U is the heat transfer coefficient (a property of the type of window), A is the area of the window, and ΔT represents the average temperature difference between the inside and outside of the house in a given month.

For these calculations, the team first measured the windows at the Redfield property and determined that all windows were double paned. Therefore, all calculations were done for replacing double pane windows with triple pane. Since some windows are newer and some are older, the team calculated replacing half of the windows.

Rebates were also considered when calculating costs related to windows. For northern climate zones, windows being replaced with energy star rating can receive $15 rebate per window for up to 40 windows.

Door Sealing

After research on energy loss through doors in homes, a U-value for the equation was found. Following, information on the decrease in the U-value with improved door sealing was found. The U-value for a typical door was found to be 0.2Btuhrft2F and new sealants could decrease this to approximately 0.15-0.1Btuhrft2F. With the average temperatures found from weather.com and the inside temperature being averaged at 68° F the energy saved per month was calculated.

Results

Microhydro Generator

The maximum possible energy that could be expected from the waterfall was calculated to be approximately 550 kWhyr. With an estimated implementation cost of approximately $12,000 and an embodied energy of approximately 20,500 kWh, the project had an expected monetary payback time of 156 years and an expected energy payback time of 37 years. With an expected lifetime of only 25 to 50 years, the project was not viable.

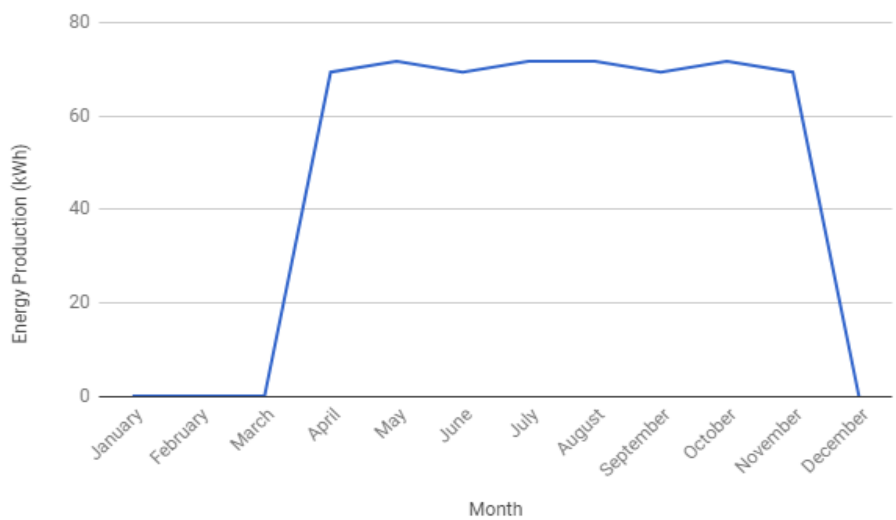


Figure 15 Hydro Generator Energy Production

Geothermal System

The purchased and installation costs, COP, and EER of each high-performing system was averaged to be $10,000, 4.5, and 30, respectively. The savings of the pump was about 3650 kWhyr. The possible rebates for geothermal heat pump installation were researched. An EER of 30 (Tier 2 Ground Source Heat Pump) would yield a $300 rebate for Mr. Redfield. The cost and payback time did not implement this rebate due to the uncertainty of time of installation. The old boiler has an estimated lifetime of 20 years and is currently in its eighteenth year. Replacement can and should take place within the next two years; however, due the variability in rebates over time, they were excluded from calculations.

Table 8 Geothermal Pump Data

	Pump 1: Hydron 2 Ton	Pump 2: Carrier 6 Ton	Pump 3: Geosource GV520	Replacement for Pump 3:
Install Year	2017	2007	2001	*2018?*
COP	5.8	4.3**	3.2	4.5
EER*	37.4	25.3**	13	30

*Energy Star Rating requires and EER or SEER of 14.5
**Average from range given in product data
***Including assumed rebate

