2010

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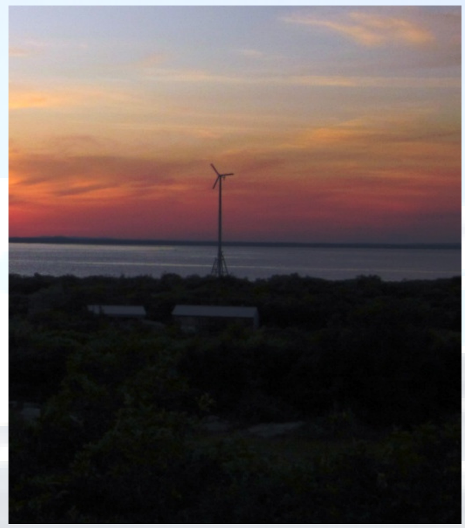

[SML SUSTAINABLE ENGINEERING INTERNSHIP]

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Introduction

At Shoals Marine Laboratory, sustainability is a ubiquitous concern; it is necessary because of the limited resources and desire to keep the environment in its natural state so its components can be easily researched. SML is the ultimate location for engineering students to explore sustainability because the scale of the systems on the island is small, so every change makes a significant difference. The Sustainable Engineering Internship program began in 2006. Since then, interns have made important discoveries and recommendations, such as adding a second saltwater pipe, installing composting toilets and leach fields, and running a smaller generator.

This summer's goal was to build on the foundation set in place by past interns via examining the island systems, making further recommendations, and providing a basis for future interns in order to minimize SML's impact on the environment. This year's challenges included determining the effectiveness of solar panels and wind turbine, determining the helpfulness of the gray water system, determining the possibility of using Crystal Lake as a freshwater source, finding ways to reduce energy use, exploring options for improving the saltwater pump, improving the acoustics of Kiggins Commons, and finding ways to winterize the Kingsbury House.

Alternative Energy

Background

Currently the green grid only powers the radio tower, AIRMAP's devices, and Dorms One and Two. It was observed that after the new solar panels were installed and connected to the green grid the batteries were frequently full. This meant that the three heaters in the tower were kicking on frequently wasting green energy produced by the island. In addition, the solar panels are programmed to collect less energy than they are capable of when the batteries are full. This is a waste of potential green energy so the possibility of expanding the green grid was explored by investigating how often the batteries are fully charged.

Objective

Maximize renewable energy output efficiency and use.

Dorm 2 Solar Panels

Data Collection

Data was collected for the battery voltage at roughly the same time every day after the new solar panels were installed by looking at the OutBack Mate in the radio tower because the battery data AIRMAP collects electronically was not available after the new solar panels were installed. This small amount of data was compared to the battery data available for the summer of 2010 before the new solar panels were installed to see how often the battery was full before the new array was installed.

Note: Battery voltage data was found on AIRMAP's data archive websites:

http://soot.sr.unh.edu/airmap/archive/

http://soot.sr.unh.edu/airmap/rawdata/

Analysis

The percentage of time each day the batteries were full during 2010 prior to the installation of the new solar panels is shown in Table 1 and graphed in Figure 1. The results of the data collected after the new solar array was installed by looking at the Mate in the radio tower is shown in Table 2 and graphed in Figure 2. We defined full to be any time when the battery voltage was above 55 volts.

Table 1: Percentage of Each Day Battery is full in Summer Season 2010

Date	% of Day Battery Full
14-May-10	0
15-May-10	30
16-May-10	35
17-May-10	35
18-May-10	0
19-May-10	75
20-May-10	35
21-May-10	35
22-May-10	10
23-May-10	30
24-May-10	35
25-May-10	70
26-May-10	45
27-May-10	20
28-May-10	0
29-May-10	0
30-May-10	25
31-May-10	30
1-Jun-10	10
2-Jun-10	0
3-Jun-10	0
4-Jun-10	0
5-Jun-10	0
6-Jun-10	0
7-Jun-10	30
8-Jun-10	30
9-Jun-10	15
10-Jun-10	5
11-Jun-10	0
12-Jun-10	0
13-Jun-10	0
14-Jun-10	0
15-Jun-10	0
16-Jun-10	0
17-Jun-10	0
18-Jun-10	0
19-Jun-10	25
20-Jun-10	30

