Sustainable Engineering Internship 2019

Final Report

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SHOALS
Marine Laboratory

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Assignment 1 - Fresh Water from the Sun and Sea

Lead Interns: Valentine Starnes and Marguerite Lorenzo

1.1 Background

By early afternoon on a sunny day the SML green energy system produces enough energy to fully charge the 300kWh battery bank. Once the batteries are fully charged, solar charge controllers regulate the charging rate to prevent overcharging. Based on the data and recommendations from the 2016 Engineering Interns, SML purchased a new (smaller) reverse osmosis water maker (RO). The new water maker will be used on sunny days when the batteries are fully charged and there is excess energy available to run the unit. The reverse osmosis water maker will supplement the drinking water from the well.

1.2 Purpose

The RO water maker helps to provide fresh water for the island but requires a large amount of electricity to operate. The purpose of this assignment is to determine whether the RO can run on excess green energy. The interns are tasked with evaluating the RO's load and its effect on the green energy grid. Any other operational changes will be recommended to ensure the diesel generator is not needed.

1.3 Scope

The interns will determine the excess energy that was previously not being utilized by the green grid and whether the power demand of the RO is below this threshold. Given that the RO can be accommodated from the green grid exclusively, the interns will recommend optimal times and weather to operate the RO. The total island's power and water usage will be analyzed to calculate how much the RO had an effect on it.

1.4 Methods

1.4.1 Ideal PV Energy

To evaluate the ideal PV harvest power interns imported solar irradiance data in W/m2 from the pyranometer. To get ideal PV output wattage values, these irradiance values were scaled down by an efficiency value and multiplied by the surface area of the solar panels. The efficiency was calculated by the following formula:

$$\eta_{max}\,(\text{maximum efficiency}) \;=\; \frac{P_{max}(\text{maximum power output})}{(E_{S,Y}^{SW}(\text{incident radiation flux}) * A_c(\text{area of collector}))}$$

All of the ideal PV output wattage values were then summed to give the total ideal power. Finally, the daily ideal PV output (in kWh) was calculated by integration of the ideal harvest curve, specifically by method of Riemman sums. The results of this calculation were then compared to the value 2016 SEI interns had acquired when they ran the ECB batteries down the night before a nice sunny day to record the ideal energy output from the solar panels. Since running down the batteries is damaging to battery life, interns decided to use the pyranometer data rather than to repeat this experiment.

1.4.2 Actual Daily PV Power Output

The interns imported PV output data from the charge controllers in the Energy Conservation Building (ECB) through the Conext ComBox on the Schneider Electric website. The real daily PV output was calculated by method of Riemann Sums.

1.4.3 Excess Energy

To determine the amount of excess solar energy that could be used to power the RO, interns subtracted the real amount of energy generated by the PV panels from the estimate of ideal PV energy on a given day.

1.4.4 RO Energy Demand

On June 26th 2019, the RO was run at a different setting combinations of motor Variable Frequency Drive (VFD) and outflow pressure (in psi). The Fluke Energy Logger was connected as to collect energy intake data, and brine and product outflow rates were also recorded. Energy intake values were given in kW, representing the active power.

Given an excess amount of energy in kWh from the green grid and a maximum run time for the RO, the interns calculated how much product water the RO would be produced for each different combination of settings. The goal was to find the combination of settings that maximizes product water output for the same energy intake.

1.4.5. Battery State of Charge

To ensure the RO is run solely off excess energy, interns needed to check that running the machine would not prevent the Energy Conservation Building (ECB) batteries from reaching their maximum state of charge. On a normal day, batteries are drained by the island load to 70% at the very least as to preserve battery life. When the sun rises and the solar panels start outputting power, the battery state of charge starts slowly increasing until it reaches its maximum state of charge usually around noon. Interns are hoping that if the RO is run during the day, there will still be enough solar output to fully charge the batteries before the sun goes down, and this way the full battery capacity will be available for use during the night.

With the help of Ross and the Island engineers, the RO was run on July 10th 2019, a mostly cloudy day, to analyze state of charge data from the ECB inverter ComBox.

1.5 Results and Analysis

1.5.1 Ideal PV energy

The ideal harvest PV curve was drawn for the span of a full sunny day on June 23rd, 2019 (Figure 1), and therefore the area beneath the curve represents the ideal amount of energy that can be generated by solar power in a day. By the method of Riemann sums, interns found this value to be 306.35 kWh.

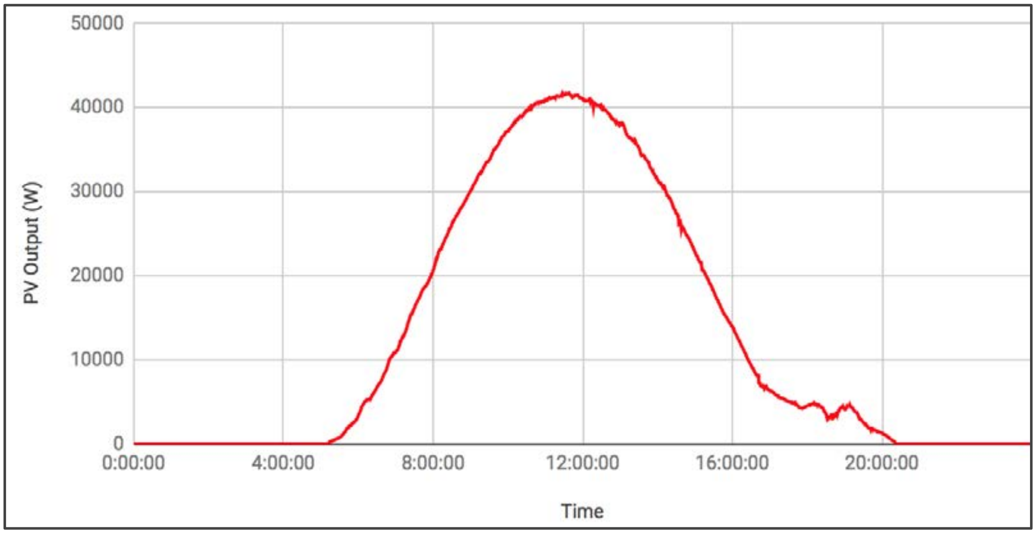


Figure 1: Graph of Ideal PV Output (in Watts) versus Time on a Sunny Day (June 23rd 2019)

The ideal generated daily PV power found by the 2016 SEI interns was 312 kWh (Figure 2), which seems in range with the 306.35 kWh per day that we found for June 23rd 2019.

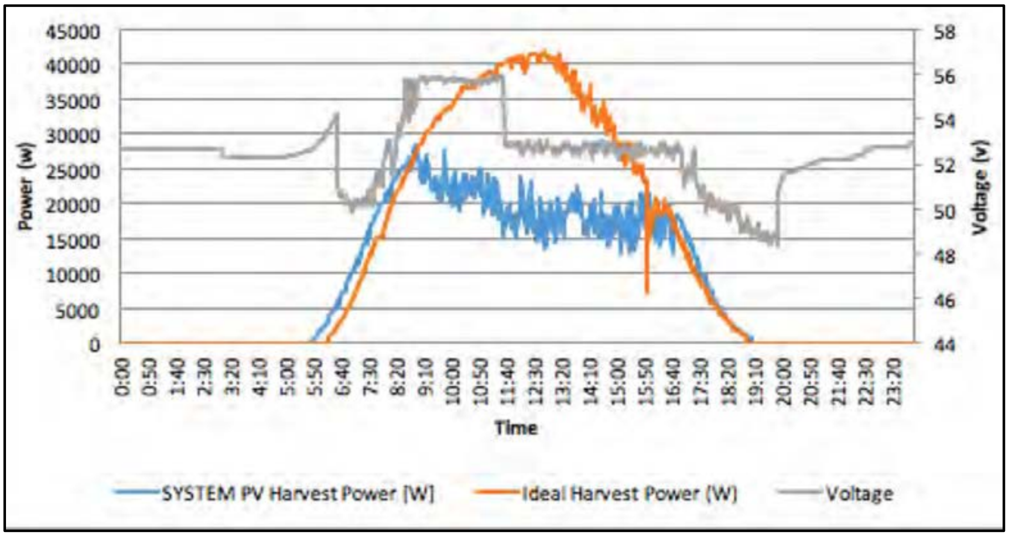


Figure 2: June 30th 2016 PV Harvest Power versus Ideal Harvest Power graph from the 2016 SEI Report

1.5.2 Actual Daily PV Power Output

The real PV output curve was drawn for the span of a full sunny day (Figure 3), and therefore the area beneath the curve represents the amount of energy that is commonly generated by solar power in a day. By the method of Riemman sum, interns found this value to be 237.84 kWh for a sunny day. The sudden decrease at around 10AM is because once the batteries are close to fully charged and the load is not demanding a large amount of energy, the solar PV output decreases and the panels are not used at their full potential.

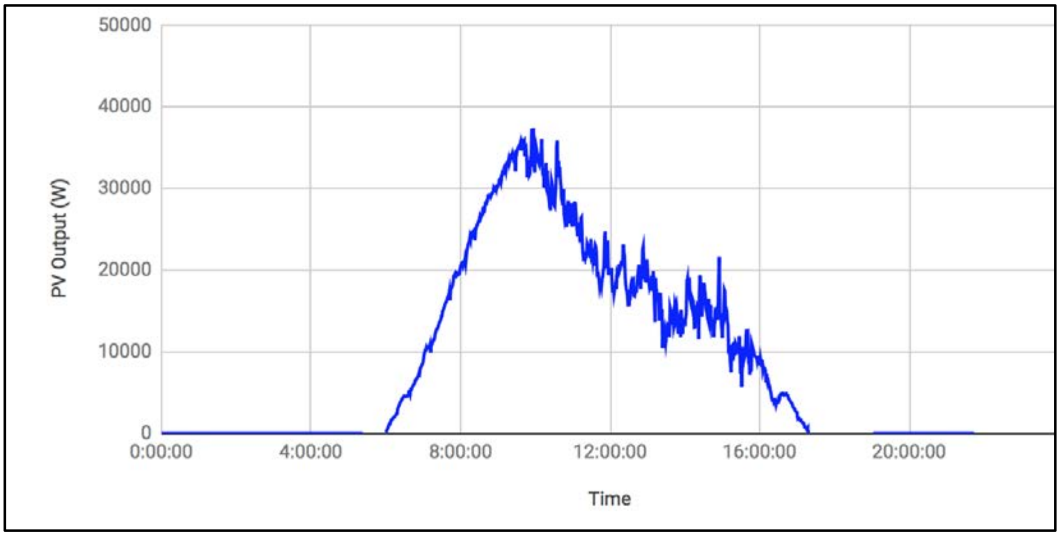


Figure 3: Graph of Real PV Output versus Time on a Sunny Day (June 23rd 2019)

1.5.3 Excess Energy

The difference between the ideal and real PV power (approximate area between red and blue curves in Figure 4) was found to be 68.5 kWh for a sunny day.

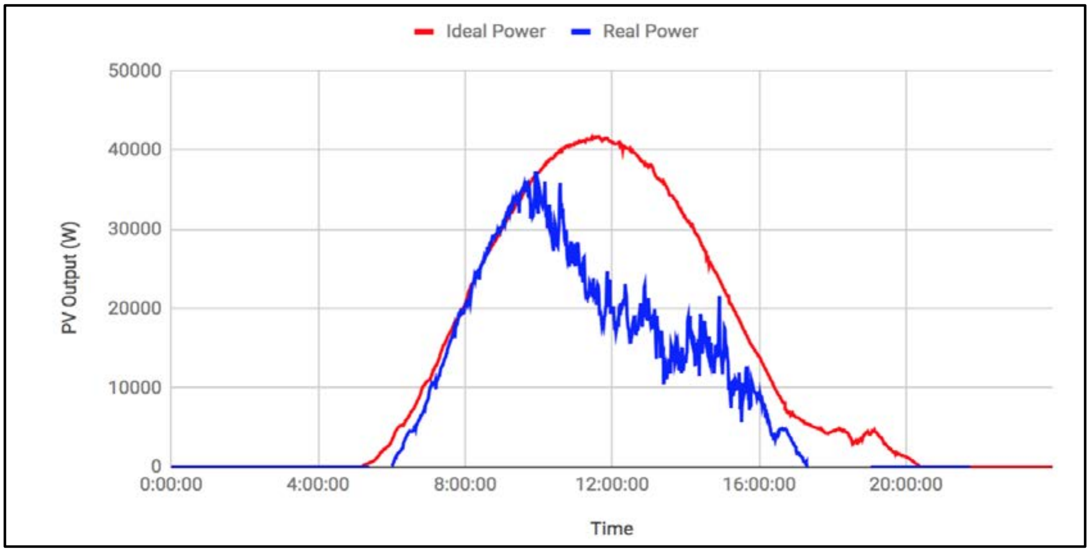


Figure 4: Graph of Ideal and Real PV Output versus Time on a Sunny Day (June 23rd 2019)

Graphs of ideal and real output for other different weather conditions (mostly sunny, mostly cloudy, cloudy, rainy) were also plotted and can be found in the Appendix.

DAYS (2019)	Weather conditions	Ideal kWh	Real kWh	Excess kWh
06/23	Sunny	306.34	237.84	68.50
07/01	Mostly Sunny	291.24	198.58	92.65
07/10	Mostly Cloudy	280.21	245.32	34.89
06/26	Mostly Cloudy	234.05	197.01	37.05
06/25	Cloudy	110.23	125.45	0
06/20	Rainy	44.87	58.01	0

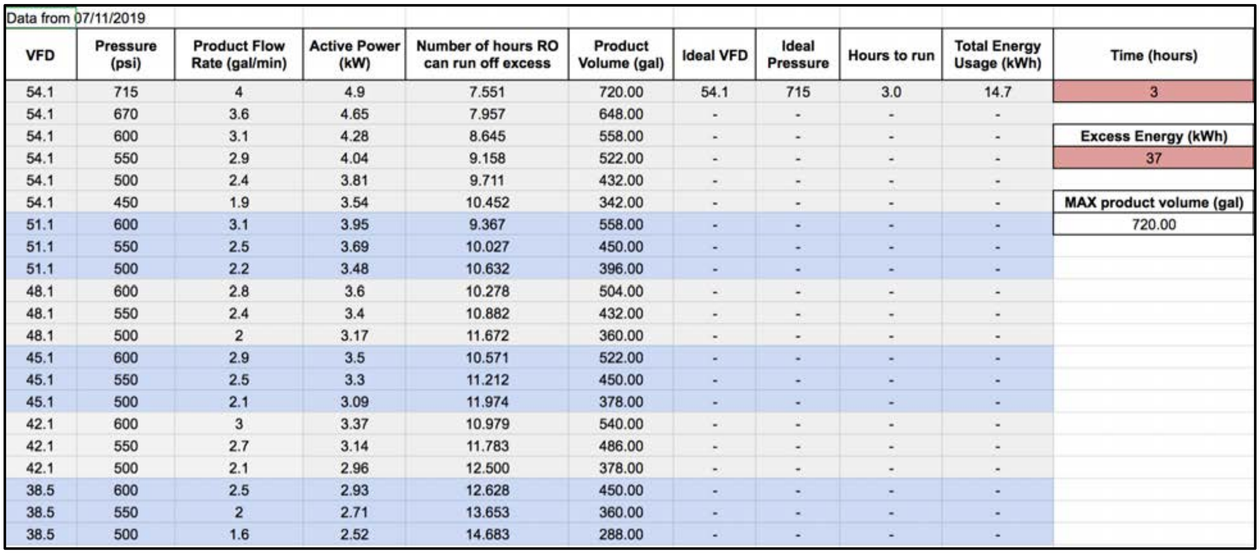
Table 1: Summary of Daily Ideal, Real and Excess Energy Values for different Weather Conditions

Table 1 summarizes key findings and shows days ranging from sunny to mostly cloudy in which excess energy can be utilized. This excess energy is limited not only by weather conditions but also by the island demand which controls the real PV harvest power. For example, June 23rd was a very sunny day and produced 68.5 kWh of excess energy while July 1st was only mostly sunny but produced 92.65 kWh of excess energy. While July 1st had lower solar irradiance, there was a lower island energy demand so there was a larger excess energy available.

1.5.4 RO Energy Demand

The interns determined that for any given number of hours and amount of excess energy to be used, the RO generates the most fresh product water if it is run at a VFD of 54.1 and a pressure of 715 psi.

An excel calculator compiling the data from the different RO setting combinations was created. This allows to input the excess energy engineers expect to have on a given day according to weather predictions and the number of hours they expect to have strong sunlight to automatically calculate the product output for each setting combination.



Data from 07/11/2019

VFD	Pressure (psi)	Product Flow Rate (gal/min)	Active Power (kW)	Number of hours RO can run off excess	Product Volume (gal)	Ideal VFD	Ideal Pressure	Hours to run	Total Energy Usage (kWh)	Time (hours)
54.1	715	4	4.9	7.551	720.00	54.1	715	3.0	14.7	3
54.1	670	3.6	4.65	7.957	648.00	-	-	-	-	
54.1	600	3.1	4.28	8.645	558.00	-	-	-	-	**Excess Energy (kWh)**
54.1	550	2.9	4.04	9.158	522.00	-	-	-	-	37
54.1	500	2.4	3.81	9.711	432.00	-	-	-	-	
54.1	450	1.9	3.54	10.452	342.00	-	-	-	-	**MAX product volume (gal)**
51.1	600	3.1	3.95	9.367	558.00	-	-	-	-	720.00
51.1	550	2.5	3.69	10.027	450.00	-	-	-	-	
51.1	500	2.2	3.48	10.632	396.00	-	-	-	-	
48.1	600	2.8	3.6	10.278	504.00	-	-	-	-	
48.1	550	2.4	3.4	10.882	432.00	-	-	-	-	
48.1	500	2	3.17	11.672	360.00	-	-	-	-	
45.1	600	2.9	3.5	10.571	522.00	-	-	-	-	
45.1	550	2.5	3.3	11.212	450.00	-	-	-	-	
45.1	500	2.1	3.09	11.974	378.00	-	-	-	-	
42.1	600	3	3.37	10.979	540.00	-	-	-	-	
42.1	550	2.7	3.14	11.783	486.00	-	-	-	-	
42.1	500	2.1	2.96	12.500	378.00	-	-	-	-	
38.5	600	2.5	2.93	12.628	450.00	-	-	-	-	
38.5	550	2	2.71	13.653	360.00	-	-	-	-	
38.5	500	1.6	2.52	14.683	288.00	-	-	-	-	

Table 2: Excel Calculator of Product Volumes for Different RO VFD and Pressure Setting Combinations

For example, as seen in Table 2, if the amount of daily excess solar energy available is 37 kWh and the maximum number of hours we can run the RO is 3, the calculator outputs that the maximum product volume will be of 720 gallons if the RO is set to 54.1 VFD and 715 psi and run for 3 hours.

1.5.5. Battery State of Charge

State of charge data for July 10th was collected and plotted for the full mostly cloudy day. It revealed that despite running the RO for 5 hours from 10 AM to 3 PM at the previously determined optimal setting, the batteries were still able to reach their maximum state of charge (100%) at 1:45 PM. In Figure 5, interns overlaid the plot of state of charge for this day with a normal sunny day (June 23rd 2019) when the RO was not run. On June 23rd, the maximum state of charge was attained only about an hour earlier, at 12:35 PM.

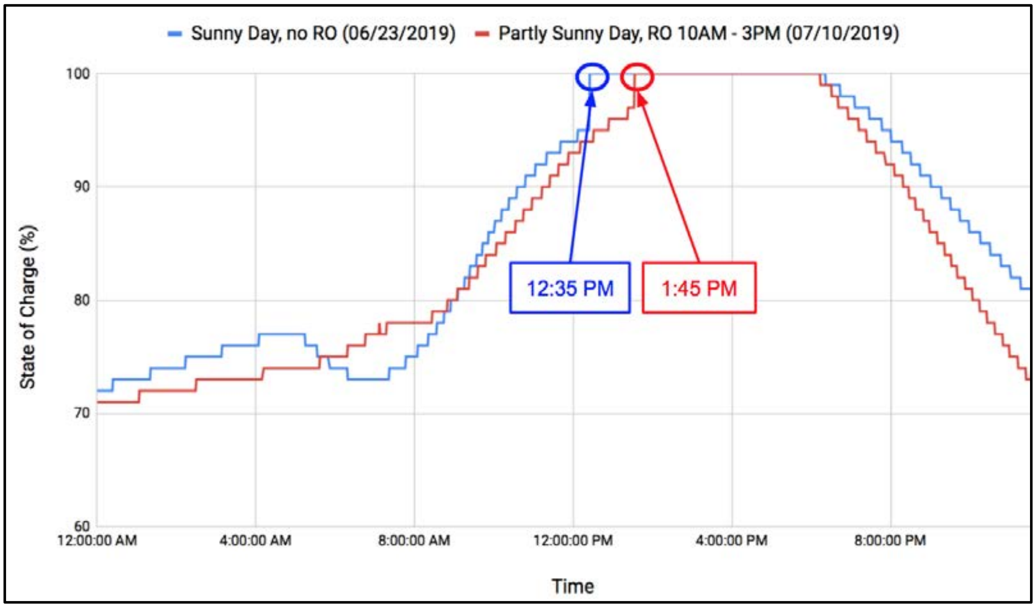


Figure 5: Battery State of Charge Levels over time on June 23rd and July 10th 2019

The result is promising as it shows that even on a mostly cloudy day, the RO can be run for up to 5 hours without preventing the batteries from reaching their maximum state of charge. Figure 6 overlays the state of charge plot with plots of ideal and real power, confirming that running the RO for those hours would allow to be within the excess energy range of time while still reaching the maximum state of charge.

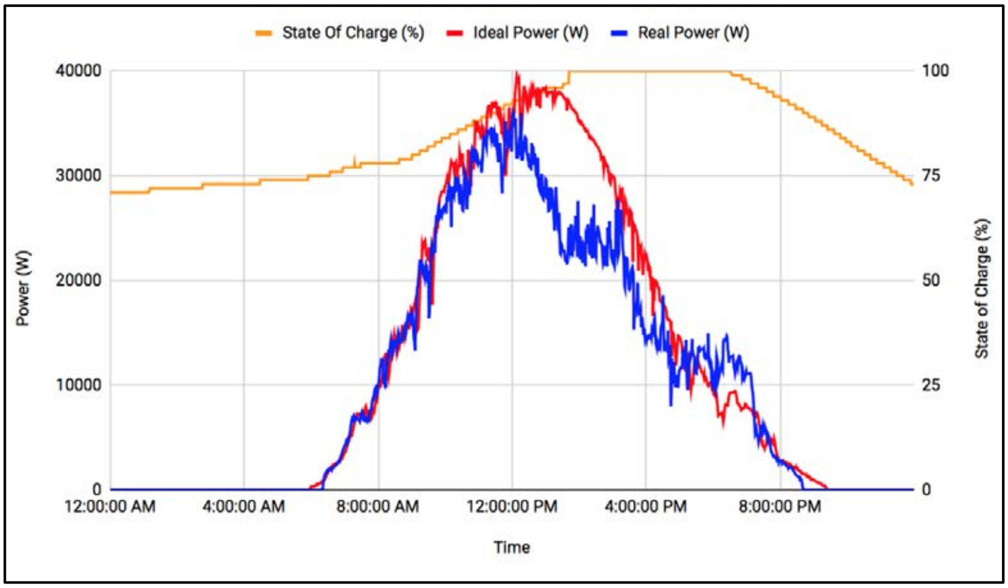


Figure 6: State of Charge, Ideal Power, and Real Power over Time on a Mostly Cloudy Day (July 10th 2019)

Graphs of daily state of charge over time for other different weather conditions (mostly sunny, mostly cloudy, cloudy, rainy) were also plotted and can be found in the Appendix.

1.6 Conclusions and Recommendations

The new Reverse Osmosis machine will be a powerful tool in supplementing the drinking water from the well on Appledore island. Since it is a very energy efficient machine, if it is run at adequate settings, in the proper conditions, and at the right times, Shoals Engineers will be able to significantly increase their freshwater resource solely off excess solar energy. From the above analysis, interns came up with a list of recommendations on how to use the RO machine in a way that maximizes its product water output but also ensures it runs only on excess green energy.

Weather Forecast	Run RO?	Time Frame	Product Volume (gallons)	Excess Energy (kWh)
Sunny	Yes	10 AM - 3 PM	1,200	68.51
Mostly Sunny	Yes	10 AM - 3 PM	1,200	92.51
Mostly Cloudy	Maybe	12 AM - 3 PM	720	37.05
Cloudy	No	-	-	0
Rainy	No	-	-	0

Table 3: RO Use Recommendations According to Weather and Run Time For Recommended Optimal Settings

Table 3 shows the recommended run times and associated maximum product volume. For example, it’s recommended to run the RO from 10 AM to 3 PM on a sunny day which produces 1,200 gallons of freshwater. The time frame from 10 AM to 3 PM is suggested since the real PV harvest power tends to be overtaken by the ideal power around 9 AM to 10 AM. On more cloudy days, the proposed time frame is not only shortened to 3 hours but also pushed back to 12 PM to 3 PM. This shift is suggested since with more cloud cover, the batteries take longer to charge to their absorption state. Interns do not recommend running the RO machine on cloudy or rainy days as data supports that there is usually no solar excess energy on those days.

Furthermore, the table shows the maximum product output given certain run times. These values were calculated using the ideal 54.1 VFD and 715 psi settings. The interns do not necessarily recommend using these settings all the time since there is not a huge demand for water on a daily basis. Instead, the interns suggest that the island engineers use the excel spreadsheet to input excess energy and run times for a given day and then select a certain combination of settings to produce a determined amount of product volume.

Interns also recommend for engineers and future interns to keep collecting ideal versus real PV output data for a broader range of days and weather conditions. The data analysis done by interns was time limited and therefore only one daily excess energy value was calculated per type of weather condition. Gathering more data and computing more excess energy values would allow to confirm these findings as well as to refine RO run time recommendations.

1.7 References

Chen, David, et al. "Sustainable Engineering Internship." *Shoals Marine Laboratory*, 18 July 2016, www.shoalsmarinelaboratory.org/sites/shoalsmarinelaboratory.org/files/media/pdf/SEIReports/sei_2016_final_report1_reduced.pdf.

Conext Combox: http://10.50.0.47/login.html.

Assignment 2 - Saltwater Temperature Profile

Lead Interns: Colleen Tobin and Valentine Starnes

2.1 Background

SML pumps and distributes saltwater 24/7 throughout the island. Saltwater is pumped from the ocean to supply sea tables, saltwater spigots and faucets, a reverse osmosis unit, and the fire hoses. The saltwater intake is secured to the ocean floor about 10-20 feet deep (varying with the tide) and pumped through exposed black polyethylene pipe run along the ground to each building. The sea tables are operated continuously to supply salt water at a constant temperature and to supply oxygen for the flora and fauna in the sea tables. It has been brought to the engineering staff's attention the water in the sea tables may be too warm at times.

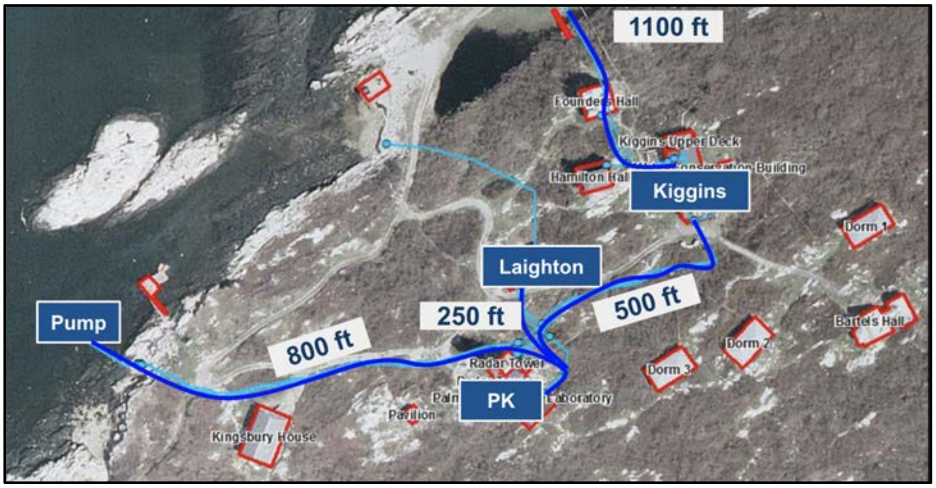


Figure 7: Seawater Path

2.2 Purpose

Some faculty members have suggested that the water is too warm for the aquatic life and that the organisms are showing signs of fatigue and are even dying. Interns are tasked with determining the water temperature and dissolved oxygen levels of the sea tables to see if they are habitable.