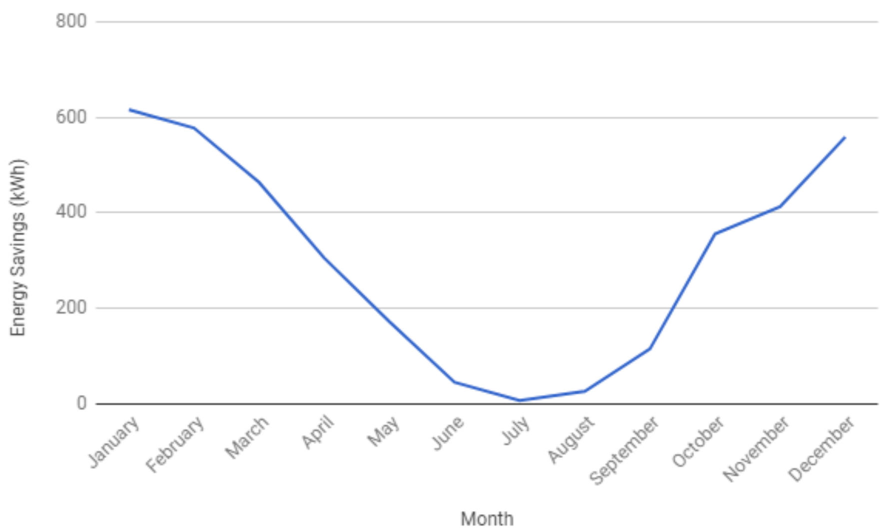


Figure 16 Geothermal Energy Savings

Window Replacement

The window replacement offered the highest total savings. In energy terms, the project saved approximately 3,700kWhyr. This results in an energy payback period of 8.6 years. The monetary investment includes a $38,000 per year capital investment and a respective payback period of 63 years. To be noted, in the long term Mr. Redfield will need to replace windows due to lifetime expectancy of windows, making this project mandatory throughout his lifetime in the home. This project, though, will reduce the savings from the geothermal project since there would be less heat loss.

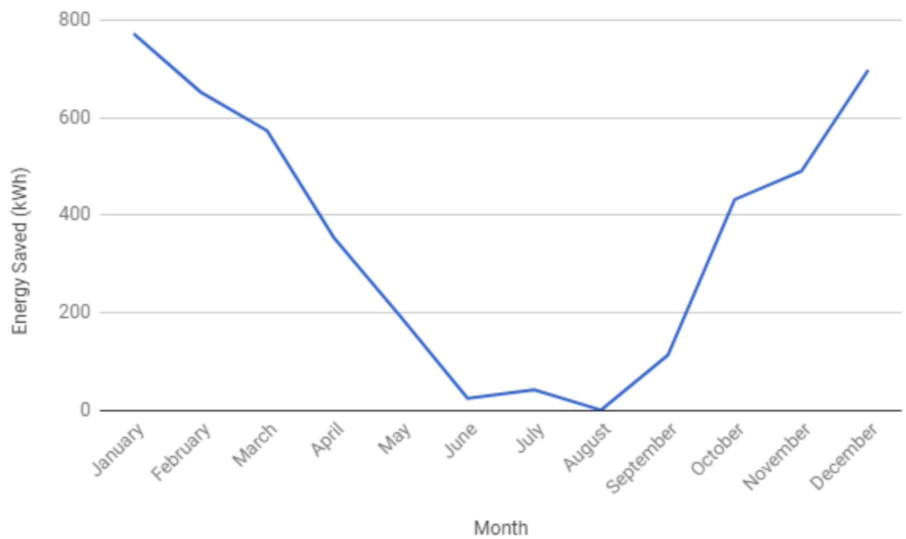


Figure 17 Window Energy Savings

Door Sealing

Door sealants were determined to be a cost efficient way to save a small amount of energy annually. The energy savings from replacing the door seals with new sealant would only save around 1.02% of Mr. Redfield's total energy; however, the sealant would approximately cost only $25, making the monetary payback period only 0.51 years. In respect to energy, the sealants would save 344 kWhyr, which has an energy payback period of only 0.08 years. This low cost and quick payback periods make this an easy way to find savings in Mr. Redfield's home.