21-Jun-10	0
22-Jun-10	0
23-Jun-10	0
24-Jun-10	5
25-Jun-10	25
26-Jun-10	40
27-Jun-10	0
28-Jun-10	0
29-Jun-10	20
30-Jun-10	0
1-Jul-10	50
2-Jul-10	40
Average	**16.7**

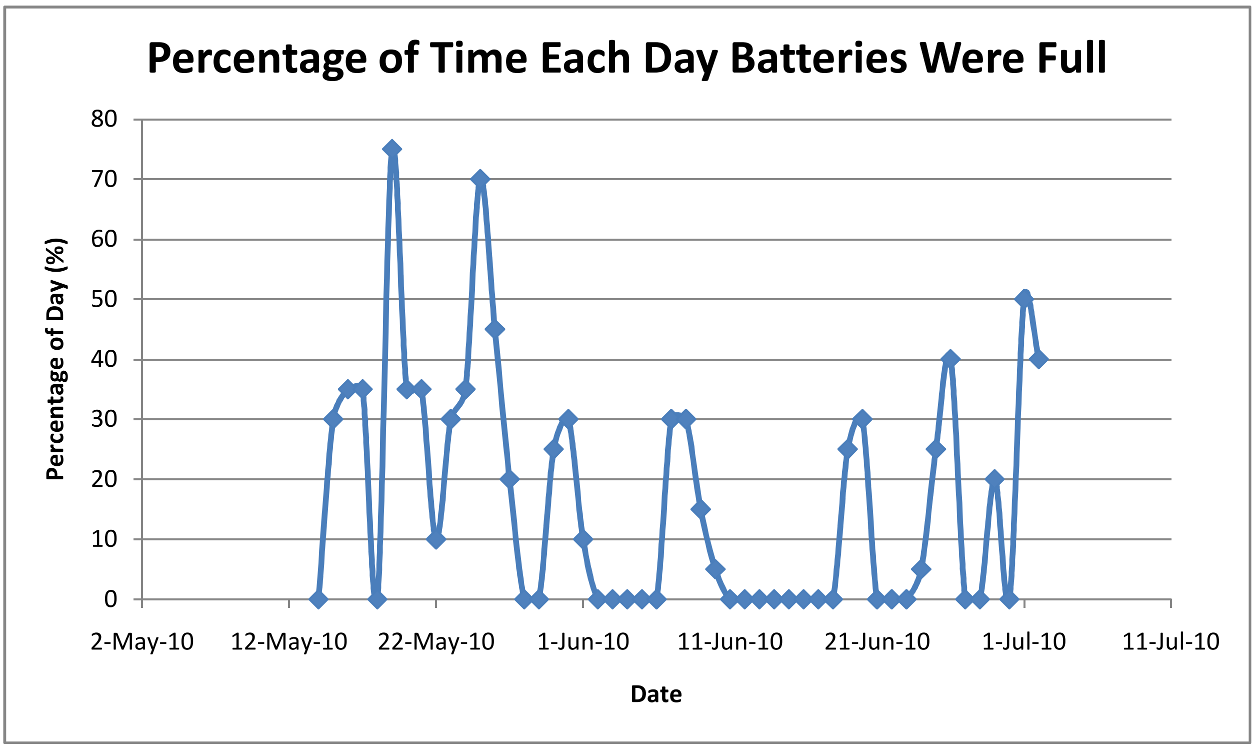

Figure 1: Percentage of Time Each Day Battery is full in Summer Season 2010

Table 2: Battery Voltage at Various Times of Day after New Solar Panels were Installed

Time	Battery Voltage (volts)
6/30/2010 16:35	55.1
7/1/2010 8:50	55.2
7/2/2010 8:30	55.3
7/3/2010 8:30	52.1
7/4/2010 9:25	55.4
7/5/2010 8:30	53.2
7/6/2010 7:20	52.4
7/7/2010 8:20	52.4
7/8/2010 8:40	52.8
7/9/2010 9:20	55.6
7/10/2010 8:40	55.2
7/11/2010 9:20	54.4