2.3 Scope

The interns must determine if the various seatables are too warm and if the dissolved oxygen levels are acceptable. If the temperature and dissolved oxygen levels are not within an acceptable range, the interns will recommend solutions.

2.4 Methods

2.4.1 Acceptable Water Temperatures and Dissolved Oxygen for Aquatic Life

To determine if the water temperature of the sea tables were too warm, an analysis of acceptable ranges for various aquatic life was completed. The general water for the aquatic life used on the island for tests has a temperature range of 55°F - 71.6°F. It was found that some of the aquatic life, specifically the fish start to die when dissolved oxygen drops below 2 mg/L. This will be the overall minimum allowable dissolved oxygen. The given ranges for the dissolved oxygen is the range at which they are most productive. The aquatic creatures can survive in higher dissolved oxygen.

Organism	Temperature	Dissolved Oxygen
Algae	Min 60.8°F	7 mg/L - 15 mg/L
Crab	60°F - 75°F	1.3 mg/L - 8 mg/L
Fish	Min 55°F	4 mg/L - 12 mg/L
Mussels	55°F - 68°F	1 mg/L - 6 mg/L
Small Shark	59°F - 86°F	2 mg/L - 10 mg/L
Snail	65°F - 82°F	2 mg/L - 8 mg/L
Worms	59°F - 86°F	Min 2mg/L
Soft Coral	64°F - 84°F	7 mg/L - 15 mg/L
Starfish	Max 78°F	4 mg/L - 12 mg/L
Lobster	59°F - 77°F	8 mg/L
Cod	30°F - 68°F	4 mg/L - 12 mg/L
Hagfish	Max 71.6°F	4 mg/L - 12 mg/L

Table 4: Acceptable Temperatures and Dissolved Oxygen for Aquatic Life

2.4.2 Water Temperature Loggers

Four temperature loggers were used, three in the seatables and one on the pump intake. Data was collected from the loggers for two weeks, June 20 to July 3. The loggers were attached to rocks with notes requesting that they not be moved. The temperature loggers would continuously record data from their locations. The data was analyzed over 14 hours in two hour blocks from 7:00 to 21:00. The data was analyzed using HOBOware and Microsoft Excel.

2.4.3 Dissolved Oxygen Probe

Originally, dissolved oxygen was going to be recorded every two hours similar to the water temperature. After discussion with staff, a test was completed to see if that was necessary. It was found that the dissolved oxygen did not vary greatly in two hour segments. It was decided that dissolved oxygen levels would be taken four times a day in four hour intervals, 8:00, 12:00, 16:00 and 20:00, instead. The dissolved oxygen levels for the pump intake would be recorded from the dock. A boat would have been necessary to reach the pump intake. To prevent complications, such as adverse weather and boat availability, the measurement location was moved.

Time	DO
9:00	11.08 mg/L
11:00	10.7 mg/L
13:00	11.2 mg/L
15:00	10.66 mg/L
17:00	10.65 mg/L
19:00	10.75 mg/L

Table 5: Initial Dissolved Oxygen Test

2.4.4 Distances

Originally, the pipe lengths were to be measured manually. During measuring, the interns were dive-bowed by multiple seagulls since the seagulls had created nests next to the pipes. Due to the timing of the chicks hatching, the interns looked into a different method to determine pipe lengths. The interns ended up using a map to approximate the lengths. An inch to foot conversion was used to determine general lengths of the pipes.

Location	Length
Pump to Palmer - Kinne	800 ft
Pump to Kiggins	1100 ft
Pump to Reverse Osmosis	1750 ft
Palmer - Kinne to Laighton	250 ft
Palmer - Kinne to Kiggins	500 ft

Table 6: Pipe Lengths

2.4.5 Historic Reverse Osmosis Data

The data collected during 2019 only shows the water temperature distribution during the cooler months of the summer. Historic reverse osmosis data was used to compile a water temperature distribution during the warmer months of the summer over a span of eleven years. The reverse osmosis machine, located in the Grass Lab, is farthest from the pump. This gives the seawater in the back pipes the most time to heat up.

2.4.6 Tidal Heights

It was suggested that tidal heights may have an effect on the water temperature and dissolved oxygen levels. High and low tides from Gosport Harbor, New Hampshire were used. The island staff recommend Gosport Harbor as they use it for other activities on the island. The website US Harbors was used to determine the high and low tides throughout the day. The National Oceanic and Atmospheric Administration's Tide predictions site was used to compile a graph of the tidal heights throughout the two week period.

2.4.7 Air Temperature

Air temperature was collected for the Isle of Shoals from the National Oceanic and Atmospheric Administration. Air temperature was collected under the same two hour blocks and time duration, 7:00 to 21:00, as the water temperature.

2.4.8 Reduced Retention Time

A test was conducted in the Palmer - Kinne North seatable to see if reducing the hydraulic retention time will decrease the water temperature. The theory is that reducing the amount of time the water is in the tank will reduce the water temperature since it will have less time to heat up. The hydraulic retention time during the initial test was 23.1 minutes. The hydraulic retention time was reduced to 11.21 minutes for this test. The average water temperature from Palmer - Kinne South was used as a comparison.

2.4.9 Fan Tests

A standard box fan was placed by the Palmer-Kinne North seatable to see if it was able to cool the water to an acceptable temperature. The standard box fan was used for two days. The standard box fan was placed next to the seatable on a raised platform. The standard box fan was set to medium for the first day. On the second day the fan speed was increased to high. A standing fan was going to be used. However, it was broken. Palmer-Kinne South seatable was used for a comparison. This test was to see if a removable fan, that was designed for aquatic creatures like axolotls, was a suitable way to reduce the water temperature on warmer days.

2.5 Results and Analysis

2.5.1 Water Temperature

The water temperature rose during the day, as expected. Once the sun was gone, the water temperature began to decrease. The range that was deemed acceptable for the aquatic life was 55°F - 71.6°F. The average water temperatures did stay within this range. Some of the seatables were close to 70°F on the hotter days. However, there are some aquatic life, such as hagfish, that need colder temperatures.

Below are the average water temperatures at the various seatables and the intake pump from June 20 to July 3.

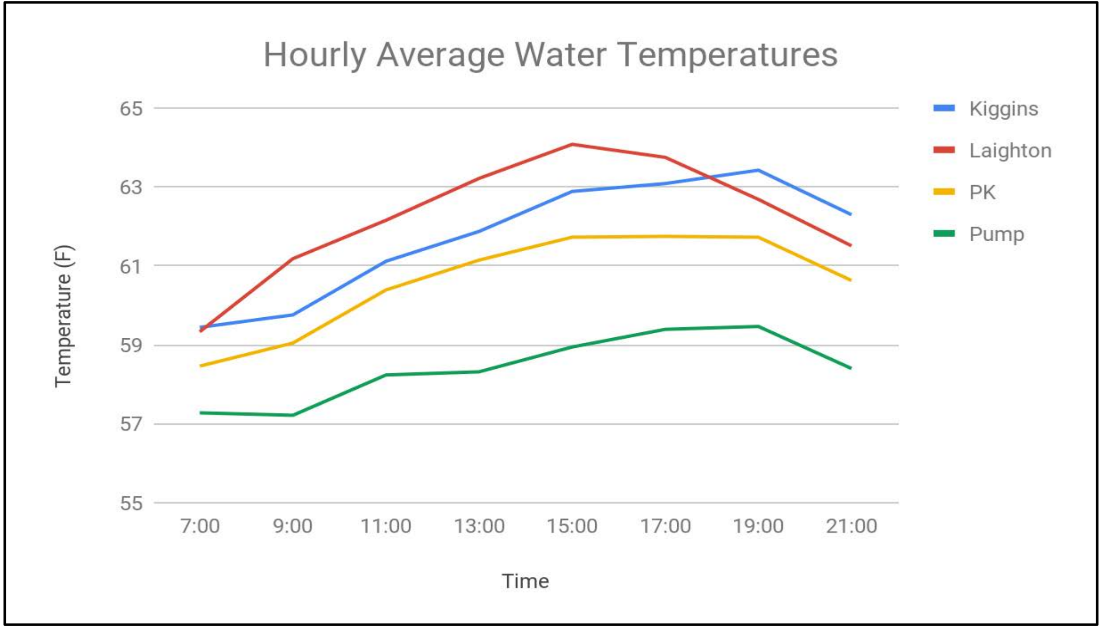


Figure 8: Average Hourly Water Temperature for the 2 Week Period

The graph above shows that on average, all the seatables and pump stayed within the acceptable range of 55-71.6 °F during the course of one day. The logger by the pump had the lowest temperatures as expected since the ocean has a much larger volume. On the other hand, the Laighton and Kiggins tables had the highest temperatures. We noticed that these were the tables that the biologists tended to change the inflow and outflow more often.

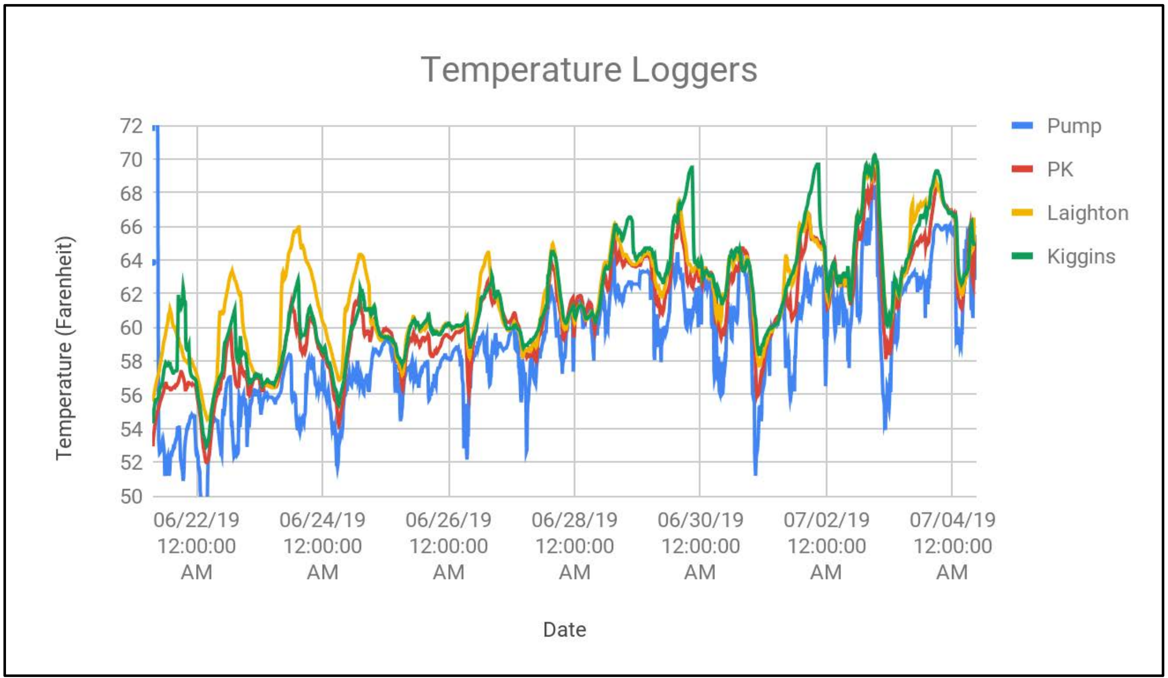


Figure 9: Water Temperature for the 2 Week Period

The temperature loggers in each of the seatables and at the ocean pump were also plotted for the entire 2 week period at 10 minute intervals. Overall, there is a clear increasing trend from June to July. The graph also shows that most of the data stays within the acceptable temperature range of 55 - 71.6 °F. However, on exceptionally hot days, the tables and sometimes the ocean did get up to around 70 °F. Extrapolating into August, we would expect there to be more hot days where the tables could bypass the maximum temperature.

On June 29th, the graph shows a spike in temperature for especially the Kiggins tank. The ocean rose to 64°F while Kiggins reached 68°F. The interns noticed that the nozzles in the Kiggins tank had been turned off for the majority of the day. Based off this difference between the ocean and the Kiggins, the interns hypothesize that the biologists decreasing the flow rates into and out of the tables would have 3-4°F impact on the temperature.

On July 2nd, there was also a noticeable jump in temperature for both the ocean and the seatables. The ocean reached 68°F while the Kiggins tank got up to 70°F. On this day, there was a constant high flow into all the seatables. The interns hypothesize that since the source of the saltwater at the pump itself is getting very warm, there will need to be solutions for lowering the temperature at the pump.

2.5.2 Dissolved Oxygen

The minimum dissolved oxygen level for all of the organisms in the tables was determined to be 2 mg/L. Shown in the graph below, the dissolved oxygen levels at the seatables and the dock are well above 2mg/L. The graph shows the average dissolved oxygen levels at the various seatables and the intake pump from June 20 to July 3.

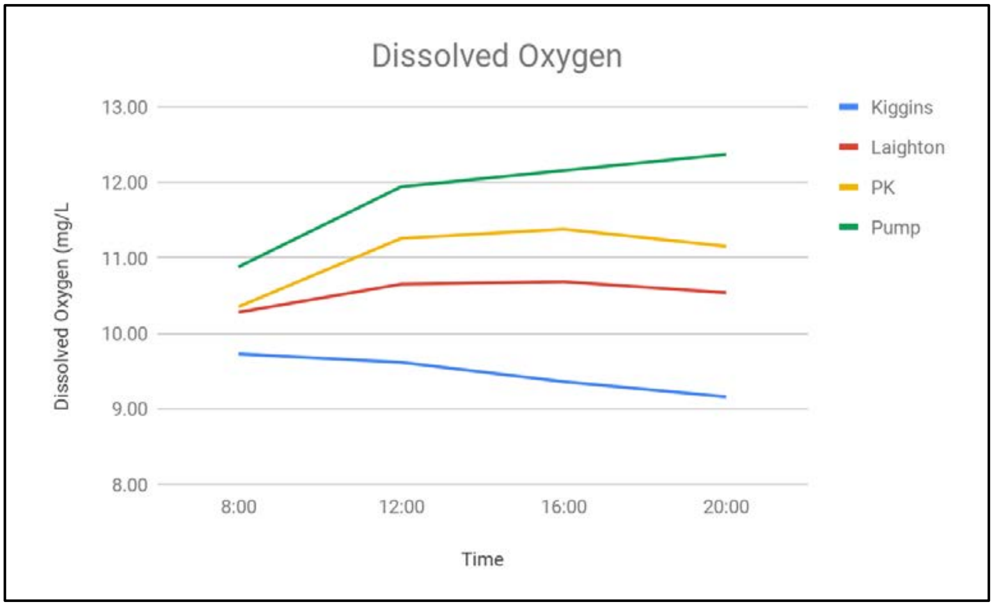


Figure 10: Average Dissolved Oxygen Levels for the 2 Week Period

It was important that DO levels stayed above 2 mg/L since the fish would start to die after that level. The pump had the highest dissolved oxygen levels compared to all the seatables. This was expected since there is much more reaeration due to the mixing from waves as well as colder temperatures as seen previously. From the graph, the pump data showed a slight increase of dissolved oxygen throughout the day. Since the ships arrive in the afternoon and the ships' propellers can increase the amount of dissolved oxygen in the water from reaeration, this could explain the increase in dissolved oxygen. The Kiggins seatable that was selected for the test was routinely shut off for hours at a time. The inlets were shut off multiple times during the afternoon to clean the top tables. For the bottom tables, since the water had higher retention times, those tables had more time to heat up and decrease the dissolved oxygen.

2.5.3 Historic Reverse Osmosis Data

The water inlet temperatures for 11 years are shown in Figure 11. Temperatures generally stayed between 50°F and 70°F. There were some days that went above 70°F. For the most part the water temperature was clustered around 60°F. The aquatic life in the sea tables require water temperatures to be between 55°F and 71.6°F. The water temperatures for the warmer months appear to be within the acceptable range.

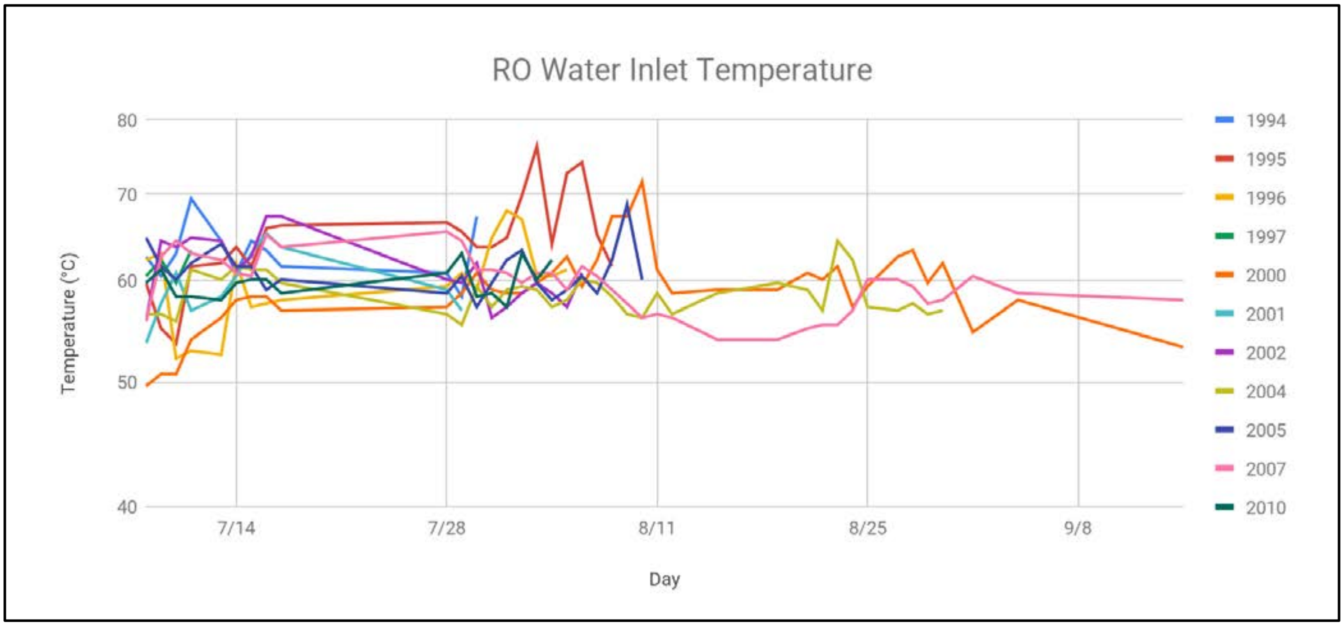


Figure 11: Reverse Osmosis Inlet Water Temperature

2.5.4 Tidal Heights

Tidal heights were approximated to 8:00, 12:00, 16:00, and 20:00 to correspond with the times that dissolved oxygen levels were recorded. High and low tides did not significantly change over the two week testing period. High tide was between 7.7 ft and 9.9 ft. Low tide was between -0.5 ft and 1.6 ft.

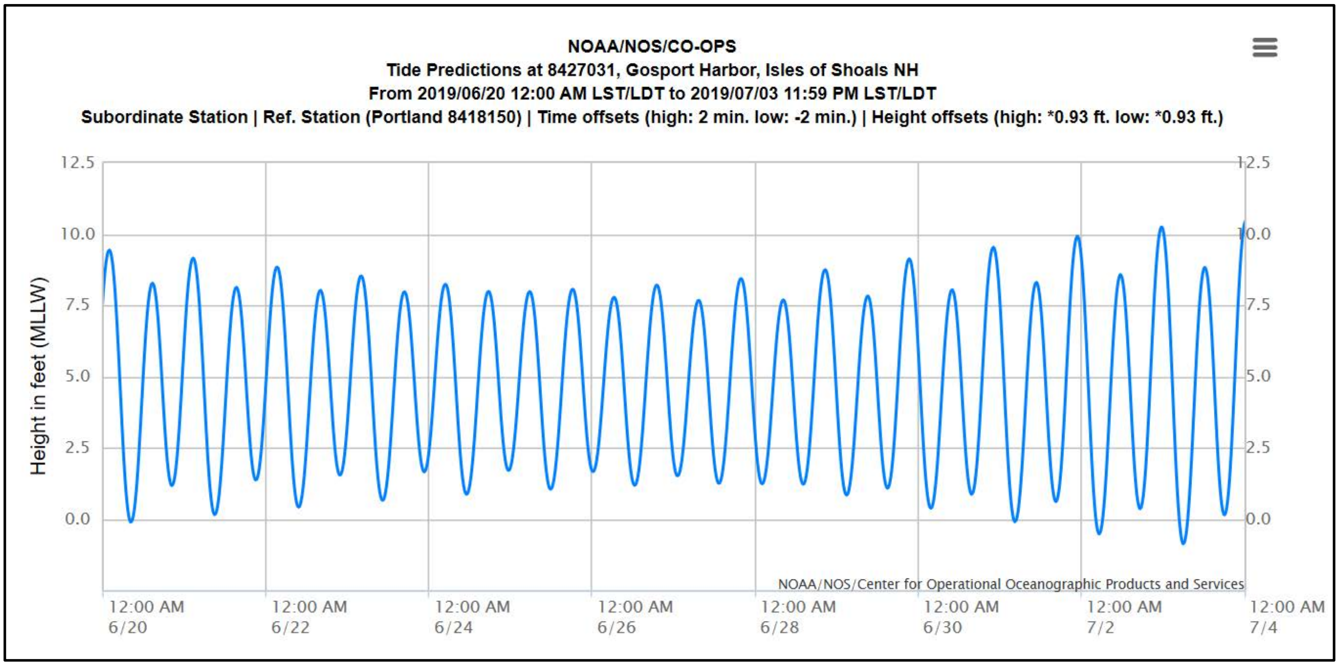


Figure 12: Tidal Heights from 6/20 to 7/3

Comparing the tidal heights to the temperature data for the 2 week period showed a correlation between low tide and higher water temperatures. Lower tide would correspond to higher temperatures since the sun can heat up water from a lower depth where the pump is pulling water from. Conversely, at high tide the sun can only heat up higher depths so the inflow from the pump has colder temperatures.

2.5.5 Air Temperature

During the duration of the test, the weather had been getting warmer. The water temperature is on average 10 degrees cooler than the air temperature. Below is the average air temperature from the National Oceanic and Atmospheric Association for the Isles of Shoals from June 20 to July 3.

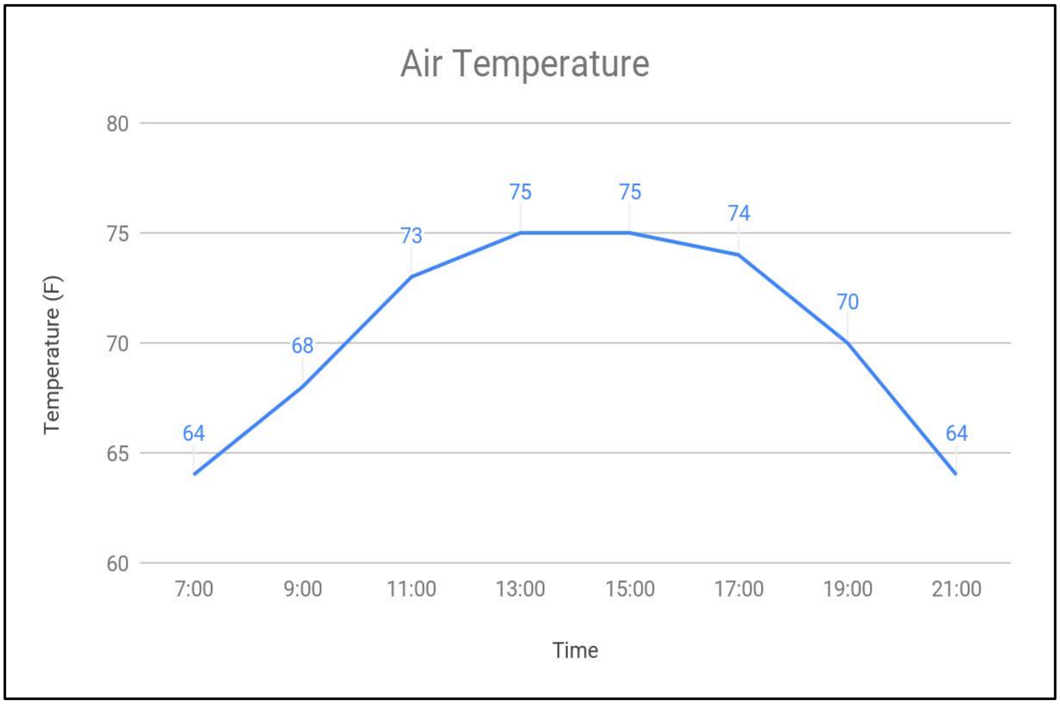


Figure 13: Average Air Temperatures for the 2 Week Period

2.5.6 Reduced Retention Time

PK South seatable was the original flow while the PK North seatable was set at a double flow. This increased flow was used to reduce the retention time in the seatable. There was about a 2-3°F difference between the two seatables' water temperatures.

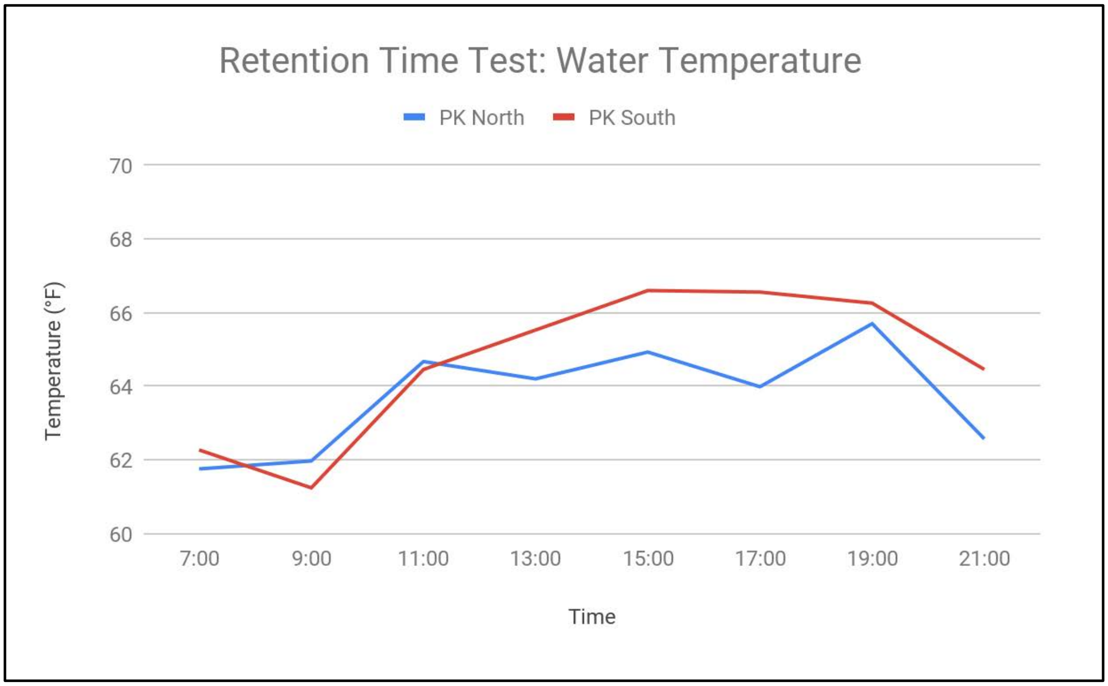


Figure 14: Water Temperature for Retention Time Test

2.5.7 Fan Test

Once again, PK South seatable was used as a control to see if the fans were able to reduce the water temperature. There was no discernible difference between the PK North seatable and PK South seatable when the standard box fan was set to high. There was a difference between the water temperatures when the standard box fan was set to medium. There was a few degree difference between the seatables. A more powerful fan may be able to further reduce the water temperature.