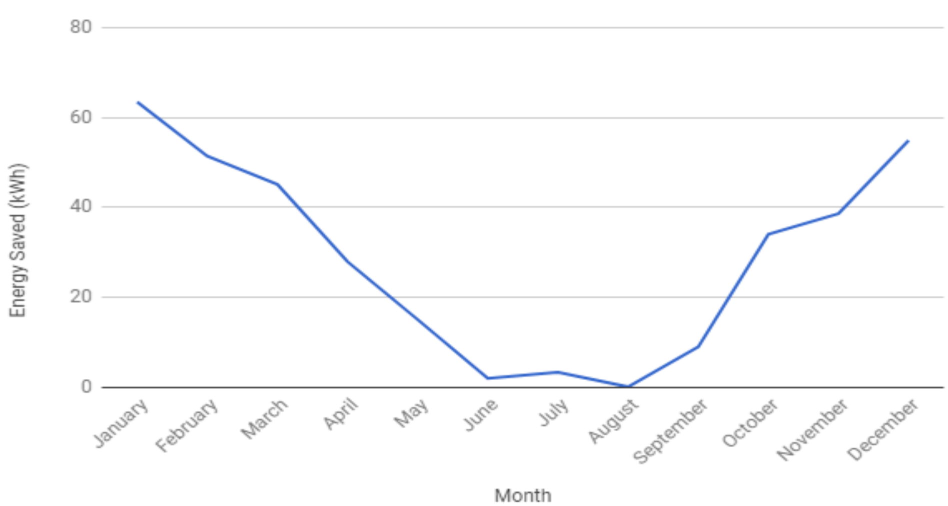


Figure 18 Door Sealant Energy Savings

All the results from our put forward results can be seen in Figure C5 below as a percent of his total energy usage.

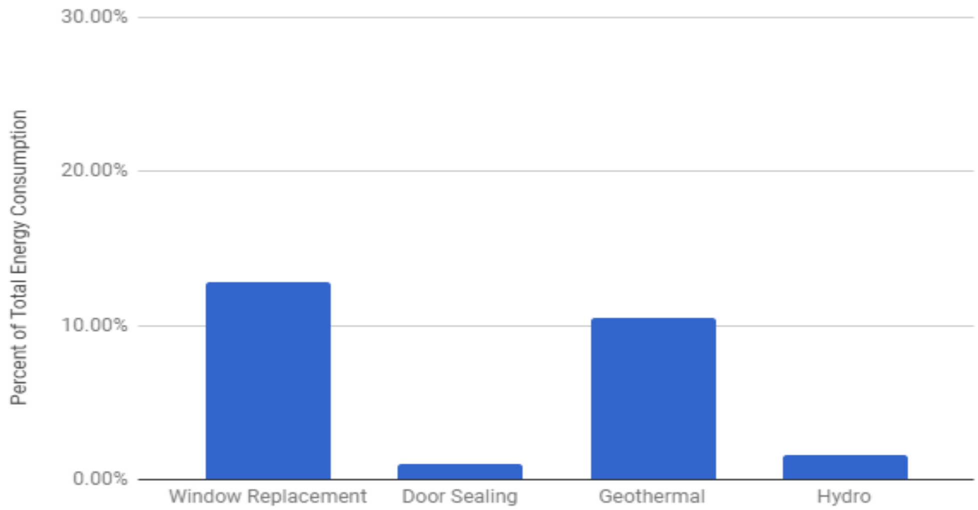


Figure 19 Summary of Energy Savings

Conclusion

Throughout the analysis of hydro, geothermal, and efficiency energy savings for the Redfield property, it was determined that all projects, except hydro, should be recommended. Since hydro had an excessive monetary and energy payback period in respect to its life cycle, the project was determined unsatisfactory. The geothermal projects are both recommended. Maintenance of the current furnaces can be an easy way to keep the system efficient. Replacing the oldest furnace would also be recommended since it has an obtainable monetary and energy payback period in respect to the lifecycle of a new purchase and is nearing the end of its lifetime. For creating a more efficient home, since the older windows will need to be replaced in Mr. Redfield's lifetime, the project is recommended. The energy payback period will greatly surpass the life cycle, making it a viable project. Lastly, the door sealants are also recommended since they have the shortest monetary and energy payback periods. In all, these projects could make a substantial difference in the energy efficiency of the Redfield property.