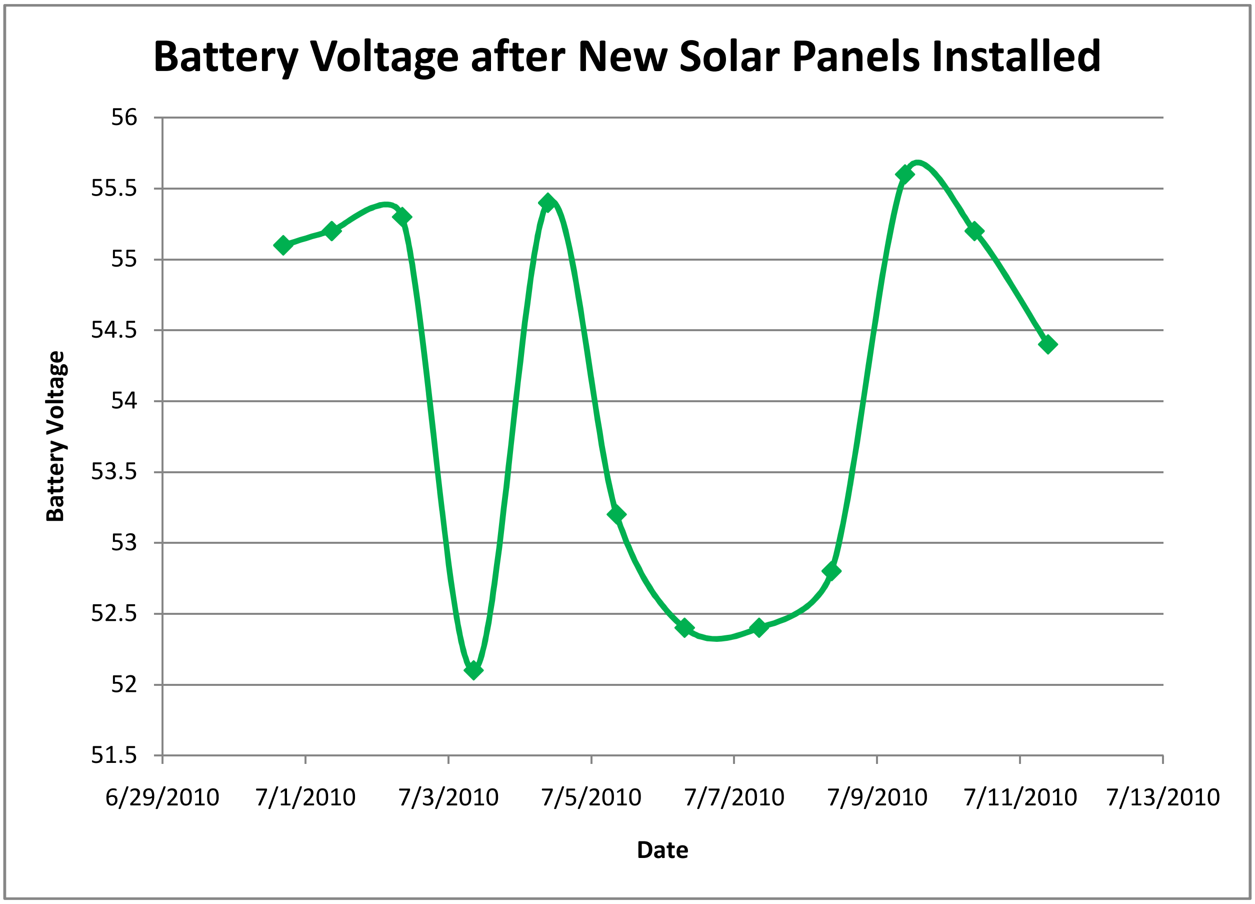

Figure 2: Battery Voltage at Various Times of Day after New Solar Panels were Installed

It can be seen from this data that six of the twelve days we checked the battery voltage in the morning the battery voltage was full. This is in no way conclusive evidence that the batteries are frequently full because this data only represents the instantaneous battery voltage at one time in the day. These results simply suggest that the battery voltage level be investigated further as Kevan Carpenter's data become available to determine how much potential green energy is actually being wasted.