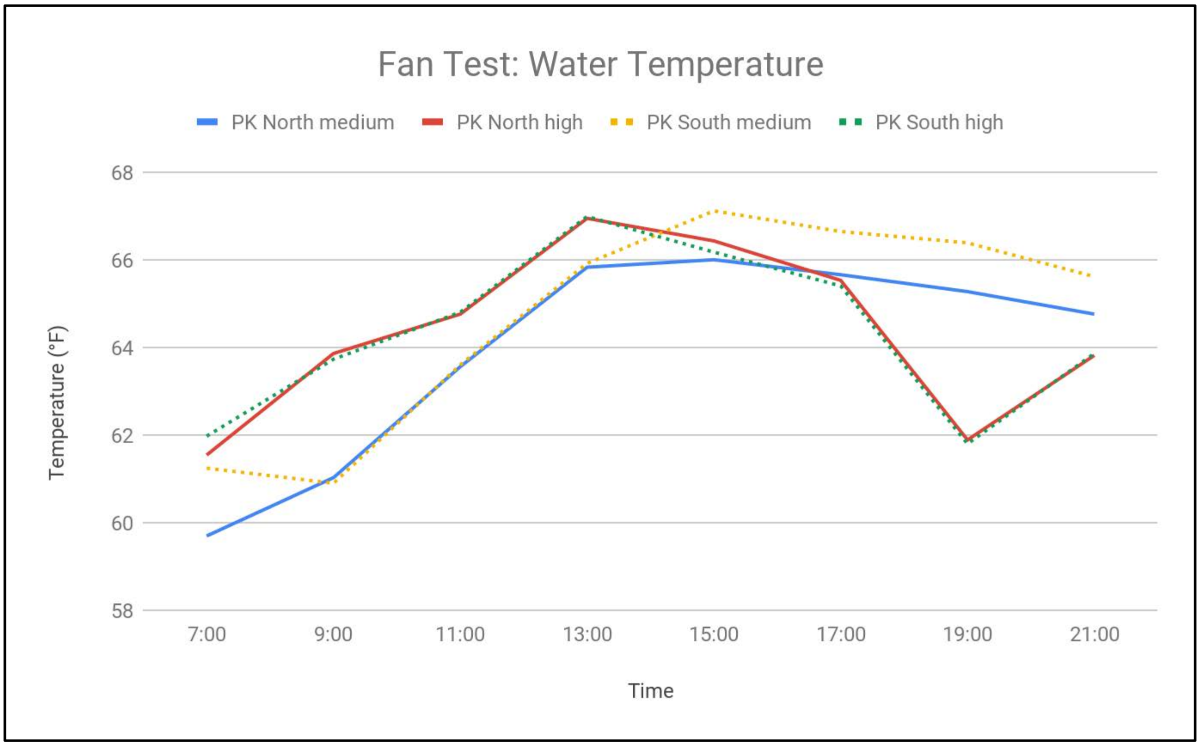


Figure 15: Water Temperature for Fan Test

2.6 Conclusions and Recommendations

The dissolved oxygen levels are well above the 2 mg/L threshold. High and low tides do not appear to have an effect on the DO levels. DO levels do not need to be adjusted. Currently, the water temperatures are within the acceptable range, 55°F - 71.6°F. Since the data was collected for only a 2 week period from June to July we would expect the weather to get warmer into August. The water temperatures for the seatables has also been increasing during the duration of the test. One day the Kiggins seatable reached 70°F. The water may become too warm for some of the aquatic life, like hagfish, that prefer colder temperatures.

One solution would be to draw cooler water. If the water is drawn from a lower point in the ocean, it will be cooler than the system's current inlet water temperature. This allows for a larger allowance for the water to heat up. The current intake pump is located around 15 feet below surface level. It is recommended to move the intake pump lower.

There is currently a seatable designed for aquatic creatures like hagfish that need colder temperatures. Replacing the current seatables or installing insulation to the current seatables can help to reduce the water temperature.

The seatables below Kiggins Commons are receiving a large amount of sunlight. Some of the undergraduate researchers have put up boards around their seatables to minimize sunlight exposure. A tarp can be placed around the bottom of the deck to minimize sunlight exposure. The seatables in Kiggins and Laighton are outside compared to the Palmer - Kinne seatables that are inside. This allows the Laighton and Kiggins seatables to have ventilation. Opening the windows can help increase the ventilation in Palmer - Kinne. There is an issue with opening the door since the seagulls have eaten the students' experiments in the past. The exposed black pipe heating up the water is a concern. The pipes will hold the heat for a few hours after the sun has set. It would be beneficial to look into a reflective cover. This will help to prevent the water from heating up in the pipes.

Reducing the retention time for the seatables can help to reduce the water temperature. This solution can be used on a case by case basis. The flow needed in each seatable is highly variable and depends on the needs of the aquatic life in the seatable.

A temporary fix that can work is installing fans. The fan test was able to drop the water temperature a few degrees. The fan used was not designed to cool items like seatables. In Figure 16, the aquarium fan was designed for cold water creatures like axolotl. The fan is advertised that it can lower the water temperature by 2 - 3°C. A more powerful fan, than a standard box fan, or a fan designed for aquatic life is recommended as a temporary fix to the warming seatables.

Figure 16: Aquarium Fan

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Assignment 3 - Refrigeration Evaluation/Recommendations/Monitoring

Lead Interns: Colleen Tobin and Marguerite Lorenzo

3.1 Background

SML’s commercial kitchen is equipped with a walk-in refrigerator and freezer to keep weekly food supplies fresh. Based on 2018 SEI analysis, SML plans to upgrade the 35+ year old system with newer compressors, evaporators, insulation etc.

3.2 Purpose

The walk in refrigerator and freezer were installed in the 1970s. The new compressors, evaporators, insulation, etc. will be installed before the 2020 season. Interns were tasked with determining the power usage of the system that will then be compared with the 2018 data.

3.3 Scope

The interns were tasked with analyzing how the energy consumption for the refrigeration system for 2019 compares with the data the 2018 SEIs collected.

3.4 Methods

The energy intake from compressor and fan components of the refrigeration system (fridge and freezer) were measured by Ross Hansen with the Fluke Energy Logger over one week intervals from 5/23/2019 to 6/20/2019.

This year, interns decided to also record the Apparent Power of the different refrigeration unit parts per the recommendation of Justin Ulrich, Electrical Engineer from Unitil. The 2018 interns only provide Active Power values (in kWh) in their report, but the Apparent Power values (in kVAh) allow to have a more accurate picture of the energy that is actually drawn by the system components.

3.5 Results and Analysis

3.5.1 2019 Data

The relevant 2019 data entries from Fridge and Freezer measurements are presented in Table 7. The significant differences between active and apparent power are due to the poor power factors of the refrigeration units, since they are outdated and based off running a motor.

		Apparent Energy (kVA / day)	**Active Energy (kWh / day)**	**Measurement Dates**
Fridge	**Compressor**	17.4	4.99	5/30-06/06
	Fans	12.79	8.43	06/06-06/13
	Total	30.19	13.42	
Freezer	**Compressor**	24.24	10.51	05/23-05-30
	Fans	13.87	1.27	07/08-07/10
	Total	38.18	11.78	

Table 7: 2019 Fridge and Freezer Daily Energy Consumption

The Fluke Energy Logger automatically generates instantaneous active power (in kW) plots over different intervals. Interns decided to include a time frame of an hour and a full day for the Fridge

Compressor (for completeness, the equivalent plots for the Freezer Compressor were included in the Appendix). This graphing reveals the high variability of the energy intake of the Refrigeration Unit, and shows that it is constantly self regulating temperature by turning itself on and off.

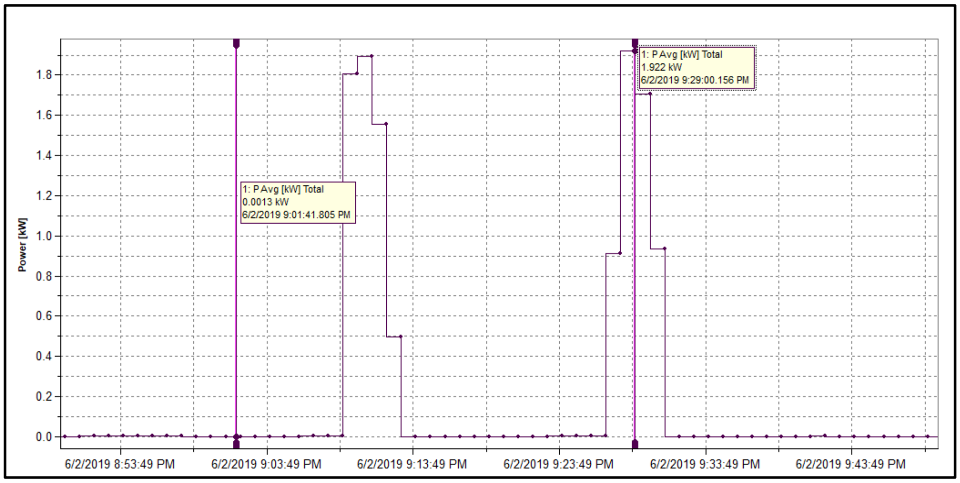

Figure 17: 2019 Graph of Power Supply to the Fridge Compressor Over One hour

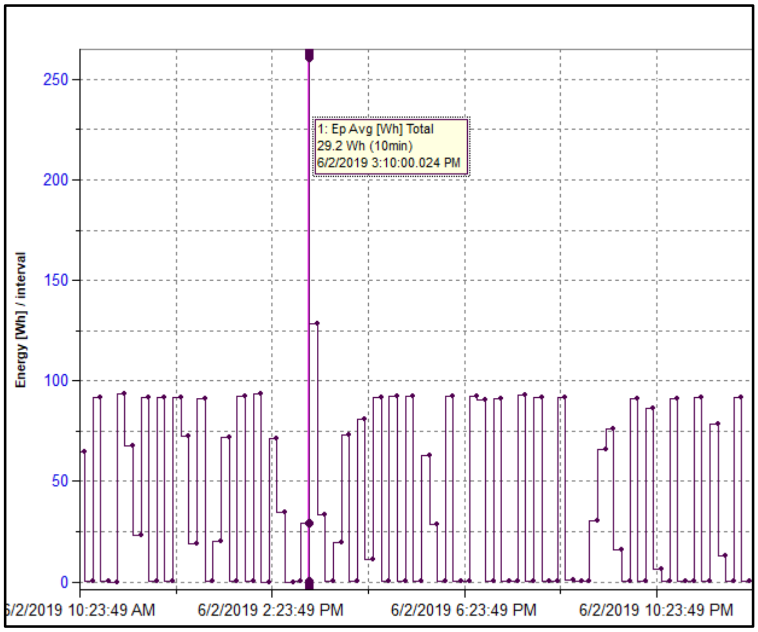

Figure 18: 2019 Graph of Energy Consumption of the Fridge Compressor Over 14 Hours

3.5.2 2018 Data

Below is the data compiled by the 2018 interns, included for comparison purposes.

		Active Energy (kWh / day)	Measurement Dates
Fridge	**Compressor**	11.14	06/05 - 06/12
	Fans	12.70	06/19 - 06/25
	Total	23.84	
Freezer	**Compressor**	10.88	05/25 - 06/01
	Fans	1.93	06/12 - 06/19
	Total	12.81	

Table 8: 2018 Fridge and Freezer Daily Energy Consumption

The energy consumption by the fridge fans was an underestimate because only 2 of the 3 fans were functional (the third fan appeared to be stuck and unable to rotate). The 2018 SEIs also plotted the fridge compressor energy intake over a span of 14 hours.

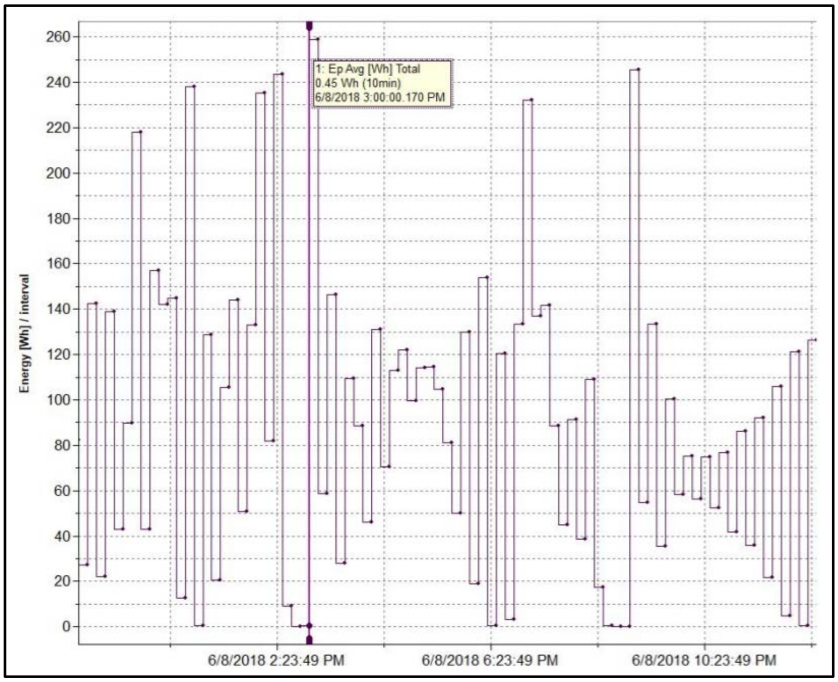

Figure 19: 2018 Graph of Energy Consumption of the Fridge Compressor over 14 Hours

3.5.3 Comparison

For all of the components of the refrigeration system, the energy intake in kWh has decreased since 2018 (negative difference value in Table 9). This pattern was expected as some improvements were made to the system since the summer of 2018 (walk-in fan was fixed, door insulation was improved), which explains that it would be more energy efficient overall. The differences for the freezer components are significantly smaller than the differences for the fridge components. This could be due to the fact that improvements were only made to the fridge segment of the walk-in refrigeration system.

		Difference (2019 - 2018)
Fridge	Compressor	-6.15
	Fans	-4.27
	Total	-10.42
Freezer	Compressor	-0.37
	Fans	-0.66
	Total	-1.03

Table 9: Comparison of 2018 and 2019 Data

Comparing the plots of Fridge Compressor energy intake over several hours for 2019 and 2018 (Figures 18 and 19) reveals that the pattern of rise and fall of power for this specific component of the refrigeration unit remains similar. It is also evident however from the Fridge Compressor plot comparison that the component uses less energy than in 2018, the maximum instantaneous energy consumption being 260 Wh/interval in 2018 but only 130 Wh/interval in 2019.

3.6 Conclusions and Recommendations

The improvements to the refrigeration system have improved its efficiency as there was a decrease in fridge and freezer energy usage from 2018 to 2019. The interns recommend to keep monitoring the fridge and freezer energy intake, as well as compare the new 2020 refrigeration system with the 2018 and 2019 data once the improvements are made.

3.7 References

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Assignment 4 - Waste Water: Solids Solution

Lead Interns: Valentine Starnes and Sawyer Hall

4.1 Background

Two leach fields with seven septic tanks totaling 8,000 gallons were installed in 2009 to handle the majority of the wastewater needs. As with any subsurface wastewater system, septic tanks need to be pumped of solids regularly to protect the leach field from solid build-up and failing. In 2018 SML worked with Environmental Septic Solutions to install a “SludgeHammer S-46” system in one of the septic tanks to control the build-up of solids. A basic schematic is shown below in Figure 20, taken from the SludgeHammer website.

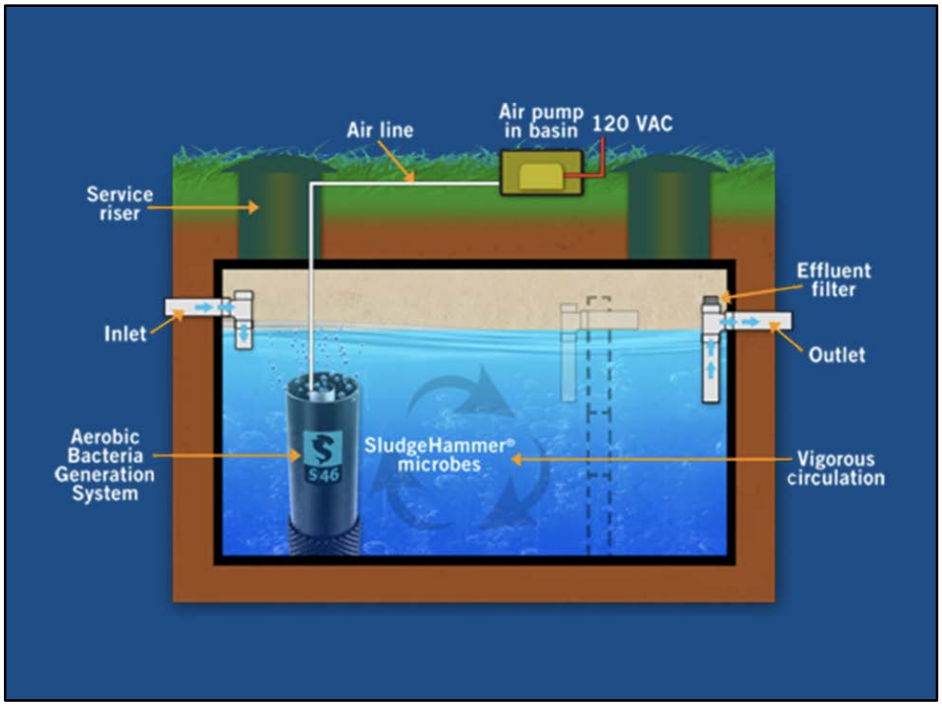


Figure 20: Schematic of the SludgeHammer System

This system pumps outside air into the septic tanks to activate a proprietary blend of bacteria and shift the tank to aerobic digestion. The SludgeHammer matrix provides surface area for the bacteria to grow on. As liquid is circulated throughout the tank, the bacteria consume and digest organic waste. As advertised from the SludgeHammer company, this system should eliminate the need to remove solid waste from the tanks due to the bacteria’s efficient consumption of the waste.

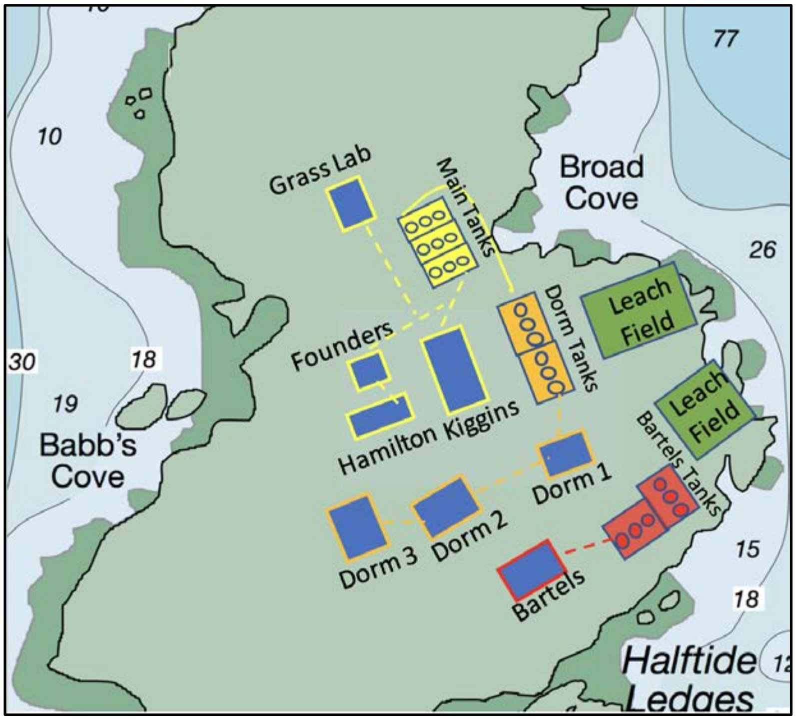


Figure 21: Schematic of the Septic Tank System

There are 3 different tank systems to handle all the wastewater. Shown in the lower right of the above graphic, the Bartels house for faculty and staff has 2 septic tanks that treats waste from toilets, showers, sinks, and a washing machine. The 2 septic tanks lead into a separate leach field to filter out liquid waste. In the center of the graphic, the 3 dorms lead into 2 septic tanks shown in orange. The dorms contribute waste from toilets and sinks only. Shown in yellow, the waste from the kitchen, Hamilton, Founders, and the Grass Lab are pumped into 3 main tanks. These receive fats, grease, oil, toilet water, sink water, dishwater and shower waste. The liquid waste from the composting toilets is also piped down to these 3 septic tanks. The septic waste is then pumped back up to a distribution box where it leads into the leach field for the dorms.

By design, septic tanks should be pumped out prior to installing the SludgeHammer, however the tanks were not pumped out prior to the implementation in 2018. The device was placed in the second hole of the first septic tank that collected waste from the three dorms since this tank had the least amount of solids at the time (It was later determined that Bartels had a slightly lower amount of solid buildup when the system was put in). The 2018 SEI's determined the buildup of solids in the septic tanks did not significantly decrease with the installation of the SludgeHammer. For this assignment, the tanks have been pumped out prior to the 2019 SEIs' arrival. The 2019 SEIs will collect weekly settleable solids tests to determine if there are different results.

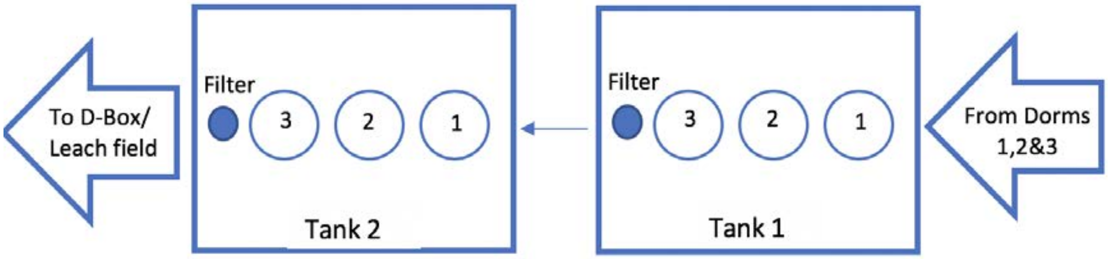


Figure 22: Schematic of the Septic Tank System for the Dorms' Wastewater

The setup of the septic tanks above is the system designed to treat waste for the three dorms. The inflow from the dorms consists of waste from toilets and sinks only. This is thought to have a heavier concentration of solids since there are no showers or kitchen sinks to dilute the incoming waste.

4.2 Purpose

Currently solid waste from the septic tanks must be removed every 3-4 years to prevent buildup. This removal process requires the transport of sewage trucks to the island which cost $15,700 in 2018 and can be upwards $20,000. The purpose of this assignment is to determine whether the SludgeHammer system effectively reduces the buildup of sludge in the septic tanks. The interns will recommend if Shoal Marine Lab should invest more into this product and install them into the other two septic systems. As a result, Shoals would not have to pump the solids out of the septic tanks as much, saving thousands of dollars.

4.3 Scope

With the septic tanks pumped out in the spring of 2019, the SEI will perform weekly settleable solids tests using a SludgeJudge device as well as Imhoff cones. This will allow the interns to determine if the SludgeHammer system is reliable in keeping solids from building up within the tanks and entering the leach field. An economic analysis will also be done to determine the payback period given the amount of years the SludgeHammer will extend the pumping service. This will allow the interns to make a more clear conclusion of whether this system is worth putting in the rest of the septic systems. The SEI interns will finish by making recommendations of whether SML should invest more into SludgeHammer products for the rest of the wastewater systems.

4.4 Methods

4.4.1 Sludge Judge Samples

In order to find the quantity of solids that have built-up at the bottom of the septic tanks, SludgeJudge sampler tubes were used. This device was a five-foot in length clear tube with a valve on the lower end. This device was lowered to the bottom of the tank with the float valve open to allow liquid and solids to flow up. Once the bottom of the tank has been reached, the check valve closes as the tube is lifted which traps the mixture inside. The depth of the solids at the bottom of the tube is read from a measuring tape held parallel to the length of the tube. These samples were taken at each of the three chambers for every septic tank on the island. Samples were collected once a week on Thursdays in each of the 7 septic tanks.

4.4.2 *Imhoff Samples*

Tests were also collected using Imhoff cones to determine the amount of settleable solids within the floating liquid of the tanks. Bottles were filled about 6 inches below the surface layer of floating sludge. These were taken in the last chamber for each of the three septic systems. The septic system that houses the SludgeHammer device will have samples taken at the end of both tank 1 and tank 2 for comparison. The bottles were then poured into clear Imhoff cones and left to settle for about 1 hour before measuring the settled solids in mL.

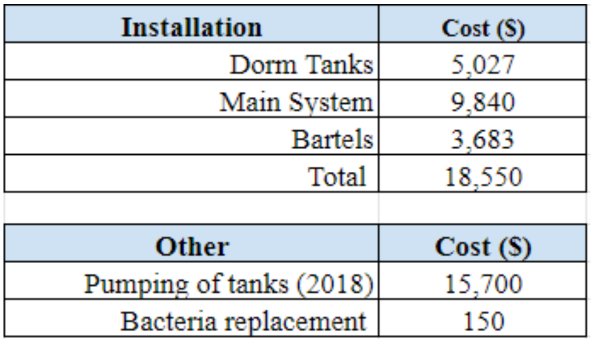
Another Imhoff cone test was taken in the last week of the interns stay directly from the distribution box located next to the dorm tanks. This distribution box collects wastewater from both the main septic tanks as well as the dorm tanks and distributes it across the leach field through pipes. As seen in the bottom part of the Figure 23 below, the incoming waste from the main system connects with the waste from the dorm septics tanks before entering the distribution box.

Figure 23: Distribution Box Next to Dorm Septic Tanks

A constant flow of liquid was coming into the distribution box from the dorm septic tanks and samples were collected from this pipe using paper dixie cups to fill a nalgene bottle. Flow from the main septic systems was not running and only came in when the pump from the bottom of the hill was turned on. This pump is usually automatically turned on when a float valve is triggered in the main septic system and will pump a significant amount of wastewater into the distribution box until a specific level of water is drawn down to. This pump was manually turned on to allow the collection of samples from this main septic system.

4.4.3 *Economic Analysis*

The interns wanted to create an economic analysis of installing the SludgeHammer Device. This analysis looked at the amount of years until payback depending on how many theoretical years the SludgeHammer device could extend the average pumping service. With the average pumping of the tanks being every 4 years, the interns used Excel to look at the extension of this pumping service by 1, 2, 3, and 4 years. To find the amount of years until payback the interns used quotes of installing these devices in Table 10 below.



Installation	Cost ($)
Dorm Tanks	5,027
Main System	9,840
Bartels	3,683
Total	18,550

Other	Cost ($)
Pumping of tanks (2018)	15,700
Bacteria replacement	150

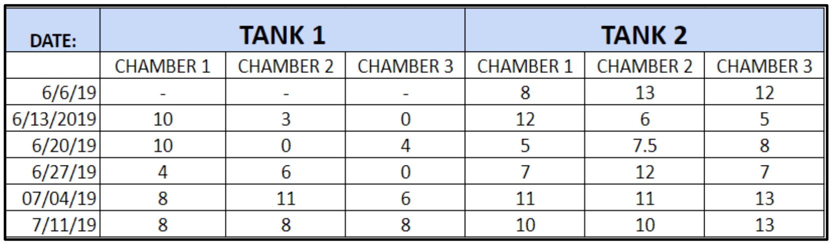
Table 10: Quotes for SludgeHammer Installation and Pumping Costs

4.5 Results and Analysis

4.5.1 *Sludge Judge Samples*

Dorm System:

The results from the 6 week period of taking Sludge Judge samples in the dorm tanks are shown below.



DATE:	TANK 1			TANK 2		
	CHAMBER 1	CHAMBER 2	CHAMBER 3	CHAMBER 1	CHAMBER 2	CHAMBER 3
6/6/19	-	-	-	8	13	12
6/13/2019	10	3	0	12	6	5
6/20/19	10	0	4	5	7.5	8
6/27/19	4	6	0	7	12	7
07/04/19	8	11	6	11	11	13
7/11/19	8	8	8	10	10	13

Table 11: Settled Solids for Dorm System

The first week of testing in the Tank 1 were missing results due to problems with the diffuser. Overall, the first tank showed Chamber 2 and 3 generally increasing in sludge depths over the 6 weeks. The low amount of solids in the initial weeks of sampling corresponds to the tanks being pumped out prior to sampling. However, there was conflicting results with Chamber 1 in the first tank since it showed higher amounts of sludge beginning in the week of June 13th.

Tank 2 showed similar results of larger initial sludge depths in the week of June 6th. Overall, Tank 2 had a constant amount of sludge buildup throughout the 6 weeks but showed significant variability from week to week. Weekly tests may have been impacted by prior sampling moving the sludge in the chamber space. The two tanks are graphed over a 6 week period in Figure 24 below.

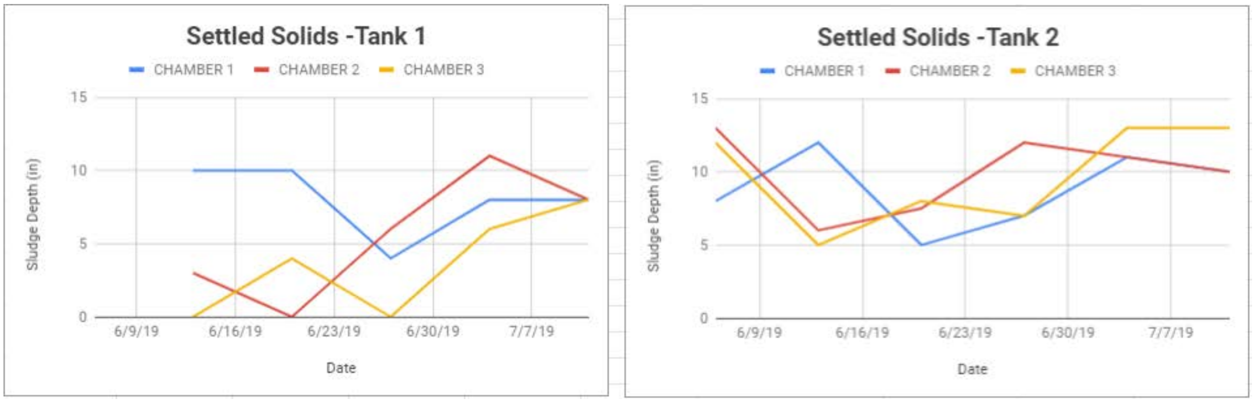


Figure 24: Settled Solids in Dorm System

The three chambers were then averaged on each day to find the amount of settled solid build-up for the entirety of the tank. This process was also done for tank 2 and the results are shown in Figure 25 below.

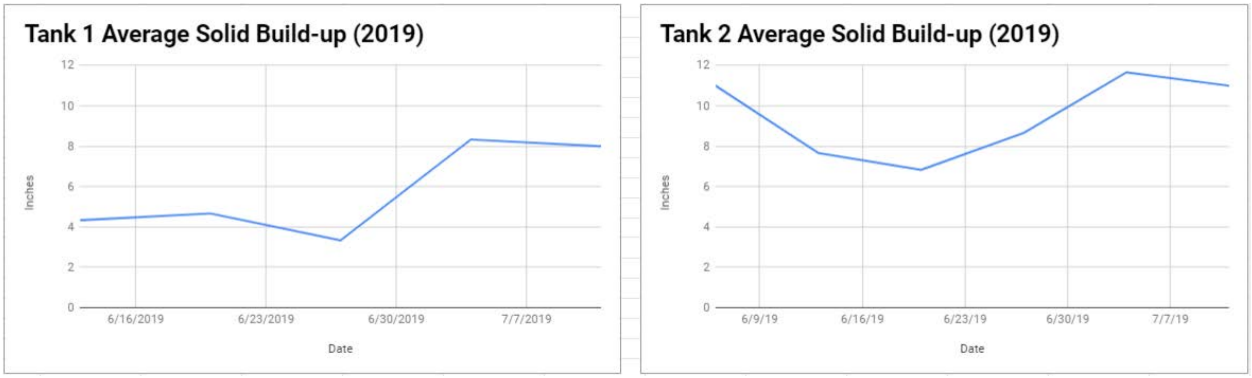


Figure 25: Total Averaged Settled Solids in Dorm System

It's important to note that the recirculation pipe was not working throughout the whole summer. Greg Teren, the SludgeHammer consultant, proposed that the system would work less effectively without proper functioning of the recirculation pump.

Bartels System:

The Bartels tanks varied significantly throughout the 6 week period between both tanks. Tank 1 especially varied between the separate chambers while Tank 2 fluctuated more as a whole. Overall, the amount of settled solids in Bartels were similar to the dorm tanks.

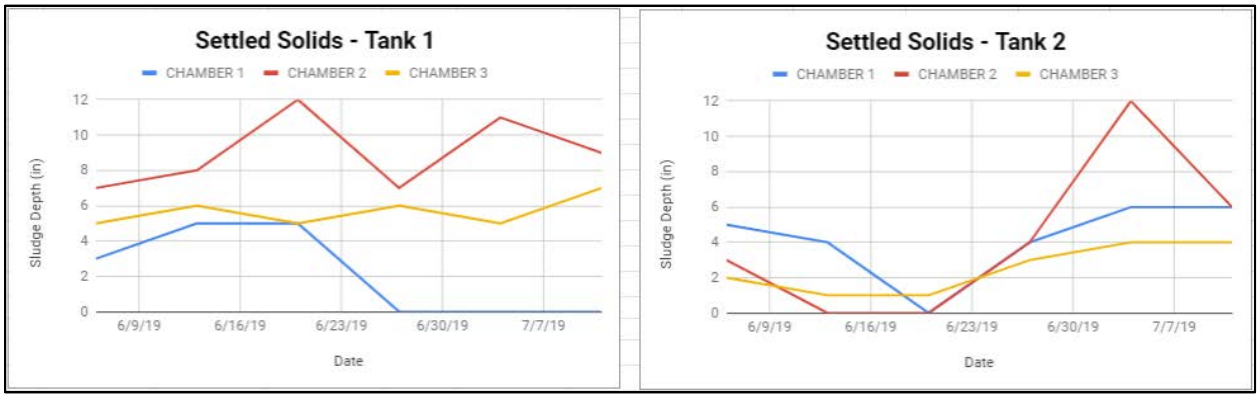


Figure 26: Settled Solids in Bartels System

Main system:

The main system tanks have three different tanks to handle the greater flow from the kitchen, Hamilton, Founders and the Grass Lab. Overall, the first tank showed an increasing trend over the 6 week period while the second and third tanks were relatively more constant. However, there was noticeable fluctuations between the chambers in each tank as well as differences within each of the separate tanks.

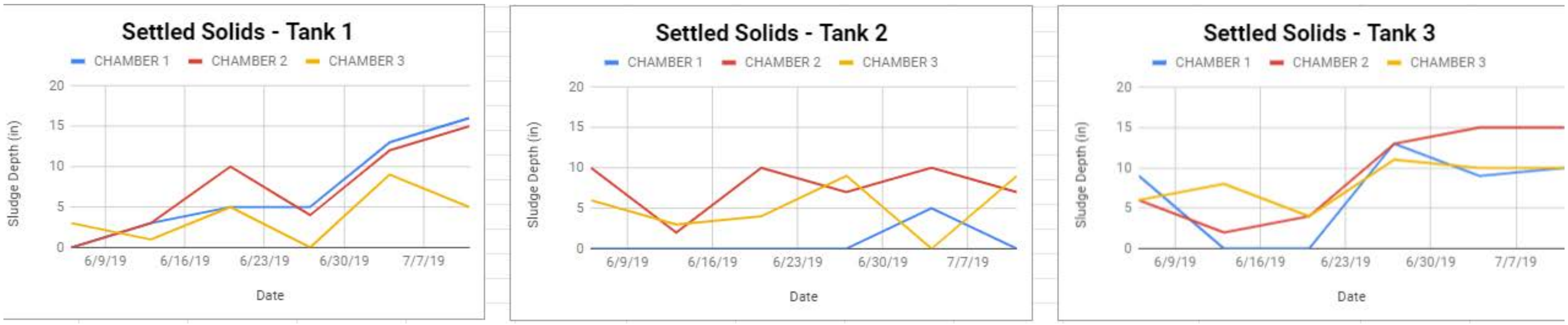
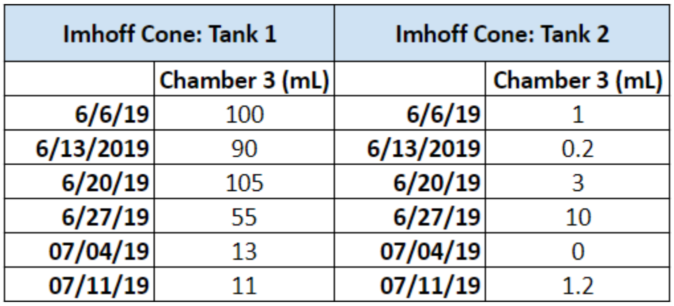


Figure 27: Settled Solids in Main System

4.5.2 *Imhoff Cone Samples*

Dorm System:

The Imhoff cone tests represent the amount of settleable solids in the middle layer of the tank that were previously still in suspension. The results from the 6 week period for the dorm tanks are shown in Table 12.



Imhoff Cone: Tank 1		Imhoff Cone: Tank 2	
	Chamber 3 (mL)		**Chamber 3 (mL)**
6/6/19	100	**6/6/19**	1
6/13/2019	90	**6/13/2019**	0.2
6/20/19	105	**6/20/19**	3
6/27/19	55	**6/27/19**	10
07/04/19	13	**07/04/19**	0
07/11/19	11	**07/11/19**	1.2

Table 12: Volume of Suspended Settleable Solids in Dorm Tanks

Overall, Tank 1 had a much higher concentration of suspended settleable solids than Tank 2. While Tank 1 did decrease significantly between June 20th to June 27th, Tank 2 generally stated at a constant smaller volume. These results contradict the Sludge Judge samples that show Tank 2 having higher settleable solids.

One hypothesis of these findings is that the settleable solids in Tank 1 are not able to settle due to mixing from the air pump. This explains why the Sludge samples in Tank 1 were lower since the particles didn't have the ability to settle out yet. The suspended samples were higher in Tank 1 since there was a chance to settle in the Imhoff cones. Figure 28 shows the trend of the suspended settleable solids for the 6 week period.

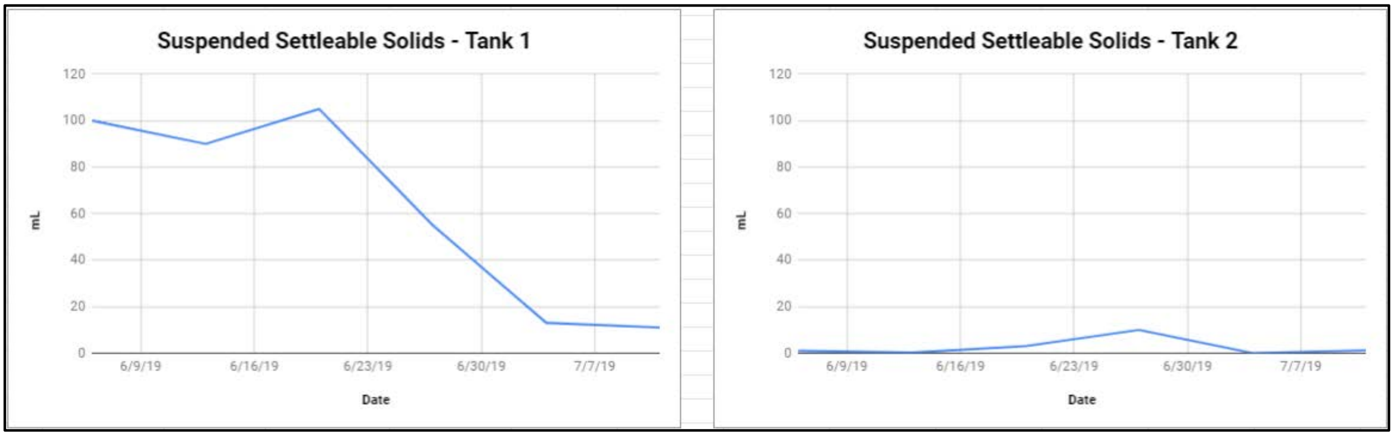


Figure 28: Suspended Settleable Solids in Dorm System

Bartels System:

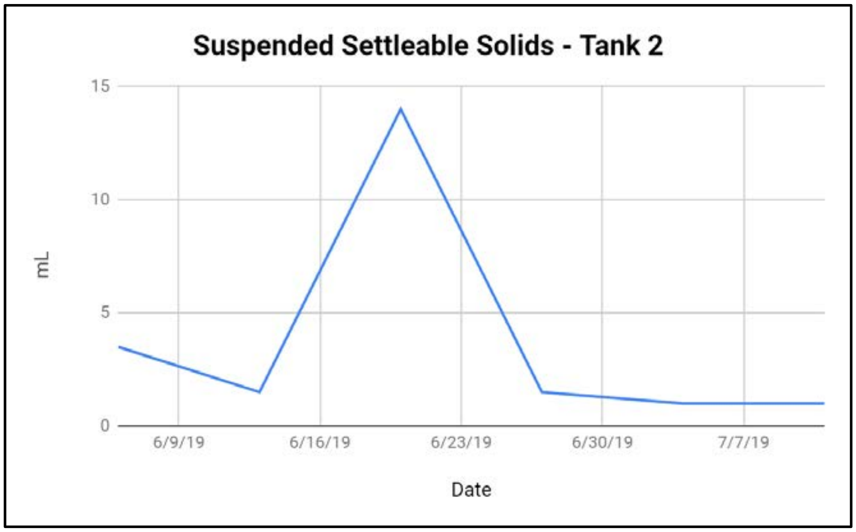


Figure 29: Suspended Settleable Solids in Bartels System

Figure 29 shows the Imhoff cone sample results for the second Bartels tank. Overall, the suspended settleable solids are much lower than the first Dorm tank and comparable to the second Dorm tank. There was a significant increase in the week of June 20th which seems like an outlier compared to the rest of the graph.

Main system:

Figure 30: Suspended Settleable Solids in Main System

Figure 30 shows the Imhoff cone samples for the third tank in the Main system. Initially, the tank showed very small amounts of suspended settleable solids but started to increase for the last two weeks in July. These results were also lower than the first Dorm tank but similar the second Dorm tank.

Distribution Box:

Taking samples from the distribution box found that both solids from the main septic systems as well as the dorm system were almost nothing. There were some very fine sediments found at the bottom of both of these samples but were not enough to quantify values. Figure 31 below shows the samples taken.

Figure 31: Imhoff Cone Samples Taken from Distribution box (Dorms-*left*, Main-*right*)

4.5.2 *Economic Analysis*

The interns used the quotes to create equations in Excel that would tell the number of years until payback. If the SludgeHammer device was able to extend the pumping service by 1 year to make it every 5 years, then the payback of installation costs would be in about 29 years. If this system was able to extend this to pumping every 8 years, then the payback would be in about 9 years. In Figure 32 below, the results of years until payback are shown.

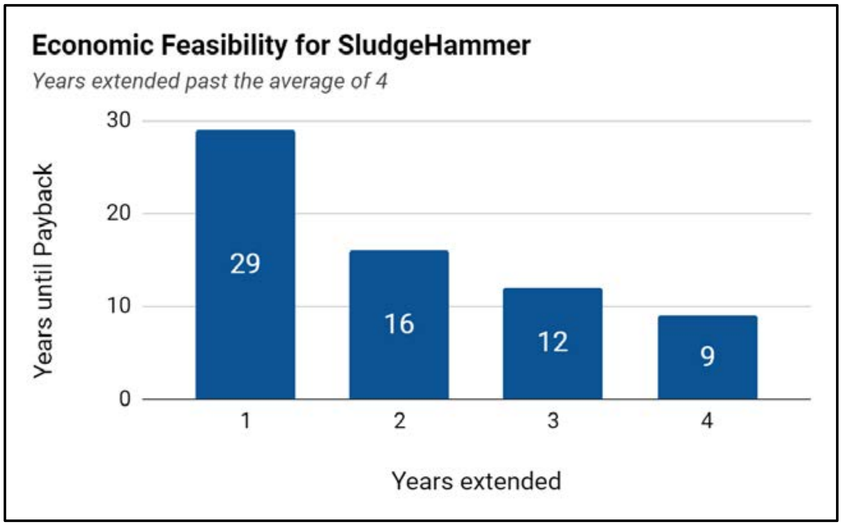


Figure 32 : Amount of Years until Payback with Different Extensions of Pumping Service

4.6 Conclusions and Recommendations

4.6.1 Conclusions

Comparing the results from the SludgeJudge and Imhoff cone samples, the interns were not able to see clear trends in the data. A lot of the data had a lot of variability either between the different tanks, between separate chambers, or on a daily basis. Since the data was so variable it was difficult for the interns to come up with the conclusions on how fast sludge was building up in the tanks.

The samples taken from the distribution box showing minimal solids were a positive result for how the septic system should be working. Minimal solids leaving the tanks mean that the leach field is not becoming clogged with waste solids which would eventually lead to failure.

The economic analysis was created as a tool for future interns and engineers to look at before the next septic pumping. This will give them a better sense of when the payback period will be and allow them to conclude whether it is worth investing in. Comparing the lifetime of the SludgeHammer system to the payback year would show the engineers whether investing in more products would be beneficial.

4.6.2 Conflicts

Making conclusions on whether the SludgeHammer was actually decreasing the rate of sludge buildup in the dorm septic tank was difficult due to several problems with the systems and experimental methods itself. In 2018, the tanks were not pumped out prior to installing the SludgeHammer system. Also for the last 2 summers, the recirculation pump was not working as it was designed to recirculate solids from Tank 2 back into Tank 1. According to the SludgeHammer company, this will affect the ability of the system to function properly. Additionally, there is a lack of data from sludge buildup without the SludgeHammer in the dorm tanks. The dorm tanks should not be compared to the Bartels and Main system since there are significant differences in incoming flows and concentrations. Furthermore, 6 weeks of data from this summer isn't enough time to recognize a clear trend in either the Sludge Judge or Imhoff Cone tests.

4.6.3 Recommendations

The interns recommend that island engineers and future interns should keep taking SludgeJudge and Imhoff Cone samples to get data from a more long term perspective. This will allow engineers to see whether solids are building up in the tanks over the 4 years before pumping, and whether this pumping could be extended more years. The interns also suggest taking samples in the future where the SludgeHammer is turned off or alternatively placed in a different tank. This will allow a control data set to be collected to see how sludge accumulates without the SludgeHammer.

The samples taken from the distribution box were taken to see the amount of solids that were leaving the two septic systems and entering the leach field. This type of sampling would be useful to add to the SludgeJudge and Imhoff Cone sampling to get a more accurate representation of how the SludgeHammer system is dealing with solids. The interns found this test to not be too difficult (especially for only looking at the dorm tanks) so adding this to the data collection could prove more conclusive results. This would also make sure solids are not entering the leach field in case the septic tanks start to fail.

Once these future data sets are collected, the interns recommend finding the difference in rates of sludge buildup. Depending on how many years the SludgeHammer system extends the need to pump (if at all), the engineers can use the economic analysis graph to see what year the initial cost could be paid off. After comparing the estimated lifetime of the SludgeHammer system, the engineers can make a decision whether investing in more products would be beneficial.

4.7 References

"How It Works." *SludgeHammer Group, Ltd.*, sludgehammer.net/how-it-works/

Assignment 5 - Sustainable SML Dashboard

Lead Interns: Sawyer Hall and Colleen Tobin

5.1 Background

SML currently has an online Dashboard that displays the performance of Appledore's energy grid. This includes power being generated from the wind turbine, solar panels, and generators. It also has information about how much power the island is demanding as well as information on the state of charge from the batteries. There are many other data fields that are included, all relating the grid on the island. The dashboard shows real-time performance of the power systems on the island as well as trends over chosen periods of time. Data on the dashboard comes from different metering boxes located around the island.

Currently the dashboard is only being projected to users that are connected to the island's wifi network, but future plans for the end of the year will make it available for public viewing on outside networks. Tyler Garzo is the SML IT specialist who is in control of the dashboard and is helping progress the Dashboard into a more final state

Figure 33 below shows the original display of the dashboard and features three distinct visuals at the top of the page showing the amount of green energy produced, diesel fuel saved, and the demand of power from the island. Below these are a few graphs as well as some links to see graphs of different parts of the green grid.

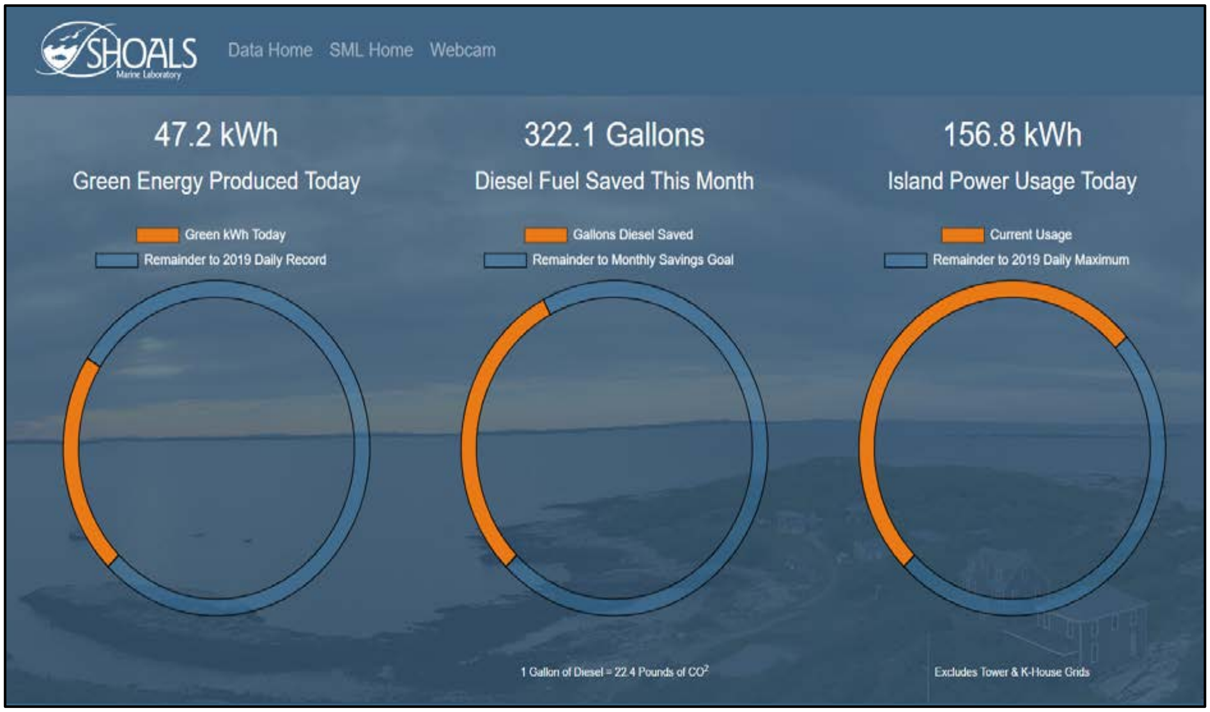


Figure 33: Original Dashboard Homepage

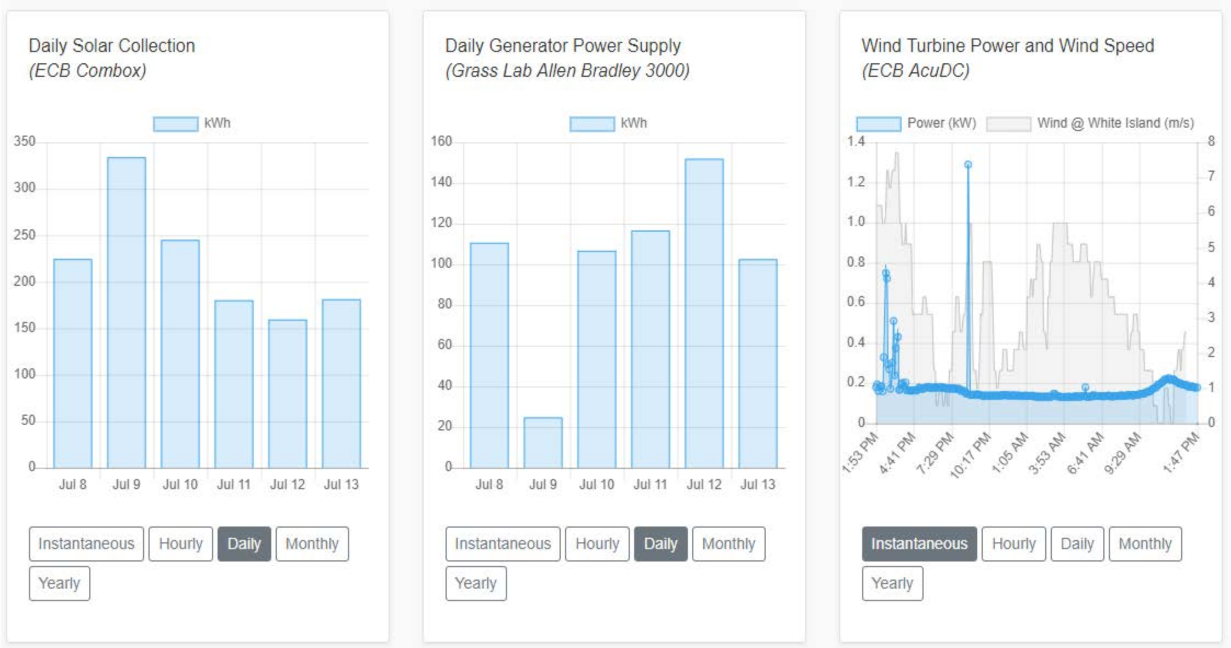
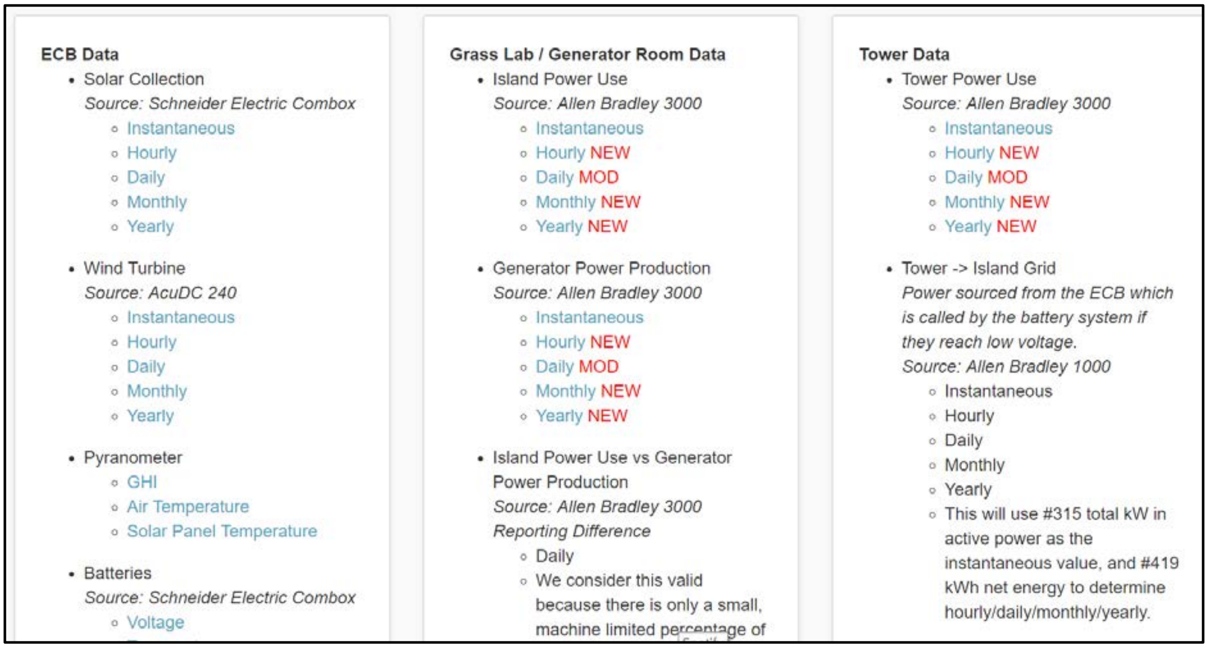