The batteries are full an average of 16.7% of the day according to our rough estimate from the summer of 2010 battery voltage data found on AIRMAP's data archive websites. Figure 2 shows that on some days the battery bank is full a significant portion of the day while many other days it is not full at any part of the day. This is very inconclusive data and it is hard to tell from this whether the old green grid could have supported another building. It must be kept in mind that Dorm 2 was only connected to the green grid starting in late June so the battery voltage does not reflect full Dorm 2 usage. There are very few days in June where the battery was full for a significant part of the day so it can be preliminarily concluded that the old green grid could not have supported another building like Palmer-Kinne.

Palmer-Kinne was selected as the next logical building to be connected to the green grid because it is the closest building to the radio tower and therefore would be the easiest to wire and lose the least energy due to line losses. Palmer-Kinne is a classroom laboratory and would also predominantly draw energy during the day. The dorms draw energy at night (due to charging computers, cell phones, lights, etc.) so connecting Palmer-Kinne to the green grid would evenly distribute the load on the green grid between night and day.

Recommendation

There is very little data about the battery voltage after the new solar panels were installed. We recommend that the battery voltage be investigated further by the interns next year to determine how often the batteries are full and how much green energy is being wasted by turning off the heaters and programming the solar panels to produce less energy when the batteries are full. It can then be determined whether this wasted potential green energy can power an additional building like Palmer-Kinne.

From the battery voltage data before the new solar panels were installed it can be concluded that there was not enough energy to connect a building like Palmer-Kinne to the green grid.

Dorm 2 Solar Panels – Bird Feces Study

Data Collection

On June 30, 2010 the new solar panel array was connected to the green grid, combining the energy of the solar panels on Dorm 1, Dorm 2, and the wind turbine.

When we installed the new solar panels we noticed that within one day there were already multiple bird droppings. After three days, the panels were as dirty as the old array. We tried cleaning them so we could take a nicer picture of them, but the bird poop did not wash off easily. Even with significant elbow grease, streak marks remained. We searched the internet and *More Other Homes and*

Garbage (1981) for scientific evidence that bird droppings and dirt reduce the power output of photovoltaic panels, but we could not find any. Although we found no scientific reports our research showed multiple sources that recommended cleaning them in order to maintain their efficiency. This is only a significant problem during dry seasons with very little rain because the rain washes off the solar panels very effectively.

We researched several products that deter birds which we could either purchase or build ourselves for a lower cost. The products are listed in Table 3, and they are pictured in Figures 3 through 7 below.

Table 3: Bird deterrent devices on the market and their characteristics

Device	Method of deterring birds	Figure number	Price	Could we make it ourselves?
Bird-B-Gone Spider	"Arms" bounce and sway in the wind, scaring birds	3	$35	Yes
Bird-B-Gone Balloon	Shiny eye spots scare gulls	4	$19.60 for a 3-pack	Yes
Red-tailed hawk decoy from Gooddeals.com	Birds are scared of hawks	5	$19.99	No
Marine Pro bird call emitter	Runs on a 12-volt battery, emits bird distress calls to make birds think there is danger around	6	Need to get a quote, probably expensive	No
Gull Sweep	Spins in the breeze, scaring gulls away	7	$41	Yes
Gull wing on a stick	Birds want to keep their wings		Free	Yes