Figure 34: Original Home Page Graphs



ECB Data

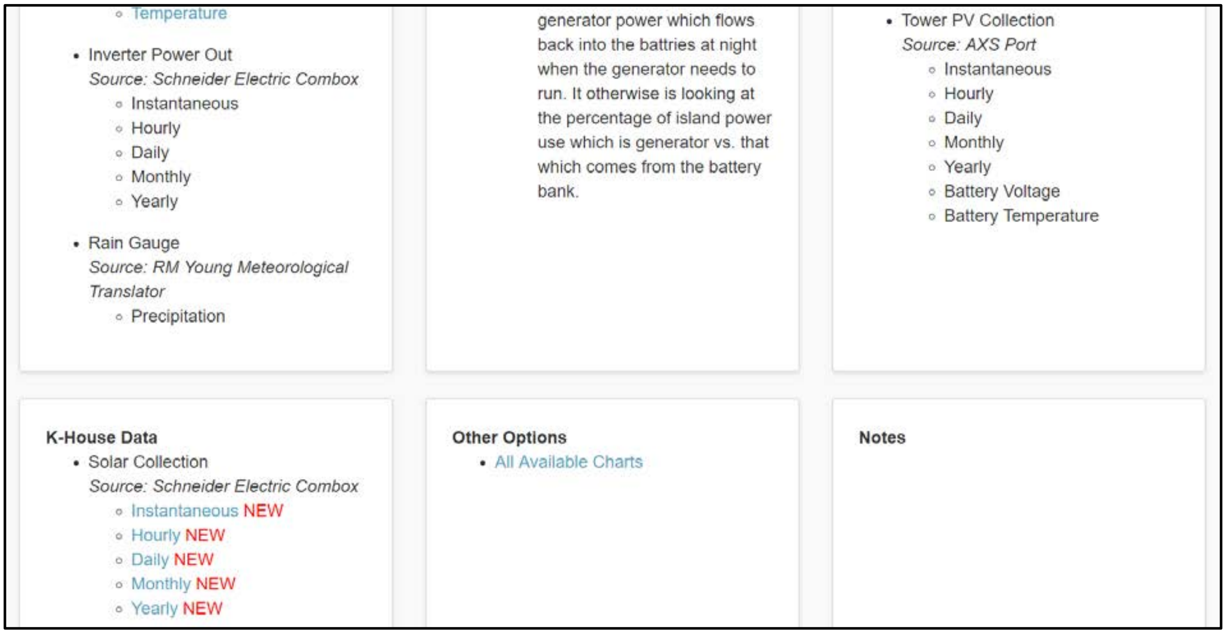
- Solar Collection
  Source: Schneider Electric Combox
  - Instantaneous
  - Hourly
  - Daily
  - Monthly
  - Yearly
- Wind Turbine
  Source: AcuDC 240
  - Instantaneous
  - Hourly
  - Daily
  - Monthly
  - Yearly
- Pyranometer
  - GHI
  - Air Temperature
  - Solar Panel Temperature
- Batteries
  Source: Schneider Electric Combox
  - Voltage

Grass Lab / Generator Room Data

- Island Power Use
  Source: Allen Bradley 3000
  - Instantaneous
  - Hourly NEW
  - Daily MOD
  - Monthly NEW
  - Yearly NEW
- Generator Power Production
  Source: Allen Bradley 3000
  - Instantaneous
  - Hourly NEW
  - Daily MOD
  - Monthly NEW
  - Yearly NEW
- Island Power Use vs Generator Power Production
  Source: Allen Bradley 3000
  Reporting Difference
  - Daily
  - We consider this valid because there is only a small, machine limited percentage of

Tower Data

- Tower Power Use
  Source: Allen Bradley 3000
  - Instantaneous
  - Hourly NEW
  - Daily MOD
  - Monthly NEW
  - Yearly NEW
- Tower -> Island Grid
  Power sourced from the ECB which is called by the battery system if they reach low voltage.
  Source: Allen Bradley 1000
  - Instantaneous
  - Hourly
  - Daily
  - Monthly
  - Yearly
  - This will use #315 total kW in active power as the instantaneous value, and #419 kWh net energy to determine hourly/daily/monthly/yearly.



- Temperature

- Inverter Power Out
  Source: Schneider Electric Combox
  - Instantaneous
  - Hourly
  - Daily
  - Monthly
  - Yearly
- Rain Gauge
  Source: RM Young Meteorological Translator
  - Precipitation

generator power which flows back into the battries at night when the generator needs to run. It otherwise is looking at the percentage of island power use which is generator vs. that which comes from the battery bank.

- Tower PV Collection
  Source: AXS Port
  - Instantaneous
  - Hourly
  - Daily
  - Monthly
  - Yearly
  - Battery Voltage
  - Battery Temperature

K-House Data
- Solar Collection
  Source: Schneider Electric Combox
  - Instantaneous NEW
  - Hourly NEW
  - Daily NEW
  - Monthly NEW
  - Yearly NEW

Other Options
- All Available Charts

Notes

Figure 35: Original Homepage Menu

5.2 Purpose

Life at the Shoals Marine Laboratory is based off the principles of sustainability and this Dashboard will educate users on how well the island is meeting these needs within the power sector. The purpose of this project is to check the accuracy of the results found on the Dashboard and to see if these are what the systems are actual supplying. Recommendations will also be made to improve on how user friendly the site is and to make sure the dashboard is not only easy to navigate but can be easily understood. This dashboard will be able to be used by engineers to check on the grid as well as an educational tool for classes on the island.

5.3 Scope

To make sure the data being displayed on the website is accurate and reliable, the interns will be making comparison checks between what the systems are putting off and what is being read from the website. These checks will be done on solar generation, wind generation, generator output, and island power demand. The interns will also recommend a list of changes and edits to ensure the website is easy and comfortable to use. It should display information in a way that someone in a non-engineering background can easily interpret and understand. It should also have a section where engineers can use to get more detailed information to help inform of the systems on the island. Educational material should be added to give site visitors more information about Appledore's sustainability in terms of energy.

5.4 Methods

5.4.1 Accuracy

On six consecutive days at varying times, interns compared the data from boxes in the Energy Conservation Building, Grass Lab, Schiender's monitoring website, and Dashboard. The solar power generation, wind power generation, generator power, and total island power usage was compared between the two sites. Any discrepancies were recorded.

5.4.2 User Friendly

To make the dashboard easier to navigate and interpret the data more efficiently, the interns worked with Tyler Garzo in implementing these ideas. A call the first week allowed the interns to introduce themselves and get a better understanding of both Tyler and the intern’s role in this project. From there on, the interns communicated with Tyler over email and were able to send possible changes and feedback for the dashboard. Various graphical designs were created and sent to Tyler to give a better understanding of what changes were needed for the dashboard.

5.5 Results and Analysis

5.5.1 Accuracy

The average difference between the data on Dashboard, the boxes, and Schiender are given in percentage. The slight discrepancy between Schiender, the boxes, and Dashboard can be explained by the data being collected at different milliseconds. These constant changes in number readings made it more difficult to accurately check the connection between the boxes and the dashboard. Table 13 below shows the percent difference between the metering comboxes and what the dashboard was reading.

	Solar Output	**Wind Output**	**Generator Output**	**Island Use**
Percent (%)	2.967	0.302	2.900	1.900

Table 13: Percent Difference between Dashboard and Schiender

One issue that we noticed was that the wind turbine appears to be outputting a minimum of 0.137 kW even when it is not moving. This appears on the Dashboard as well as the metered comboxes. Recalibrating the output from the wind turbine may solve this issue.

5.5.2 User Friendly

When the interns first started working on the Dashboard, there were many aspects that were not user friendly and made it especially confusing for people who were using the online tool for the first time. One of the main problems is that the menu to choose what type of data you want is very cluttered. To organize this better, the interns sent Tyler an idea of turning this information into a drop-down menu. This would allow the data to be less crowded and easier to find the needed graphs. Figure 36 below shows the proposed design that the interns sent Tyler.

Figure 36 Proposed Drop-down Menu

A lot of the graphs were clearly labeled but could use larger font to make it easier to read. There was no button to switch to each of the specific graphs when looking at one type of data so the interns sent Tyler another possible change to fix this. The interns also thought that having a wider range for an x-axis would allow users to view the data over a larger period. A button was put in to allow the user to view the data in a 24-hour period or week long period. Figure 37 shows this below.

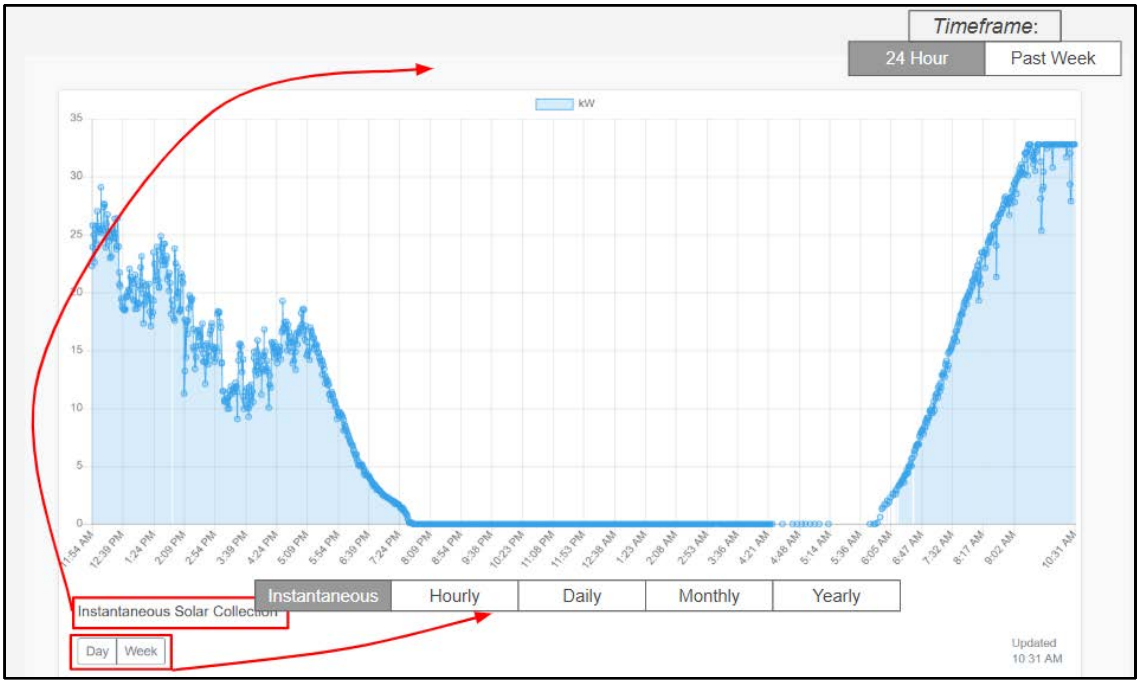


Figure 37: Proposed Graph Design

The three graphs on the top of the page were also confusing when trying to look at for the first time and no knowledge of how the data was being generated. An example of this was for the wheel showing amount of diesel fuel saved. It was hard to know if the amount of diesel fuel saved was high or not.

Below the three graphs at the top of the dashboard was a bar showing the current amount of solar panel power being generated as well as the charge of the batteries. Figure 38 below shows this bar.

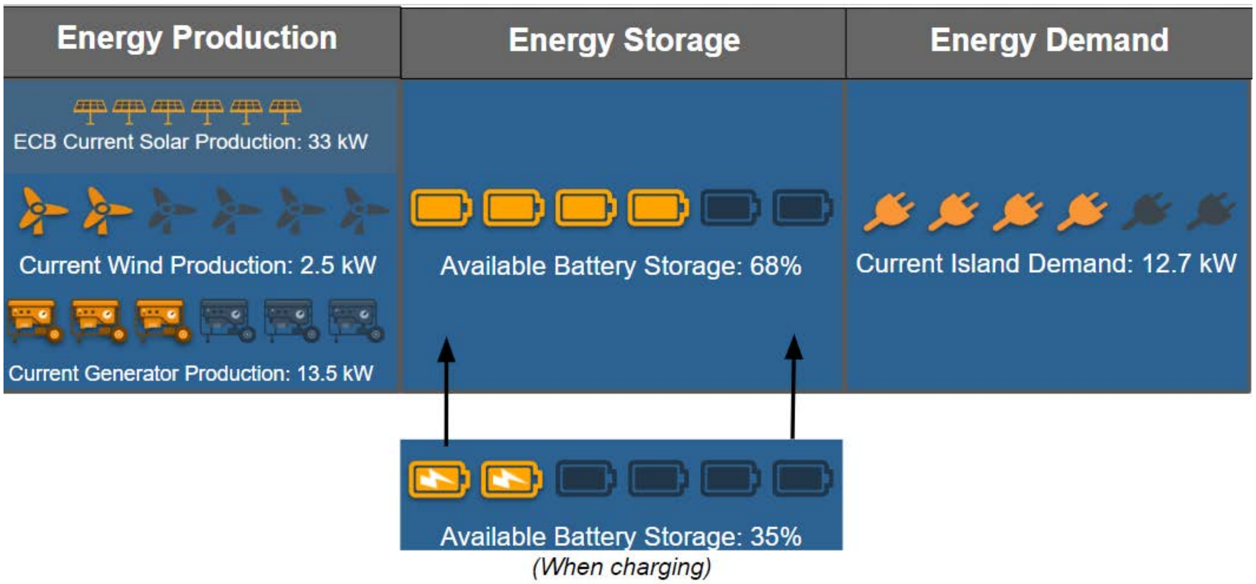
ECB Battery Bank Status: 53 V

ECB Current Solar Production: 3 kW

7 Knots ESE

Figure 38: Original Display Bar

This bar was very helpful is showing off the current power generation on the island at any given time and interns wanted to expand on this idea. Below is Figure 39 showing how the interns wanted to update this portion of the dashboard.



Energy Production	Energy Storage	Energy Demand
ECB Current Solar Production: 33 kW Current Wind Production: 2.5 kW Current Generator Production: 13.5 kW	Available Battery Storage: 68%	Current Island Demand: 12.7 kW

Available Battery Storage: 35%
(When charging)

Figure 39: Proposed Display Bar

Another graphic that the interns thought was important in showing was a pie chart depicting how much energy being used on the island was coming from renewables. This could be displayed in a monthly graphic or daily. Figure 40 below depicts what this graphic would look like.

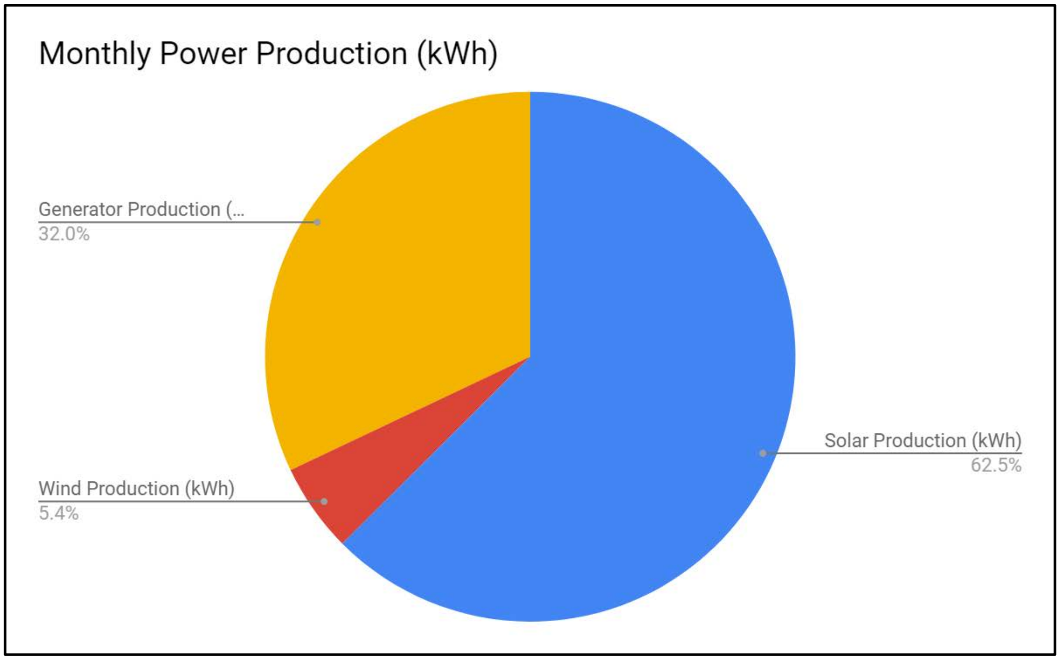


Figure 40: Proposed Monthly Power Production

To show more on the sustainable progress of Appledore, the interns wanted to have a display showing the amount of diesel consumed over the years. A specific displayed was not made but in the future an animated graphic could be made to show the data that is shown below.

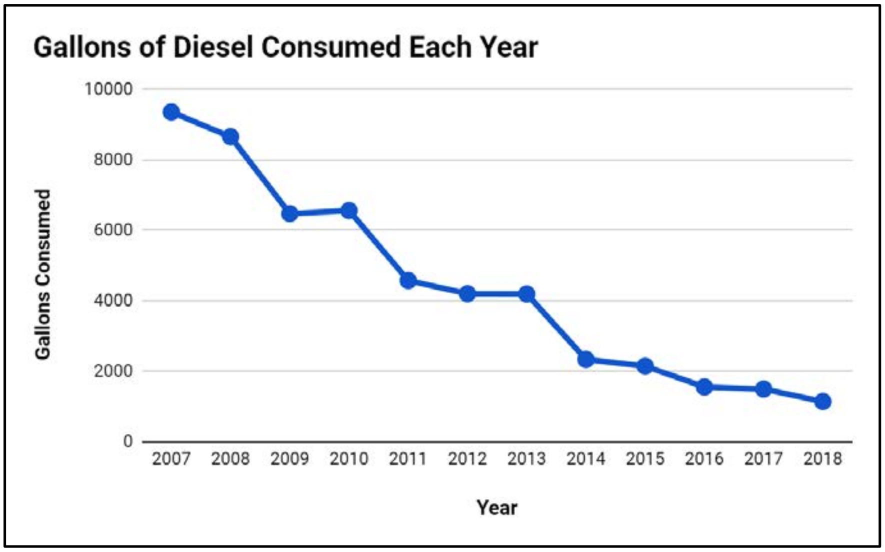


Figure 41: Proposed Diesel Consumption Graph

It was requested that educational material be added to the Dashboard to allow users to really understand how the energy grid works. The sustainable communication intern, Anna Canny, created diagrams depicting the electrical system through her work in promoting sustainability on the island. The interns thought her designs should be included so the site's visitors will learn more about the sustainability on Appledore Island. By having this on a Dashboard this graphic can be more interactive to make it easier to understand and walkthrough. An example of the main electrical grid can be seen in Figure 42.

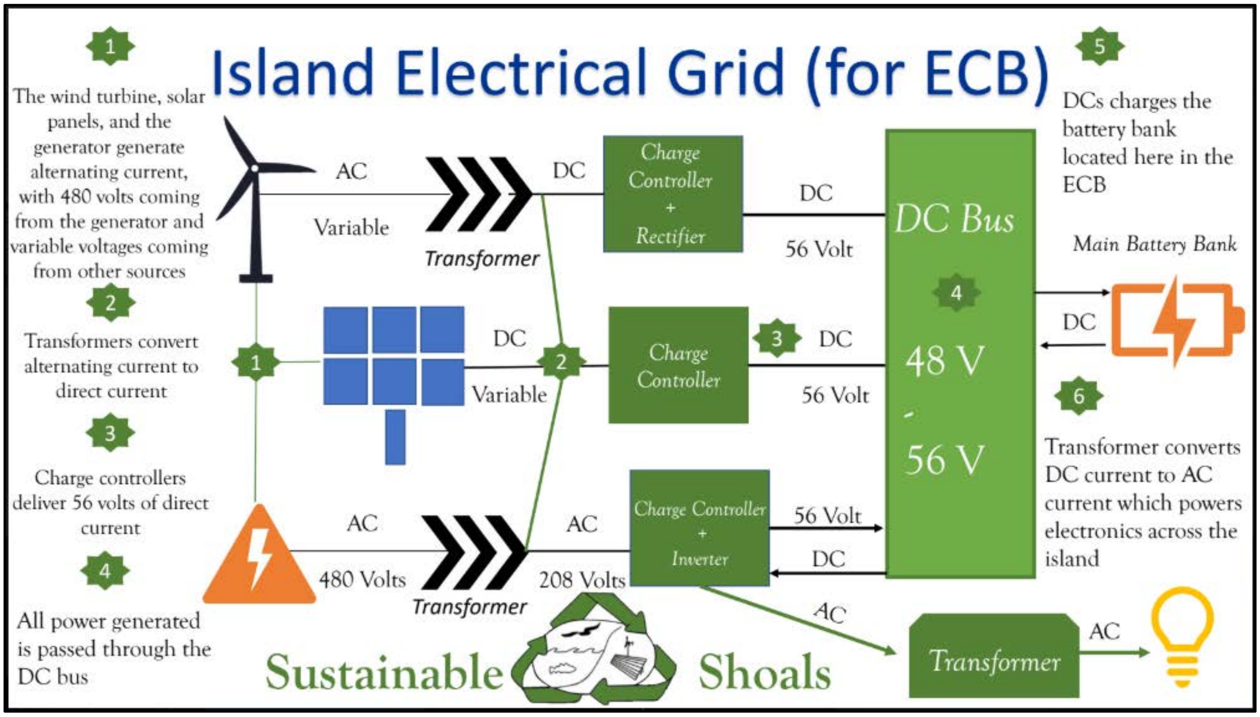
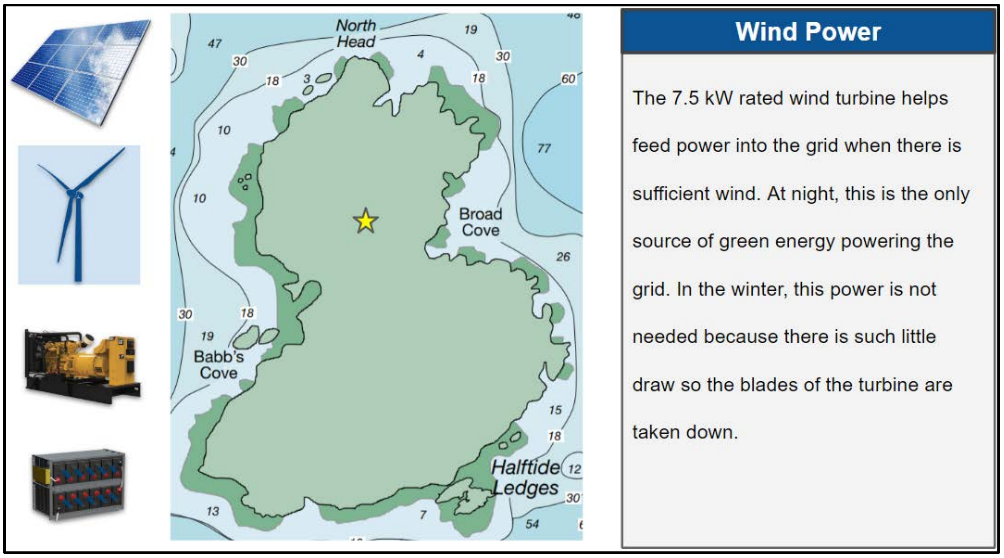


Figure 42: Rough Draft Electrical Grid Diagram

Another educational tool the interns thought about adding was an interactive map that would allow people to get a better visual of the systems on the island. An example shown in Figure 43 below shows what this would be like when looking at the wind turbine. This visual would show the location of the system as well as a quick description of how the system contributes to the power grid.



Wind Power

The 7.5 kW rated wind turbine helps feed power into the grid when there is sufficient wind. At night, this is the only source of green energy powering the grid. In the winter, this power is not needed because there is such little draw so the blades of the turbine are taken down.

Figure 43: Proposed Interactive Map of the Power System

Another possibility is to expand upon the sustainability timeline that is on the Shoals Marine Laboratory website. The current timeline states when items, like solar panels, were implemented on Appledore. The timeline can include why certain items were introduced to Appledore and how that was made possible.

5.6 Conclusions and Recommendations

5.6.1 Accuracy

The output accuracy of the solar panels, wind turbine, generator, and the island power usage are all accurate and reporting the correct values. Any small discrepancy can be due to the fact that data collection might have some off-timing issues . All the errors are below 3% and are thus insignificant. The interns can conclude that the data is accurate for most of the systems displayed.

5.6.2 User Friendly

As the interns have been sending changes to Tyler, these have been seen throughout the weeks being updated on the site. These changes have been making the site easier to navigate with the drop-down menu being a great example of this. Further changes can be made to progress in making the dashboard as easy to navigate as possible.

5.6.3 *Recommendations*

For future work on this project of updating the dashboard, there can be more involvement from the sustainable communications intern. This would be a great opportunity to allow this position to use what they have been making in their goal of promoting sustainability on Appledore and using this to make the Dashboard more educational. Then the dashboard will be better at promoting how sustainable Appledore is especially with the energy systems on the island.Future work will also be more about creating the right visuals and best way of graphically showing the data being displayed.

This would be done better with someone with a more focused background in this knowledge. Having the engineering interns work on this might limit the potential for having the public understand the data since they are looking at the data in more of an engineering perspective instead of a public one.

5.7 References

Shoals Marine Laboratory, www.*sustainablesml.org*
Schneider Electric site http://10.50.0.47/login.html

Assignment 6 - White Island Light Station: Solar Powered Electrical System

Lead Interns: Marguerite Lorenzo and Sawyer Hall

6.1 Background

The White Island Light Station is a New Hampshire State Parks Historical Site. Its remote location in the Isles of Shoals, 6 miles off the coast of Rye, NH makes it a difficult site for visitors to reach. The NH Division of Parks and Recreation took over stewardship of the site in 1992 from the US Coast Guard. One of its long term goals has been to make the light station accessible by more than recreational boaters.

In coordination with the “Light House Kids” (the official friends group for the state park historic site) a program placing volunteer docents in residence on the island has been operating for several years during the summer season which runs roughly from Memorial Day through September. The docents come out to the island for short periods of time ranging from a weekend to a full week. They live in the Caretaker’s House, perform light maintenance tasks to the buildings and grounds, and provide tours and historic interpretation to visitors who make their way to the island in privately owned boats.

In addition, naturalists from Shoals Marine Lab studying terns on the adjacent Seavey Island have used the Caretaker’s House as a base camp for their field work. One or two naturalists are in residence at a time; however there have been short periods of time when their team has expanded to four or even six members.

At the current time, living conditions for these Light Station residents are rudimentary. Sanitary facilities consist of a single composting toilet. Potable water is imported to the island, although there is a collection system for rainwater which is stored in a basement cistern. There is no regular line voltage electricity on the island; the diesel generators that once powered the lighthouse are long gone. A very modest array of solar panels charge a storage battery which is sufficient to run a few low amperage appliances and lighting fixtures for an hour or two into the evening.

6.2 Purpose

The purpose of this project is to design a reliable energy supply source that would be able to support the load of the island’s upgraded various appliances for the summer season (May through September). To achieve this goal, interns will design a solar powered electrical system for White Island capable of handling a residential level electrical load during daylight hours and extending service approximately 5 hours after dark.

6.3 Scope

To design a solar panel system able to meet the needs of the White Island researchers, interns first needed to assess the energy demand of the island. This allowed to design a system composed of photovoltaic (PV) panels, charge controllers, battery units, and inverters. Interns also conducted a spatial analysis, as to determine where the different components of the system could be placed on White Island. The approximate cost of the system was estimated. Finally, interns took a step back from the new system design to look for ways to improve the current solar system in place on the island.

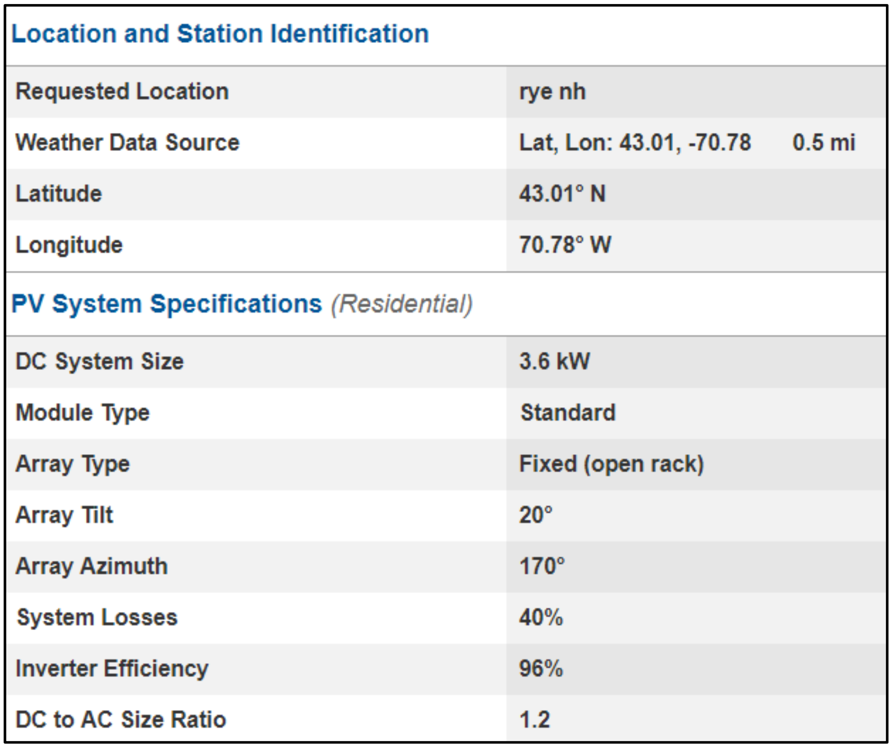
6.4 Methods

6.4.1 Caretaker House Daily Load

The first step in designing a solar energy system for White Island was to make an inventory of appliances that need to be supplied by the system. After interviewing Liz Craig, Shoals Marine Laboratory Tern Conservation Program Manager and seasonal researcher on the island, interns collected information on current appliances in the house as well as any additional appliances needed in future. The interns also looked at appliance usage habits in the Caretaker’s House and State Fire requirements to calculate its approximate total daily load.

6.4.2 PV Panel Array and Tilt Selection

For the task of choosing a PV solar panel, interns consulted Lee Consavage, Electrical Engineer from Seacoast Consulting. Lee recommended using an online PVWatts Calculator from the National Renewable Energy Laboratory (NREL) to help design the PV system. Parameters were used for the calculations and the closest available location to White Island was Rye, NH. Assumptions were that the array type is fixed, the system losses are 40%, and that the azimuth (angle relative to North) of the panels is 170 degrees (Figure 1).



Location and Station Identification	
Requested Location	rye nh
Weather Data Source	Lat, Lon: 43.01, -70.78 0.5 mi
Latitude	43.01° N
Longitude	70.78° W
PV System Specifications *(Residential)*	
DC System Size	3.6 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	170°
System Losses	40%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2

Figure 44: PV Watts Online Calculator Parameters

Different tilt angles were tested on the calculator, and interns chose a 20 degree tilt since it optimized AC output for the months of May through September. Entering a range of different values for desired array wattage allowed the interns to calculate the theoretical monthly energy output for each array size. These monthly energy outputs were then compared to the determined electrical load of the White Island house as to choose the most appropriate PV array size.

6.4.3 Spacing Between Panels

To avoid shading projected from each panel onto each other at their respective tilts, the sun altitude needed to be calculated. Everyday farther from the summer’s solstice (June 21st) means that the sun will be lower in the sky. Since the sun will be at a lower angle in the sky, it will be casting greater shadows and more space will be needed between the panels to compensate for this. To allow a full season (May to September) to not have any panel shading, the interns used the sun’s altitude for the end of September as this is when the sun is lowest in the sky so the shading would have no issue in the rest of the season

6.4.4 Panel, Charge Controller, Inverter, and Battery Bank Selection

Upon comparison of different components available and the choice of PV array size, interns decided on the number and model for the charge controller, inverter, PV panels, and battery.

6.4.5 Location Considerations

On their first visit to White Island on June 18th 2019, the interns were able to look at potential locations for the new PV panels. After calculating the dimensions of the different solar system components, they were able to come up with a more definite location plan for them. The interns were also introduced to Ben Wilson, the Director of NH Bureau of Historic Sites. He was able to give regulatory information and other important details about where these solar panels could be placed.

6.4.6 Cost Estimate

Interns made a simple cost estimate for the different components of the designed solar system based off online information for each specific model. Assignment instructions did not specify a budget to take into consideration in the model, however this cost estimate was included for future reference.

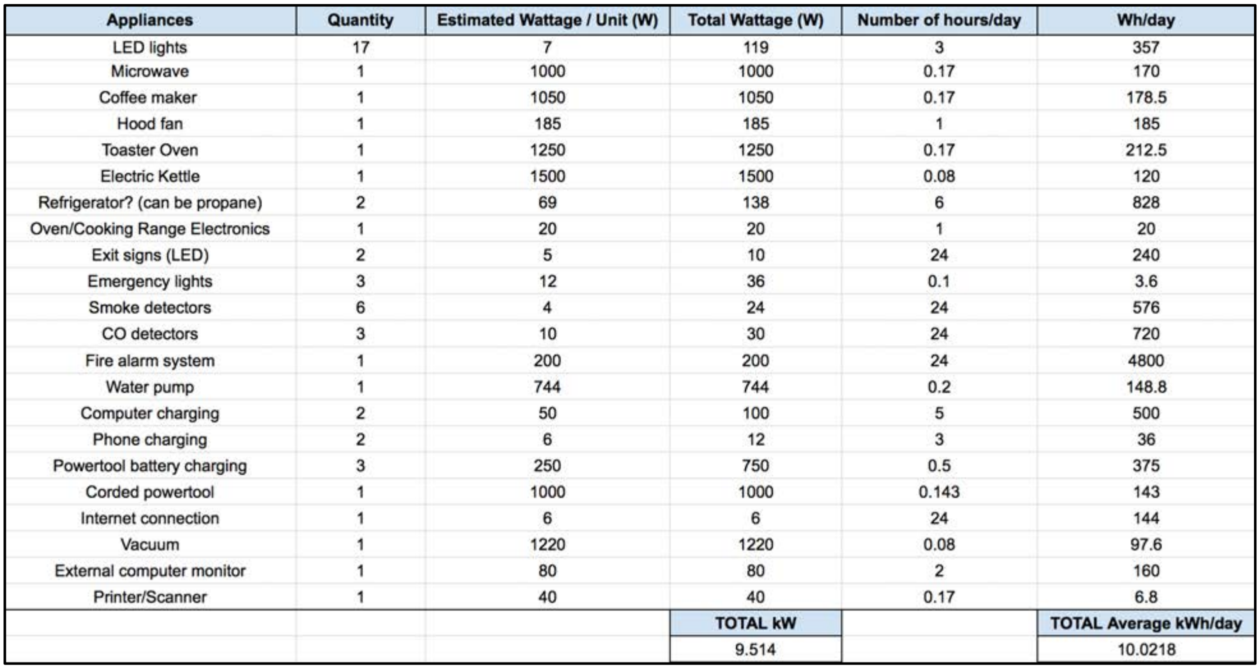
6.4.7 Current Set-Up Improvements

Implementing a full new solar system could take up to a few years (to finalize design, purchase materials, transport and set up equipment). Interns have therefore come up with temporary recommendations for the solar system currently in place on White Island, that could increase the energy output from the PV panels already set-up.

6.5 Results and Analysis

6.5.1 Caretaker’s House Daily Load

The inventory of energy draws from the Caretaker’s House includes residential appliances, charging of electronics and tools, emergency and fire alarm state fire requirements, lights, as well as a house water pump. Knowing the number of hours per day each of these appliances are used, interns calculated a total daily house demand of approximately 10 kWh.

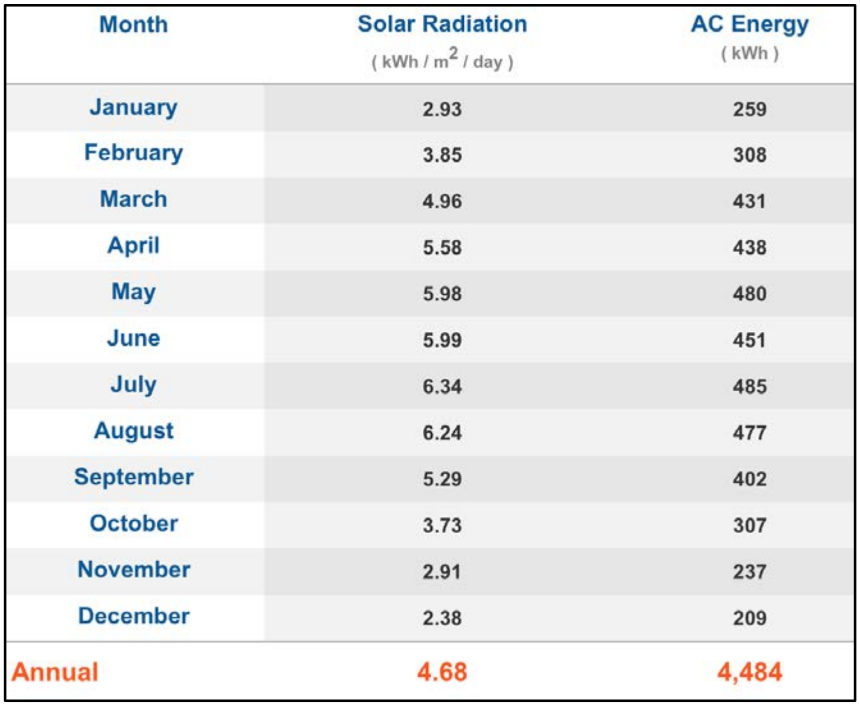


Appliances	Quantity	Estimated Wattage / Unit (W)	Total Wattage (W)	Number of hours/day	Wh/day
LED lights	17	7	119	3	357
Microwave	1	1000	1000	0.17	170
Coffee maker	1	1050	1050	0.17	178.5
Hood fan	1	185	185	1	185
Toaster Oven	1	1250	1250	0.17	212.5
Electric Kettle	1	1500	1500	0.08	120
Refrigerator? (can be propane)	2	69	138	6	828
Oven/Cooking Range Electronics	1	20	20	1	20
Exit signs (LED)	2	5	10	24	240
Emergency lights	3	12	36	0.1	3.6
Smoke detectors	6	4	24	24	576
CO detectors	3	10	30	24	720
Fire alarm system	1	200	200	24	4800
Water pump	1	744	744	0.2	148.8
Computer charging	2	50	100	5	500
Phone charging	2	6	12	3	36
Powertool battery charging	3	250	750	0.5	375
Corded powertool	1	1000	1000	0.143	143
Internet connection	1	6	6	24	144
Vacuum	1	1220	1220	0.08	97.6
External computer monitor	1	80	80	2	160
Printer/Scanner	1	40	40	0.17	6.8
			TOTAL kW		**TOTAL Average kWh/day**
			9.514		10.0218

Figure 45: Inventory of the Caretakers' House Appliances and Usage

6.5.2 PV Panel Array and Tilt Selection

These inputs totaled an amount of 2,295 kWh of AC Energy for the May through September season (sum of values shown in Table 14 below).



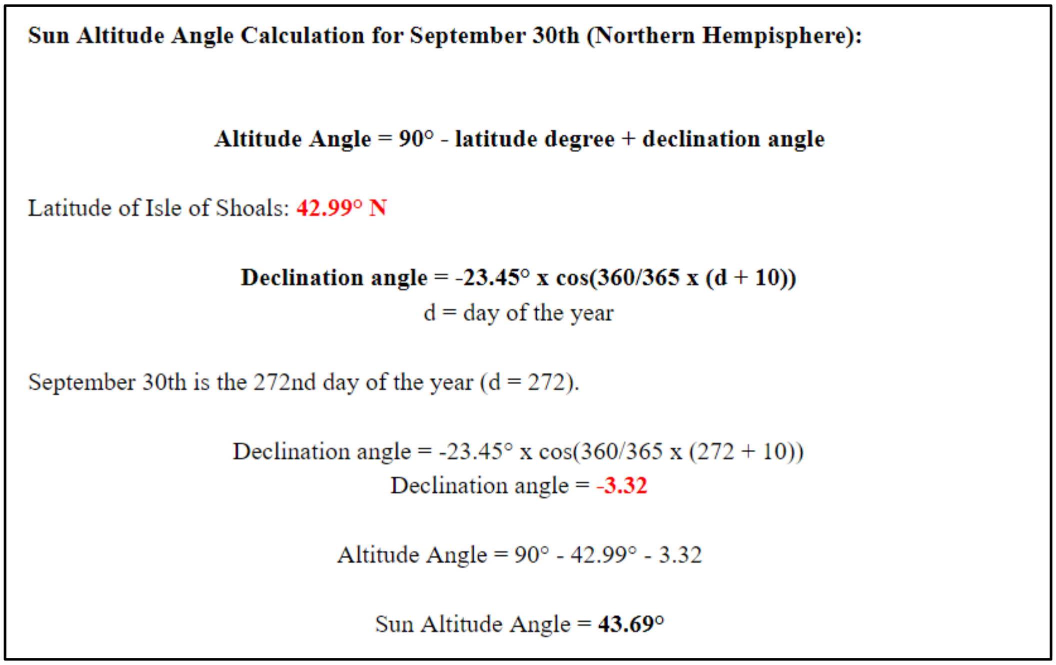
Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	2.93	259
February	3.85	308
March	4.96	431
April	5.58	438
May	5.98	480
June	5.99	451
July	6.34	485
August	6.24	477
September	5.29	402
October	3.73	307
November	2.91	237
December	2.38	209
Annual	4.68	4,484

Table 14: Screenshot from the NREL PV Watt Online Calculator for a 4.8 kW PV Array

Dividing the AC energy calculator results for May through September by the number of days in each month, it is found that this 4.8 kW array would yield 15.48 kWh, 15.03 kWh, 15.65 kWh, 15.90 kWh, and 13.40 kWh per day respectively for each month. These values are all larger than the estimated 10 kWh daily load from the White Island appliances and fire requirements, and give a safe margin of error considering the values generated by the calculator might be overestimates and the house daily load calculations are rough estimates.

6.5.3 Spacing between Panels

Figure 46 presents the calculations used to find the sun's lowest altitude angle on September 30th. The latitude of 42.99°N for the Isle of Shoals was used in these equations.



Sun Altitude Angle Calculation for September 30th (Northern Hempisphere):

Altitude Angle = 90° - latitude degree + declination angle

Latitude of Isle of Shoals: **42.99° N**

Declination angle = -23.45° x cos(360/365 x (d + 10))
d = day of the year

September 30th is the 272nd day of the year (d = 272).

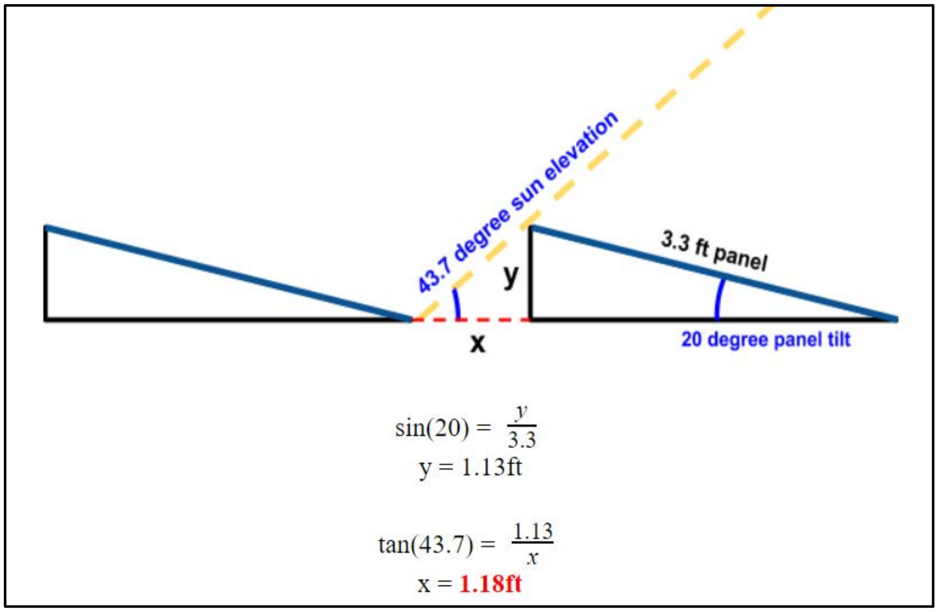
Declination angle = -23.45° x cos(360/365 x (272 + 10))
Declination angle = **-3.32**

Altitude Angle = 90° - 42.99° - 3.32

Sun Altitude Angle = **43.69°**

Figure 46: Summer Sun Angle Calculations

The lowest angle of the sun for the season was calculated to be 43.69° on September 30th. This angle was then used to find the amount of space needed between the panels for the running season. Figure 47 presents the calculations of the spacing needed in between the panels when the sun hits them at its lowest angle of the season (on September 30th).



$$\sin(20) = \frac{y}{3.3}$$
$$y = 1.13\text{ft}$$

$$\tan(43.7) = \frac{1.13}{x}$$
$$x = \mathbf{1.18ft}$$

Figure 47: Panel Spacing Calculations

A total spacing of 1.18ft is needed between the panels to allow each panel to receive the maximum sunlight without any shading.

6.5.4 Panel, Charge Controller, Inverter, and Battery Bank Selection

The solar panels that were recommended by Lee Consavage were the Canadian Solar MAXPOWER CS6X-310 panels (6.4 feet by 3.1 feet). These panels are rated at 310W, and therefore 16 of them are required to equate a 4.8 kW array (Figure 48).

$$Power\ Rating = 310\ W$$

$$\frac{4{,}800\ W}{310\ W} = 15.5 \rightarrow 16\ panels$$

Figure 48: Solar Panel Quantity Calculation

Charge controllers convert “wild” DC current from the panels to a constant 48 VDC current. The OutBack FLEXmax 60 selected by interns are rated at a maximum of 60A, and would therefore output a maximum of 2.8 kW (Figure 5). For a 4.8 kW array of 16 panels, two of these charge controllers are therefore required. For this design, there would be 8 solar panels per charge controller.

$$48\,VDC,\ 60A\ Max$$
$$Output = 48\ V \times 60\ A = 2{,}800\ W$$
$$\frac{4{,}800\ W}{2{,}800\ W} = 1.67 \rightarrow 2\ charge\ controllers$$

Figure 49: Charge Controller Quantity Calculation

Interns selected the battery bank arrangement and sizing based on the assumption that it should power the Caretaker’s house for approximately 5 hours after dark. Since the average house daily load was calculated to be 10.02 kWh, this is equivalent to a minimum of approximately 2.1 kWh of energy (for 5 hours) that should be available to drain from the batteries at night. A battery bank of 8 Trojan 8D-Gel Batteries rated at 188 Ah (5 hour rate) and 12 V, with two series of 4 batteries (since 12 V * 4 = 48 V), would allow to supply this 2.1 kWh demand for 5 hours past sunset (Figure 6). Assumptions are that the batteries will be drawn down to a minimum of 80% (therefore only 20% of their energy capacity is available).

$$\frac{10.02\ kWh}{1\ day} \times \frac{1\ day}{24\ h} \times 5\ h = 2.1\ kWh$$
$$188\ Ah \times 12\ V \times \frac{1\ kW}{1{,}000\ W} \times 8 \times 0.2 = 3.61\ kWh > 2.1\ kWh$$

Figure 50: Battery Bank Calculations

Interns sized the inverter to the rest of the system, choosing an OutBack Sealed FX3048T Inverter rated at 3 kW and 48 VDC.

6.5.5 Location Considerations

When first visiting the island the interns decided that potential locations for the solar panels, as color coded on Figure 51, would be the deck area (red), the current solar panel location (blue), the old generator room roof (green), and/or the Caretaker’s house roof space (orange).

Figure 51: Possible Solar Panel Locations on White Island

After meeting Ben Wilson, a Department Architect for the Department of Natural and Cultural Resources (DNCR), interns agreed with him that for historical and esthetic conservation of White Island, the best choice would be to locate panels on the generator room roof. According to Ben Wilson, renovation of this room should start in August 2019 and it will eventually serve as storage space. This renovation will include the construction of a flat roof and clearing out the old generators. Since the roof has to be built flat to match the historic aesthetic of what was previously there, solar panels will need to be mounted on a rack to achieve the needed 20 degree tilt.

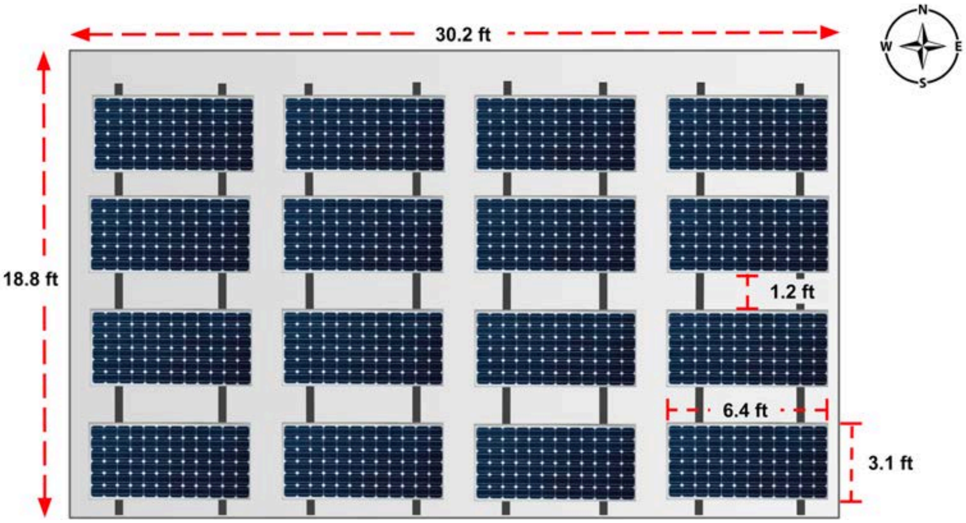


Figure 52: Diagram of Proposed Solar Panel Arrangement on the Generator Room Roof

The room dimensions were measured to be 30.2 feet by 18.8 feet (Figure 52), which allows to fit the 16 panels in 4 rows of 4 panels with the proper spacing of 1.18 feet in between them.

6.5.6 Cost Estimate

The cost for the recommended system components was estimated to be $15,304 (Table 3), the most expensive component being the batteries, which account for about 46% of the total cost.

	Model / Name	Quantity	Approximate Unit Price (USD)	Total (USD)
PV Panel	Canadian Solar MAXPOWER CS6X-310	16	335	5,360
Charge Controller	OutBack FLEXmax 60	2	420	840
Battery	Trojan 8D-Gel Solar Battery	8	888	7,104
Inverter	OutBack Sealed FX3048T	1	2,000	2,000
			TOTAL	15,304

Table 15: Estimated Cost for the Recommended Solar System Components

This budget estimate does not include the costs of renovating the generator room. Also, since the panels need to be tilted at a 20 degree angle, a roof mount for panels would need to be included which will increase costs.

6.5.7 Current Set-Up Improvements

A second visit of the island on July 3rd 2019 revealed that the solar panels are currently tilted to an angle close to 37.7 degrees (Figure 53), not the optimal 20 degrees for the summer season. Also, since the solar panels are close to one another, the rear panels are at risk of being shielded from the light when the sun angle is low. The output from these panels could therefore be increased if they were lowered to a 20 degree tilt, as modelled in our new design.

Figure 53: Picture of the Four Solar Panels Currently Set Up on White Island

Since the length of the current panels is of 3 feet, and the design goal is to maximize output during the summer season (May through September), the same calculations of sun altitude angle of 43.69 degrees (Figure 46) apply, and a panel spacing of 1.08 feet (following process of Figure 47) was calculated.

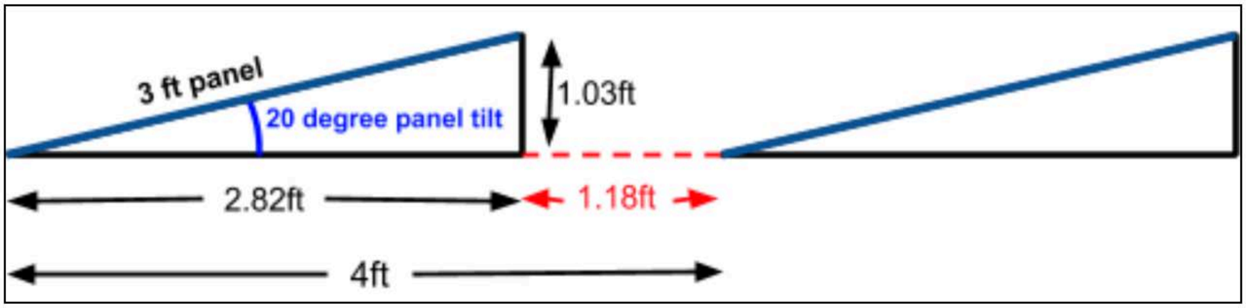


Figure 54: Recommended Set-up for Current Panels

The total distance from panel to panel in the current set-up was measured to be 4 feet. With a panel length of 3 feet and a tilt angle of 20 degrees, the horizontal panel distance is calculated by trigonometry to be 2.82 feet. Therefore, if the tilt of the panels in the current set-up is lowered to 20 degrees, the spacing would be 1.18 feet. This is larger than the calculated 1.08 feet of spacing required to prevent shading, so the current panels can simply be un-tilted without moving them.

6.6 Conclusions and Recommendations

Interns designed a solar system for the White Island Caretaker's House that is composed of 16 Canadian Solar MAXPOWER CS6X-310 solar panels, two OutBack FLEXmax 60 charge controllers, 8 Trojan 8D-Gel Solar batteries, and one OutBack Sealed FX3048T inverter, theoretically able to handle a daily house load of approximately 10 kWh, and extend power supply for at least 5 hours after dark. The specific components were chosen because their specifications worked well with model calculations, however other models from different brands with similar specifications could also be suitable.

The ideal location for the panels is on the roof of the generator room that should be renovated in the fall of 2019, in four rows of four panels. Panels should be facing South, each row separated by approximately 1.2 feet. The panels should be tilted at a 20 degree angle, which would require setting up a panel mount structure on top of the new flat generator roof. Mounting panels can increase the risk of wind damage over time which may reduce the lifespan of the panel. Building a 20 degree tilted roof for the generator room would avoid this and allow to lay the panels flat on the roof. Even though Ben Wilson from the DNCR advised against a tilted roof to maintain the historic structure of the building, interns recommend conducting a cost analysis of a tilted roof versus a flat roof with a panel mount, and looking more into New Hampshire regulations on rehabilitating historic buildings.

Assignment instructions were to design a system capable of extending supply 5 hours past dark, and to include State Fire requirements (exit signs, emergency lights, fire alarm system, carbon monoxide and smoke detectors) as part of the house load estimates. It seems unlikely that the designed system would be able to supply the fire safety appliances every day throughout the night. Interns therefore recommend that as part of the project, adding a back up generator to the system should be looked into.

Since the renovation of the generator room and the implementation of the new solar system design may take up to a few years, improvements should be made to the current solar panel system as to maximize energy output. Interns recommend simply lowering the tilt of the four panels to the optimal summer panel angle of 20 degrees. Due to the 4 week time constraint of the SEI program, interns did not get the opportunity to return to White Island for a third time to make the specified adjustments. Therefore, interns recommend for SML Island Engineers to make a trip to White Island at some point this summer and untilt the panels as per the recommendation in section *6.5.7*.

6.7 References

Canadian Solar CS6X-310P Solar Panel - 310 Watt Max Power, www.solarelectricsupply.com/canadian-solar-cs6x-310p-solar-panel-max-power-wholesale

“8D-GEL | Trojan Battery Company.” *Trojan Battery*, www.trojanbattery.com/product/8d-gel/

“FLEXmax 60/80.” *FLEXmax 60/80 - OutBack Power Inc*, www.outbackpower.com/products/charge-controllers/flexmax-60-80

“Outback FX3048T 3000 Watt 48 Volt Sealed Turbo Inverter / Charger.” *Inverters R Us*, https://invertersrus.com/product/outback-fx3048t/

“PVWatts.” *PVWatts Calculator*, https://pvwatts.nrel.gov/pvwatts.php

Assignment 7: Sustainability Rock Talk

All interns

7.1 Background

From the m1oment a student arrives on Appledore until they leave they are inundated with talk and signage about electrical and water conservation, composting toilets, composting food scraps, recycling, etc. SML promotes and strives to be a sustainable community not only out of necessity but also to set an example of what is possible in hopes that some lessons are transferable to the student's everyday lives on the mainland.

7.2 Purpose

Interns were tasked with seeing if residents were aware of various sustainability efforts. The interns were tasked with finding ways to improve Appledore's sustainability messaging.

7.3 Scope

Interns interviewed students to assess their knowledge of Appledore's sustainability efforts. Interns presented a 30 minute rock talk on their findings on July 8th 2019 to a group of high school students and undergraduate researchers.

7.4 Method

Interns compiled a list of 11 sustainability efforts. Interviewees were asked to name sustainability efforts off the top of their head. The interviewees were then asked to rank the 11 sustainability efforts by how important they thought they were to the island's sustainability. They were then asked what improvements could be made to increase Appledore's sustainability. Lastly, interviewees were asked what practices they would bring back with them to mainland. 30 Appledore residents were interviewed. This included students, undergraduate researchers, student staff, and captains.

Interns also sat in on the fire and water talks every new resident hears and various day tours. Interns identified all the various signage on the island.

7.5 Results and Analysis

Most people were able to name the efforts that they had interactions with and what was clearly visible. Other efforts could fall under the idea of out of sight, out of mind. Most residents do not have direct interactions with the rainwater collection system and solar water heaters. Some interviewees mentioned that they believed that the solar water heaters on the Water Conservation Building were additional solar panels. These results can be seen in Figure 55.

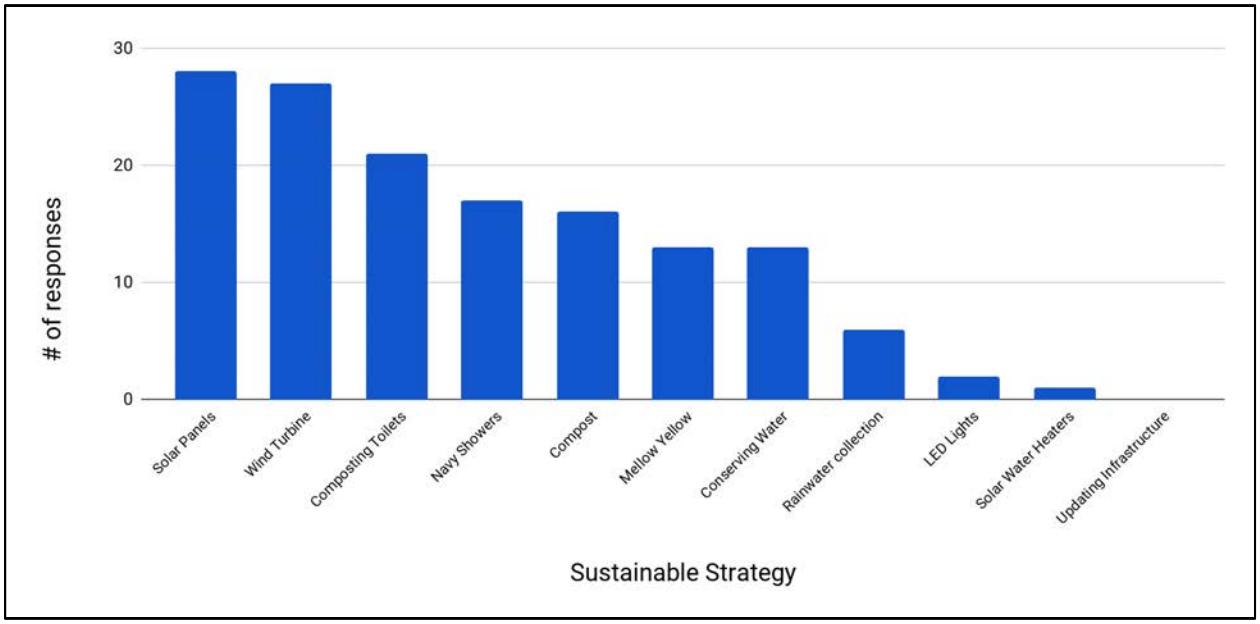


Figure 55: Known Sustainability Efforts

Residents made recommendations to improve conserving electricity, conserving water, and other introduced other sustainability efforts. To increase conservation of electricity, it was suggested that additional motion sensor lights be added. There are currently motion sensor lights in the Water Conservation Building and the showers. It was noted that some lights have been left on after people have left rooms or buildings. Converting the lights to motion sensor lights will help to eliminate this problem. There was a suggestion to implement seawater showers to reduce the draw on the well. Residents suggested expanding the garden to include fruits and vegetables and to use the compost to fertilize it.

7.6 Conclusion and Recommendations

There are informative and educational signs on the island. The informative signs are for things like remember to not let water flow unused or what items can be recycled. The educational signs talk about how Appledore residents use 20 gallons of water a day compared to the mainland where a person uses 100 gallons a day. It is suggested to increase the number of these signs and to increase their size. Some of the signs are small and easy to overlook.

The fire and water talk includes water conservation efforts and electrical conservation habits. It is suggested that the reason behind these efforts be included. Currently they efforts are briefly mentioned. Contextualizing the efforts can help the residents understand the importance of Appledore’s sustainability efforts.

Future Project Suggestions

Evaluation of New Refrigeration System

A new refrigeration system will be installed before the 2020 season. An evaluation of the system would be used to see how much the new refrigeration system has improved the energy usage compared to the 2018 and 2019 data.

Evaluation of New Compost

A new compost bin was installed down by the Energy Conservation Building before the 2019 season. There is currently a temperature logger in the compost. An evaluation can be completed to see how the compost is functioning. Possible uses for the compost can be explored.

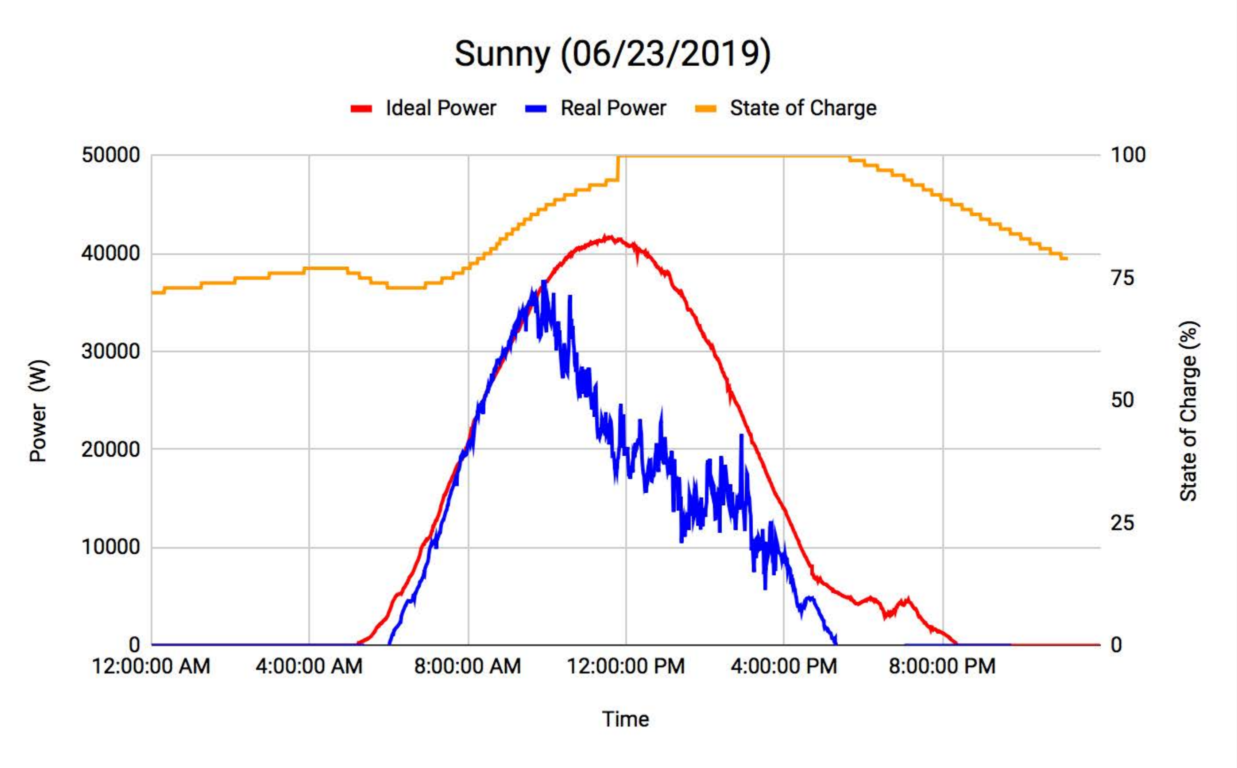
Radar Tower and Research Battery Technology

The Radar Tower batteries are the oldest batteries in the island's energy system. This means that they will be the first to be replaced. Interns should look into alternatives, both in terms of new battery technology and new ways to distribute the load on the island. Lithium batteries should be considered because of their superior technology.

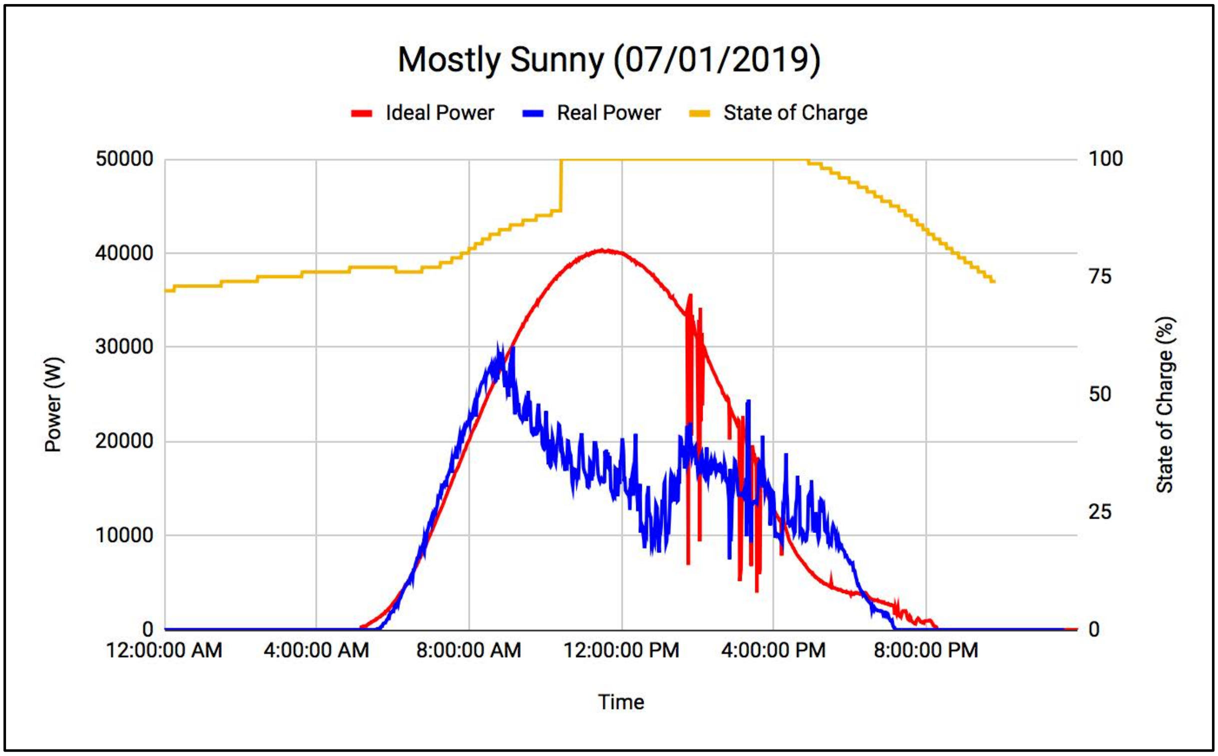
Stationary Bicycle for Energy Production

Many of the students and faculty iniquire about ways to exercise on the island. A new stationary bicycle could be made or purchased for people to use daily. Energy produced from cycling could be used for the green grid and displayed on the Dashboard for monitoring.

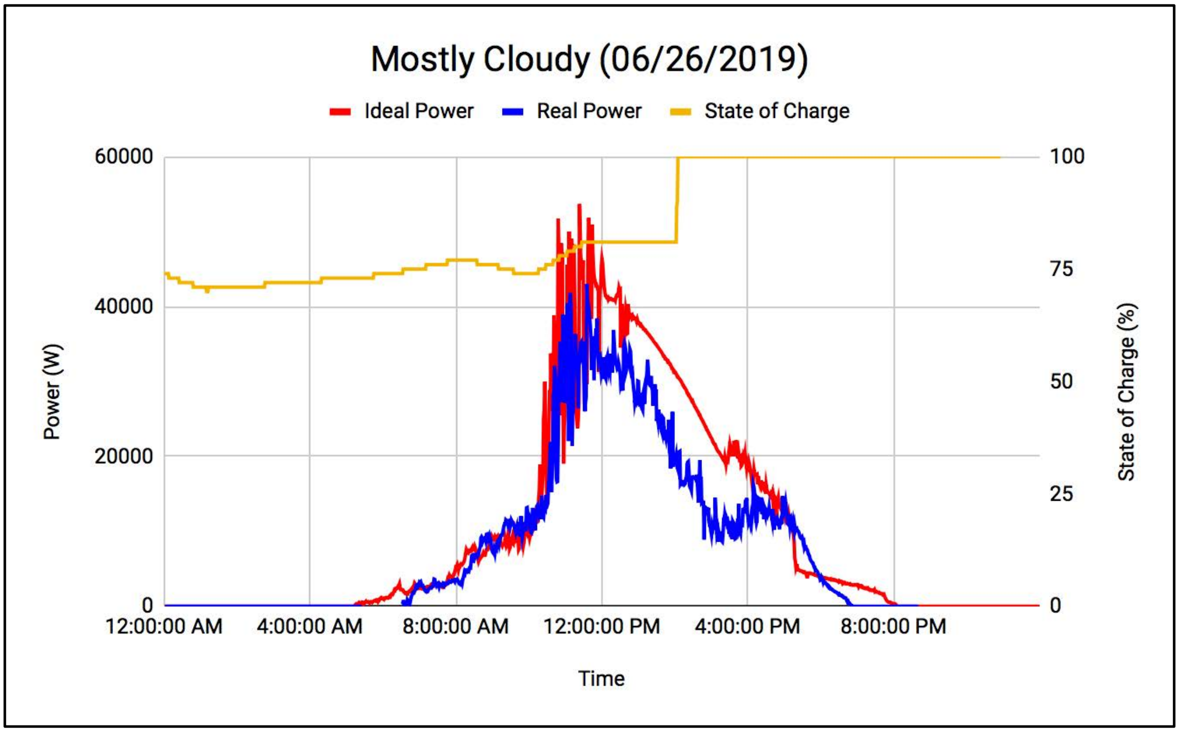
Appendix



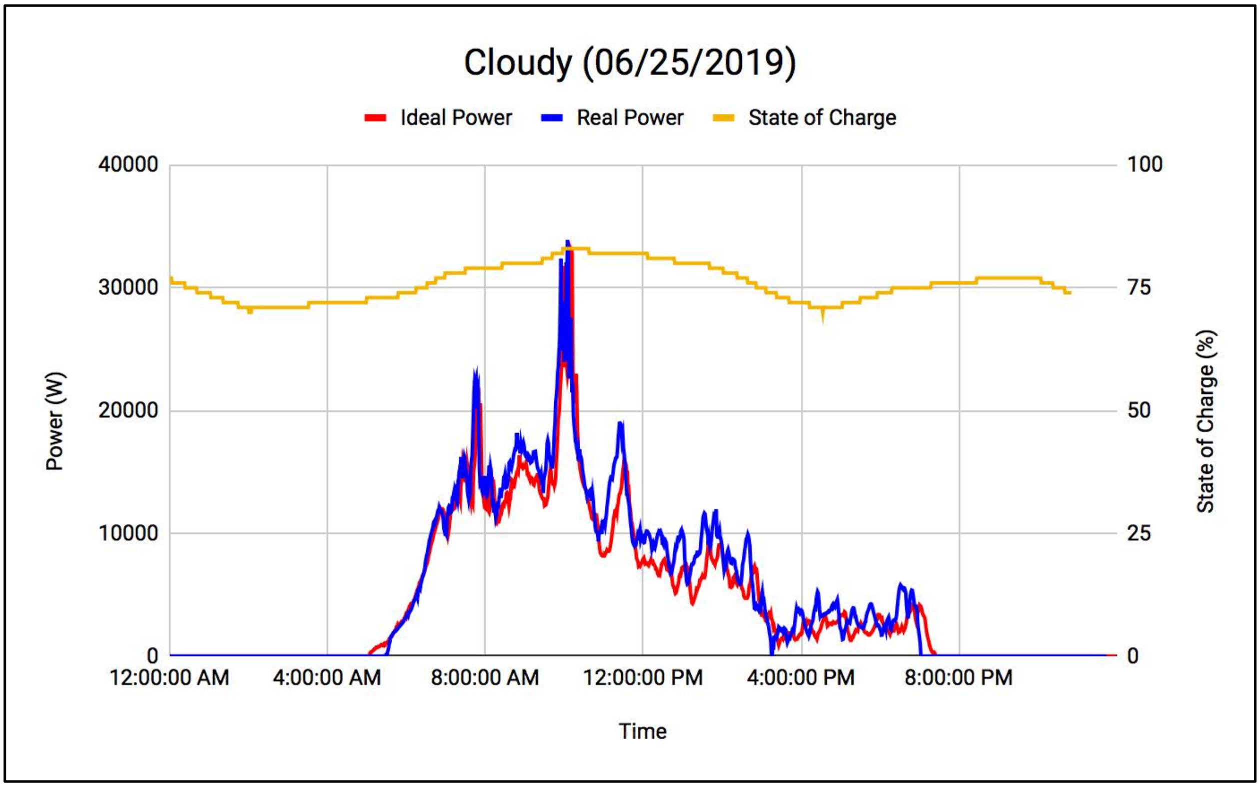
Appendix 1: Graph of State of Charge, Ideal Power, and Real Power over Time on a Sunny Day (June 23rd 2019)



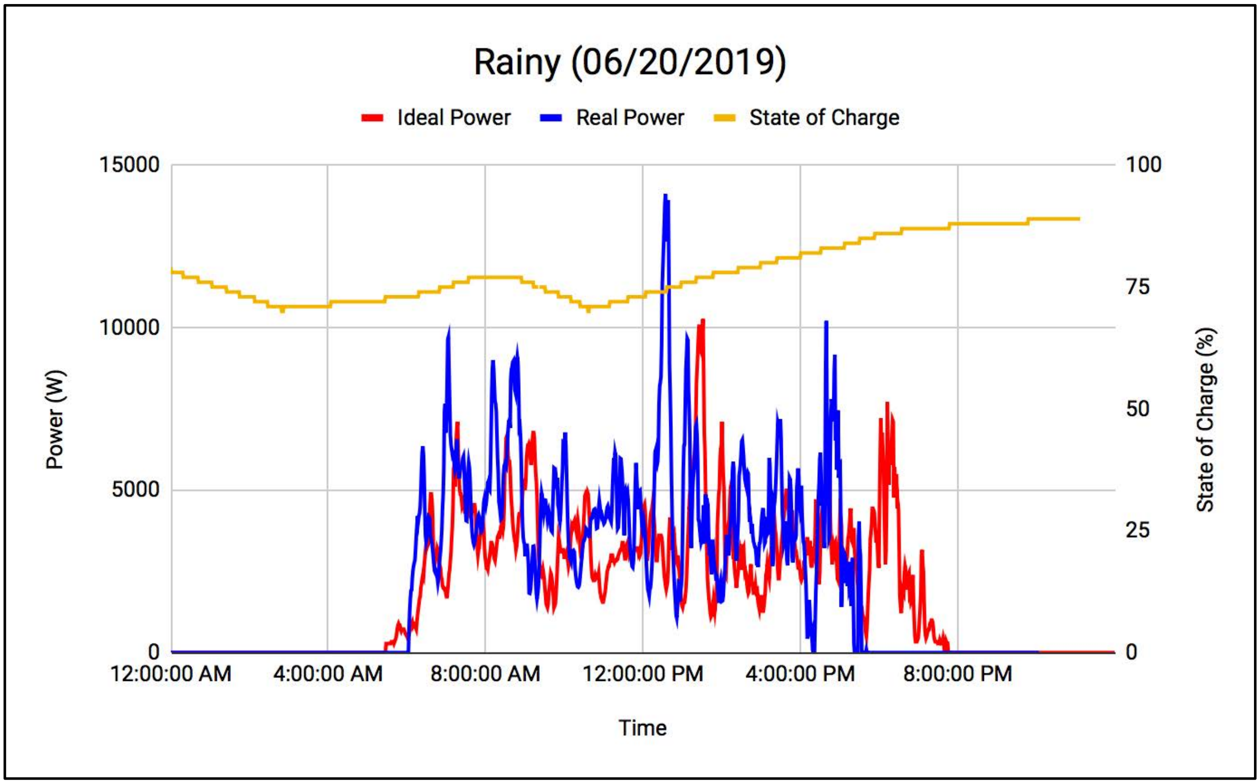
Appendix 2: Graph of State of Charge, Ideal Power, and Real Power over Time on a Mostly Sunny Day (July 1st 2019)



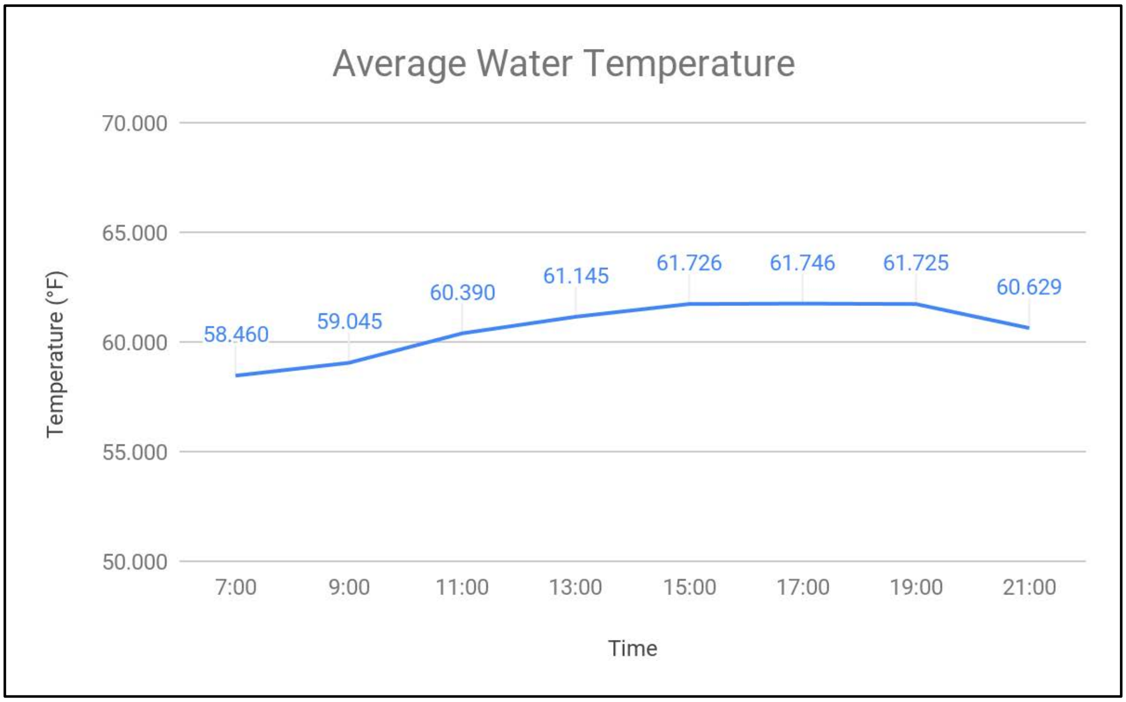
Appendix 3: Graph of State of Charge, Ideal Power, and Real Power over Time on a Mostly Cloudy Day (June 26th 2019)



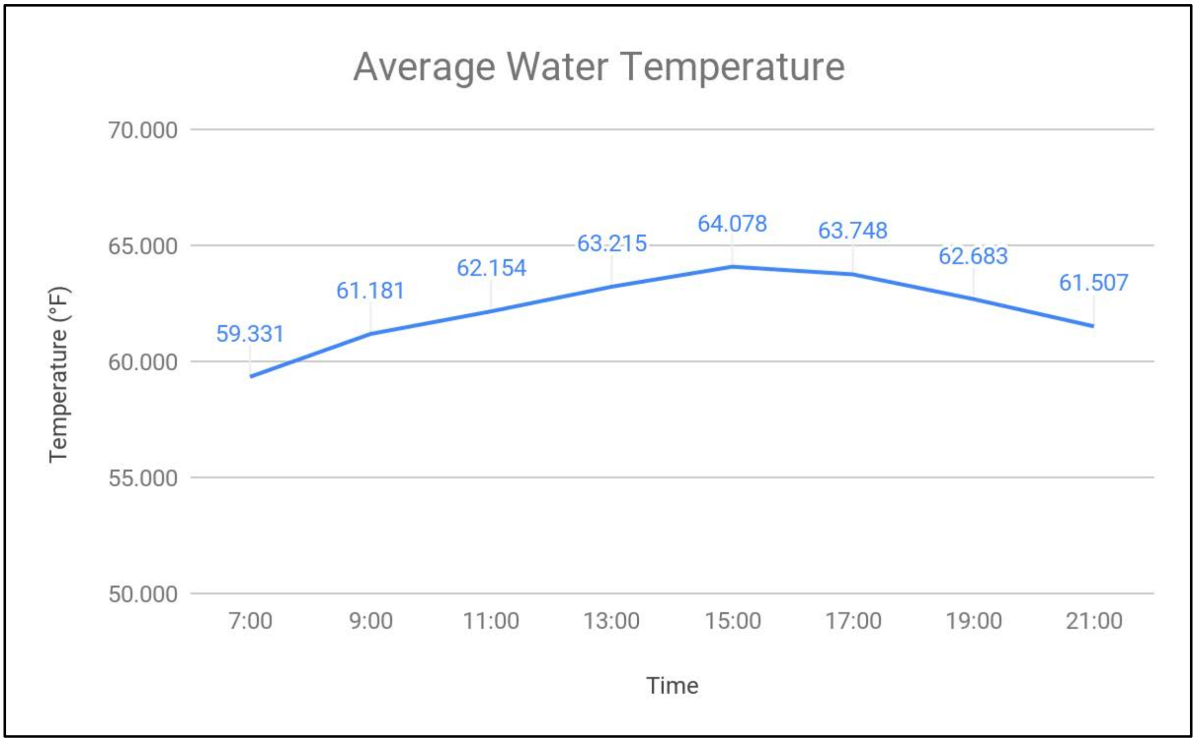
Appendix 4: Graph of State of Charge, Ideal Power, and Real Power over Time on a Cloudy Day (June 25th 2019)



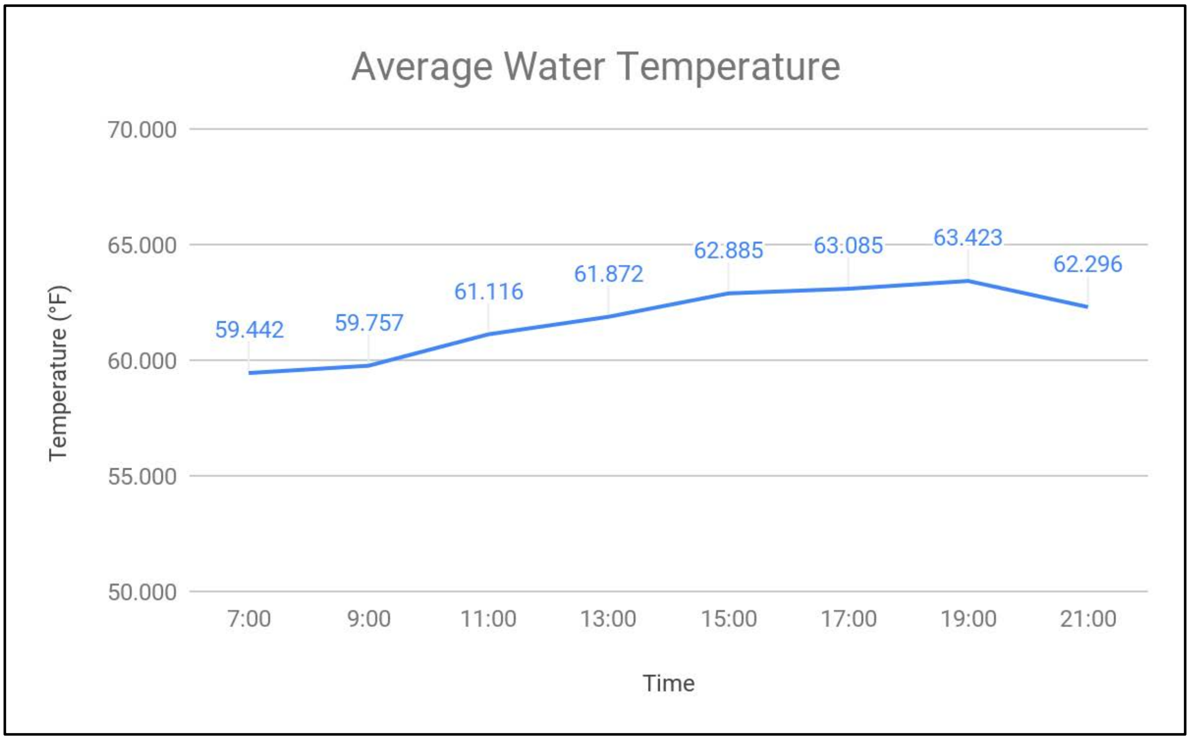
Appendix 5: Graph of State of Charge, Ideal Power, and Real Power over Time on a Rainy Day (June 20th 2019)



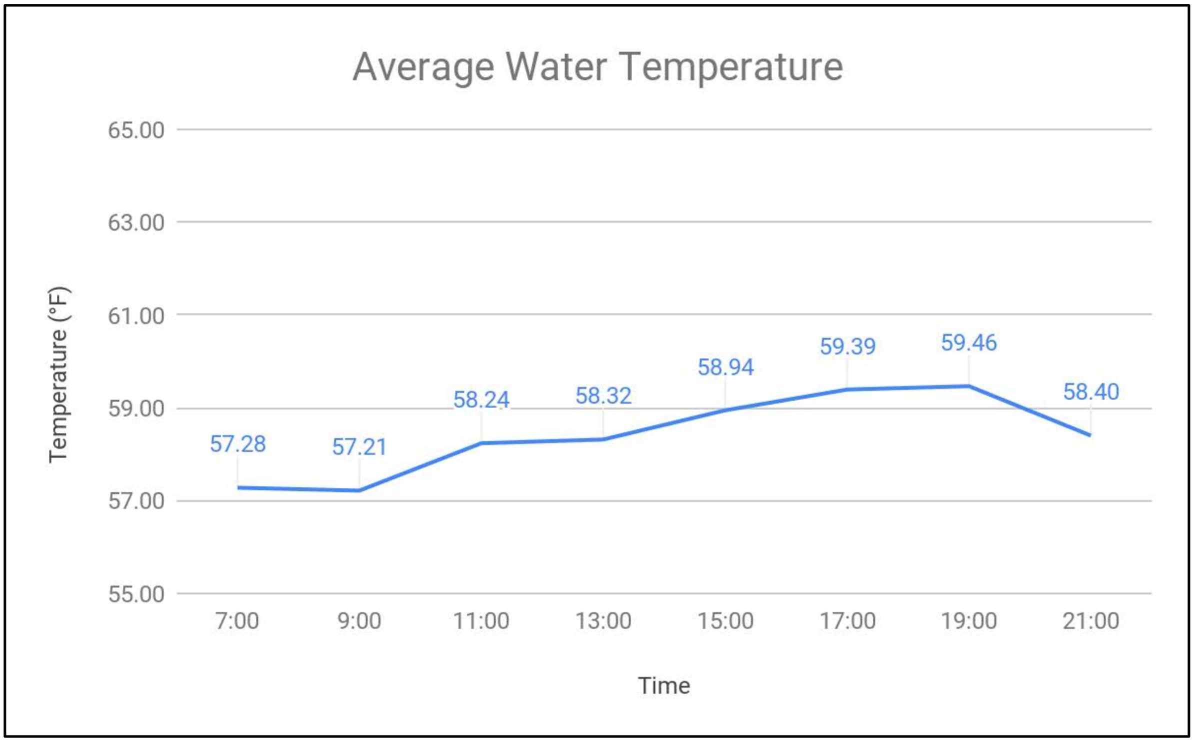
Appendix 6: Average Palmer - Kinne Sea Table Temperature



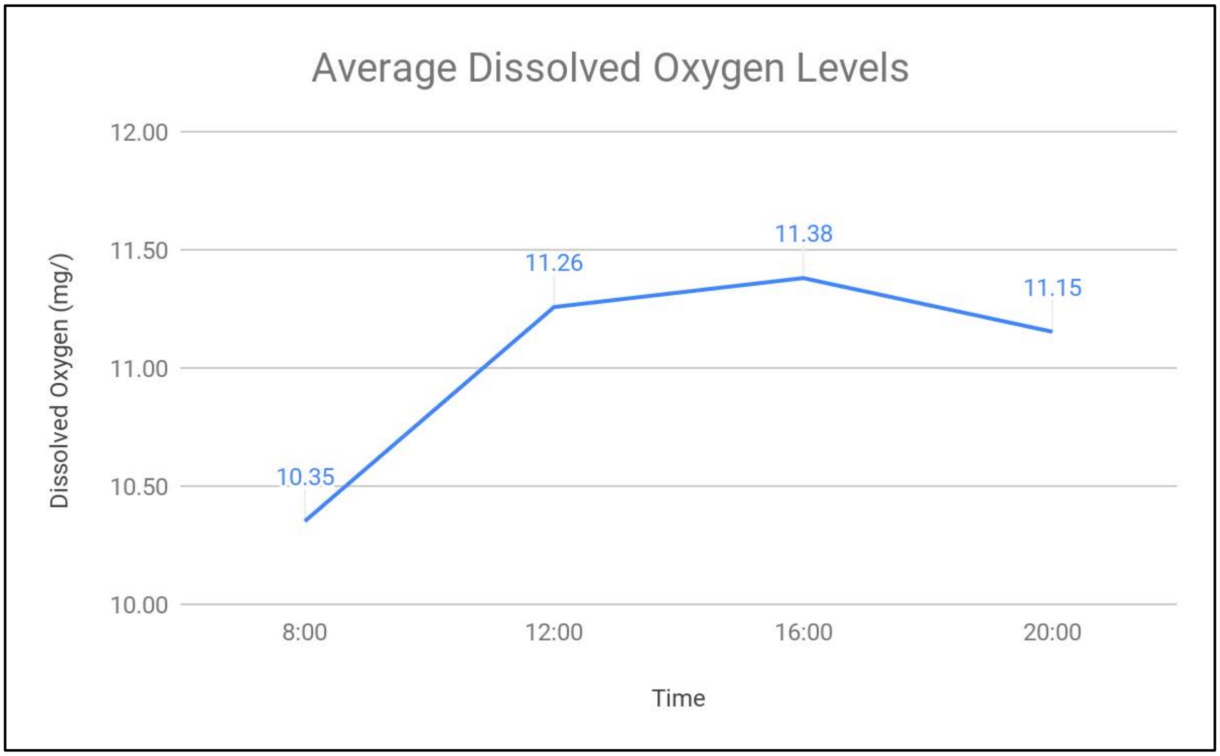
Appendix 7: Average Laighton Sea Table Temperature



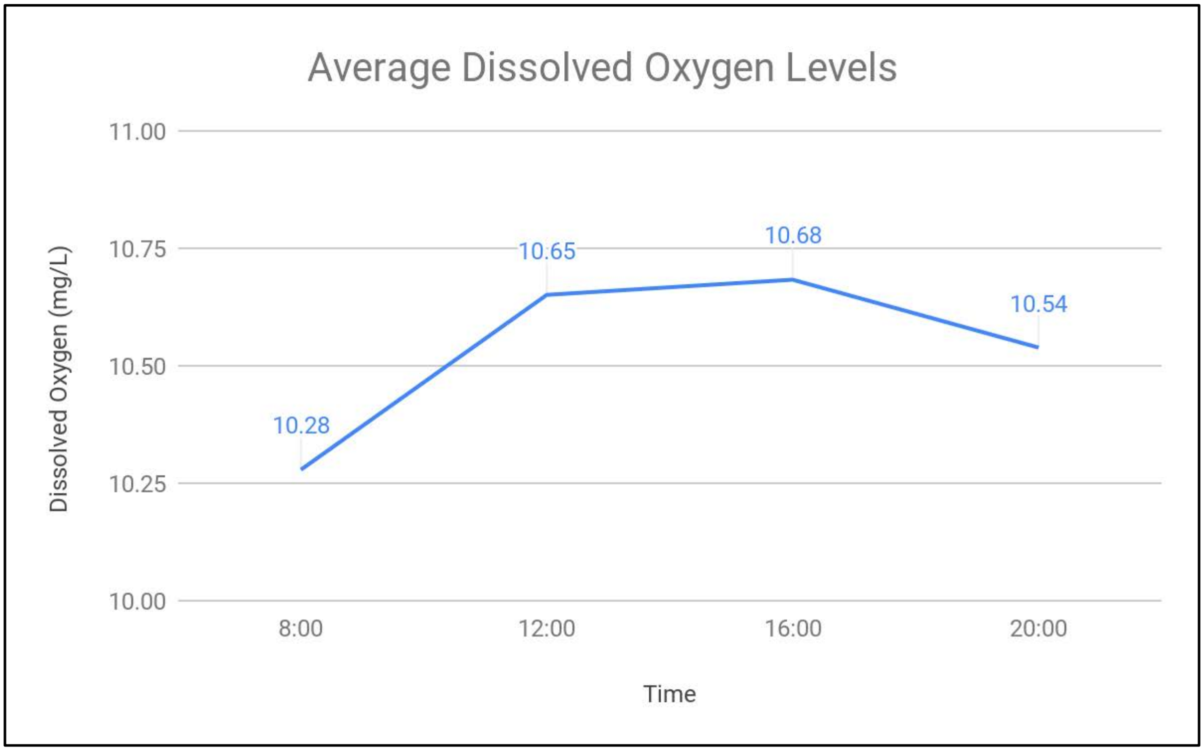
Appendix 8: Average Kiggins Sea Table Temperature



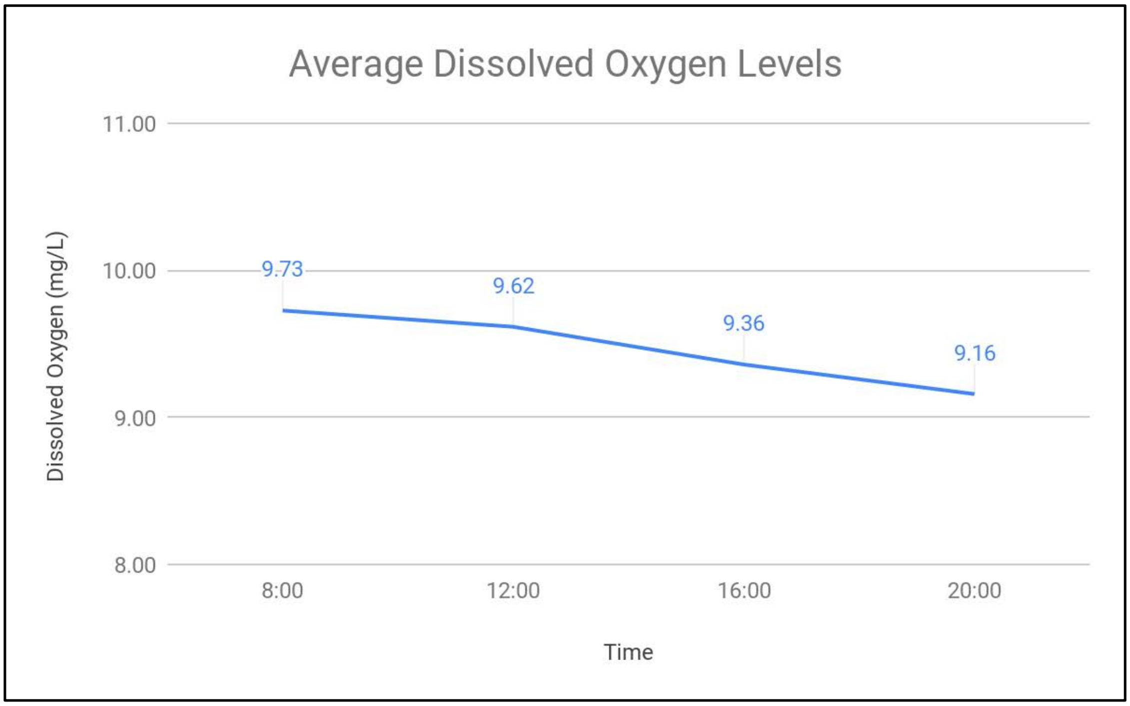
Appendix 9: Average Pump Intake Temperature



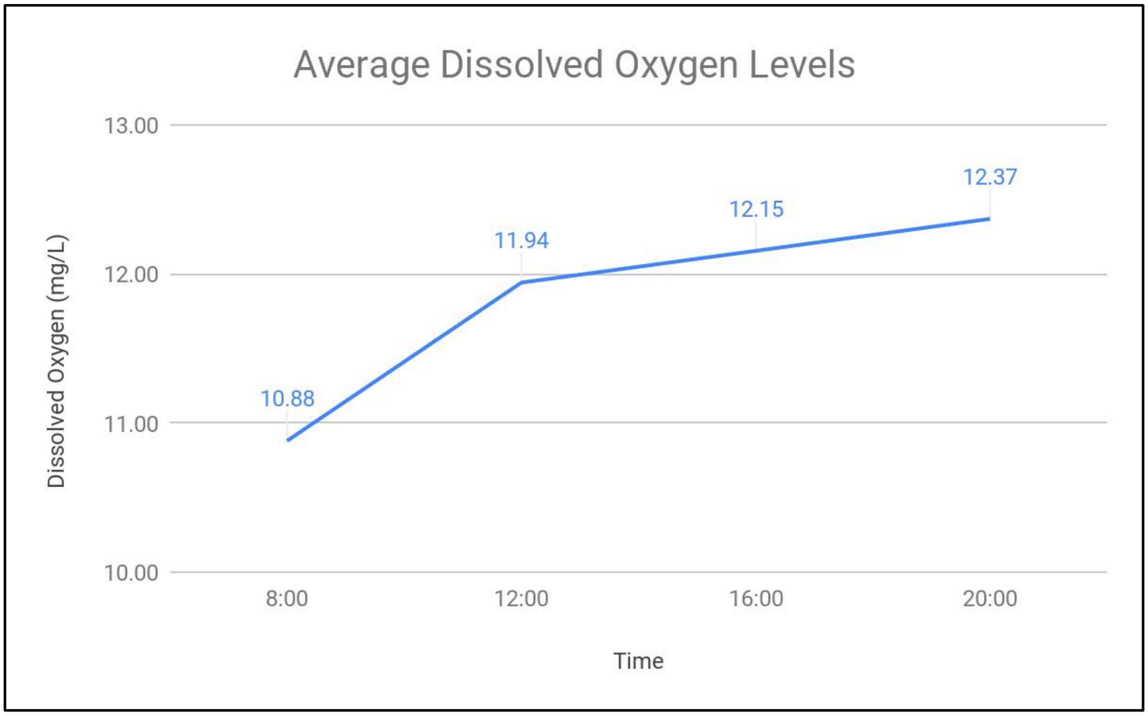
Appendix 10: Average Palmer - Kinne Sea Table DO Levels



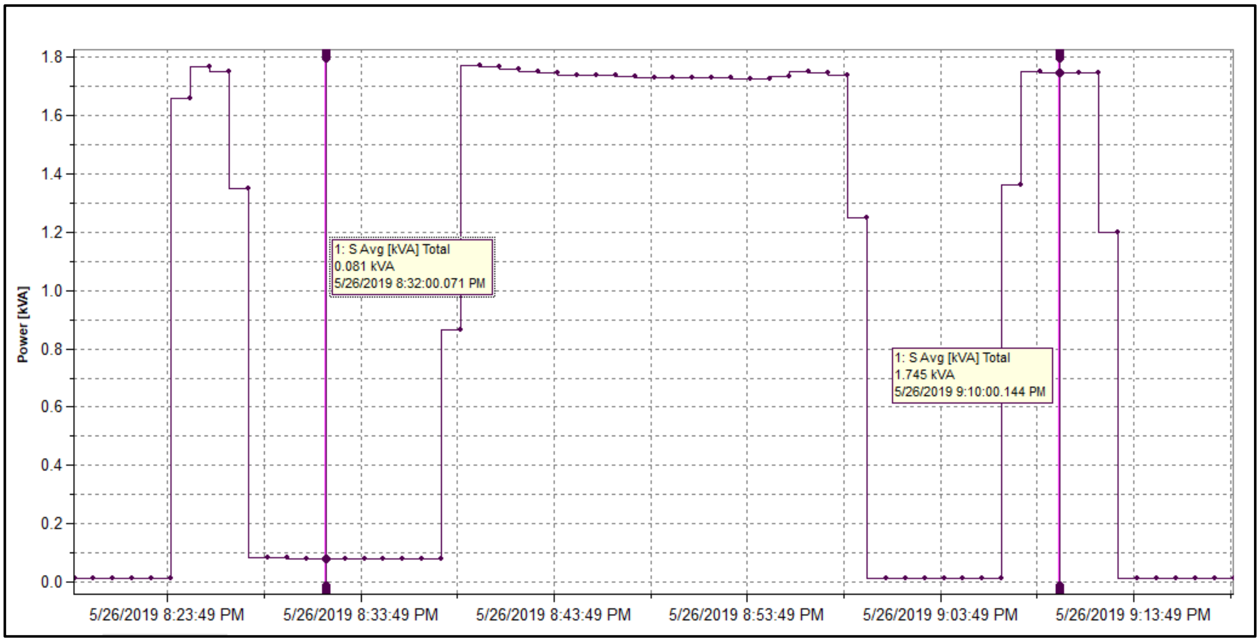
Appendix 11: Average Laighton Sea Table DO Levels



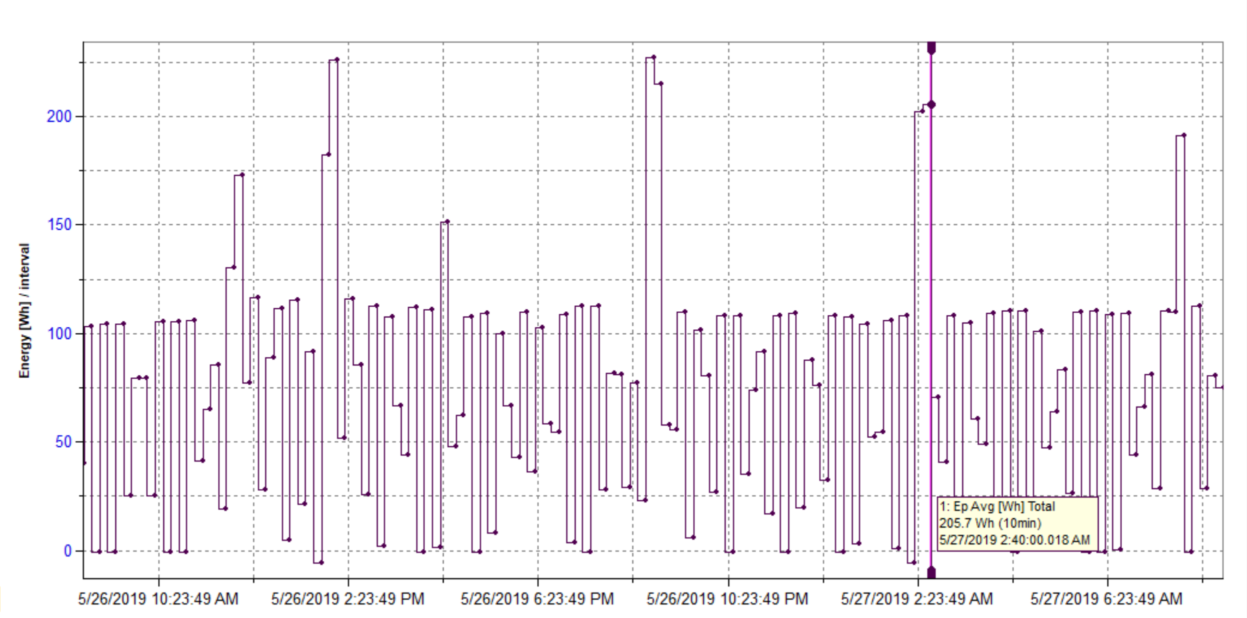
Appendix 12: Average Kiggins Sea Table DO Levels



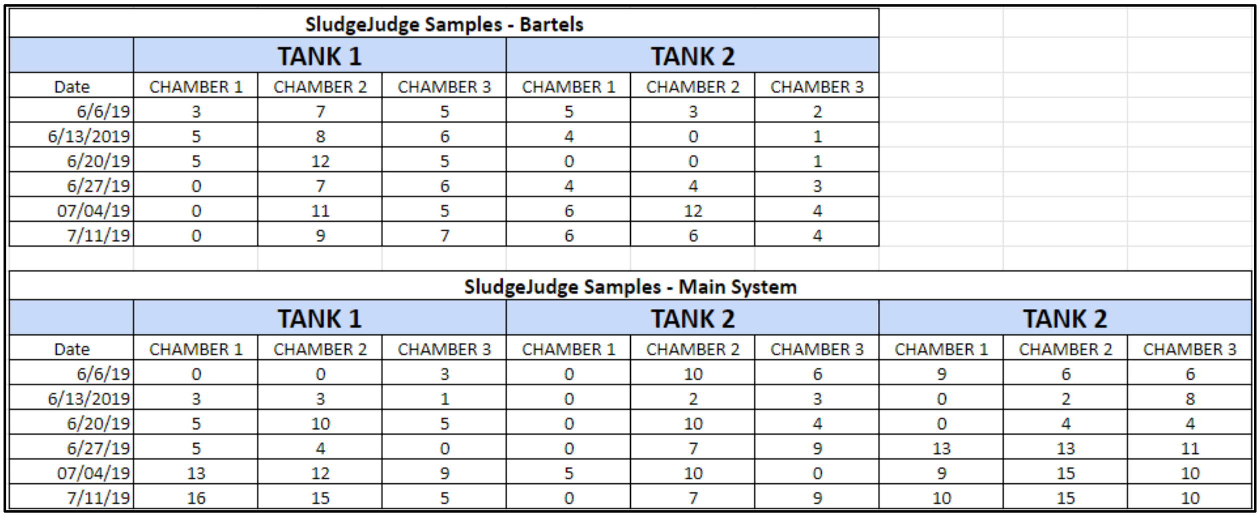
Appendix 13: Average Pump Intake DO Levels



Appendix 14: 2019 Graph of Power Supply to the Freezer Compressor Over One hour



Appendix 15: 2019 Graph of Energy Consumption of the Freezer Compressor Over One day



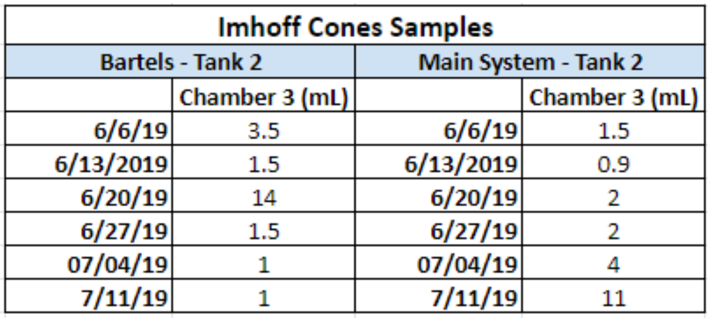
SludgeJudge Samples - Bartels

	TANK 1			TANK 2		
Date	CHAMBER 1	CHAMBER 2	CHAMBER 3	CHAMBER 1	CHAMBER 2	CHAMBER 3
6/6/19	3	7	5	5	3	2
6/13/2019	5	8	6	4	0	1
6/20/19	5	12	5	0	0	1
6/27/19	0	7	6	4	4	3
07/04/19	0	11	5	6	12	4
7/11/19	0	9	7	6	6	4

SludgeJudge Samples - Main System

	TANK 1			TANK 2			TANK 2		
Date	CHAMBER 1	CHAMBER 2	CHAMBER 3	CHAMBER 1	CHAMBER 2	CHAMBER 3	CHAMBER 1	CHAMBER 2	CHAMBER 3
6/6/19	0	0	3	0	10	6	9	6	6
6/13/2019	3	3	1	0	2	3	0	2	8
6/20/19	5	10	5	0	10	4	0	4	4
6/27/19	5	4	0	0	7	9	13	13	11
07/04/19	13	12	9	5	10	0	9	15	10
7/11/19	16	15	5	0	7	9	10	15	10

Appendix 16: Sludge Judge Data for Main System and Bartels



Imhoff Cones Samples

Bartels - Tank 2		Main System - Tank 2	
	Chamber 3 (mL)		Chamber 3 (mL)
6/6/19	3.5	**6/6/19**	1.5
6/13/2019	1.5	**6/13/2019**	0.9
6/20/19	14	**6/20/19**	2
6/27/19	1.5	**6/27/19**	2
07/04/19	1	**07/04/19**	4
7/11/19	1	**7/11/19**	11

Appendix 17: Imhoff Cone Samples for Bartels and Main Syste