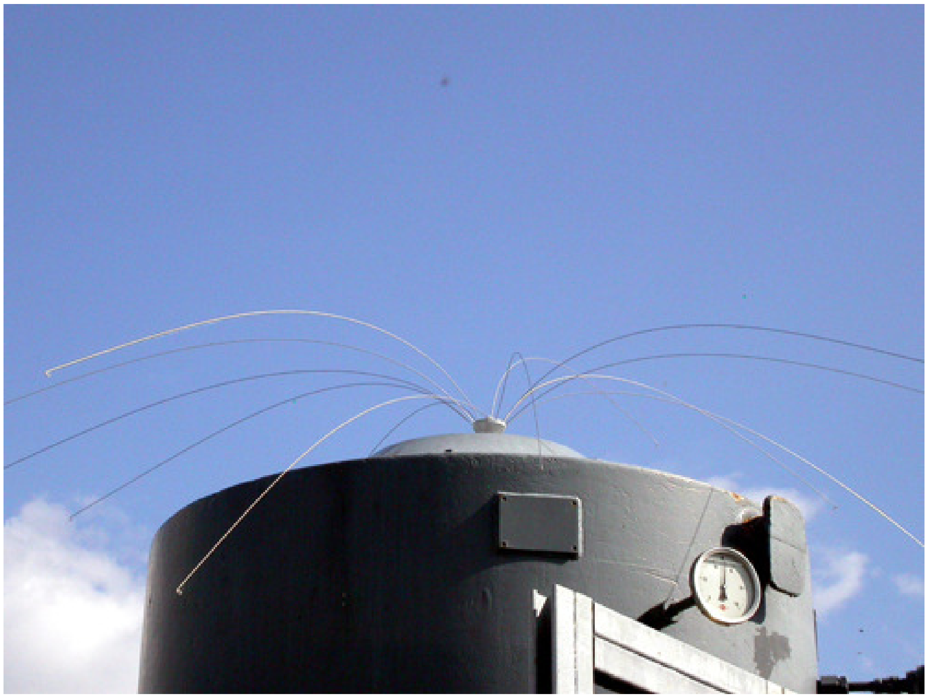

Figure 3: Bird Spider. Picture courtesy of Bird-B-Gone

Figure 4: Bird-X SE-PAC Scare Eye Balloon. Picture courtesy of Amazon.com

Figure 5: Red-tailed hawk decoy. Picture courtesy of Gooddeals.com

Figure 6: Marine Pro bird call emitter. Picture courtesy of Bird Gard Australia

Figure 7: Mike Dalton's boat with a Gull Sweep (horizontal bar with red flags)

Analysis

The Bird Spider, balloons, and Gull Sweep are all inexpensive solutions to the gull problem. A concern with the hawk decoy is that it might scare all of the gulls off the island. A snowy owl scared away all the gulls on White Island a couple of years ago. The Marine Pro bird call emitter uses electricity, and is probably very expensive. A bird wing tied to a stick might scare birds away, but it also might decay and have to be replaced often. Replacing the dead bird body part would be an unpleasant job, and sometimes there are no dead birds around. We mounted a dead bird wing we found on the ground to a wooden support and put it on the roof of Dorm 2. It has been up for several days but gulls have still been found on and around the solar panels. Mike Dalton brought a Gull Sweep that he had on his boat that seems to work well. It is a simple bar mounted on a small mast. The cross bar is free to turn, and it has flat pieces of plastic attached vertically to the ends to catch the wind.

Recommendation

To keep the gulls and their droppings off the solar panels, we recommend that the island staff purchase or build one of the simple products in the table above. The spider, the balloon, and Mike Dalton's gull sweep would all be adequate.

Wind Turbine Energy Output

Data Collection

There is no meter on the wind turbine to record the actual energy output, so a theoretical evaluation was conducted. The estimated power generation from the wind turbine based on wind speed data was calculated using the following equations.

Power Calculation

$$Power = Power\ Density\ \cdot Area\ of\ Turbine$$

$$Power\ Density = \frac{1}{2} \cdot (air\ density) \cdot (wind\ speed)^3$$

Using the air density at sea level:

$$Power\ Density = 0.05472 \cdot (wind\ speed)^3$$

Where: the units of power density are in Watts per square meter and the units of wind speed are in miles per hour

$$Area\ of\ Turbine = \pi r^2$$

Where: r = 3.5 m is the radius of the wind turbine at Appledore Island

$$Area\ of\ Turbine = \pi \cdot 3.5^2 = 38.48\ m^2$$

Therefore:

$$\boldsymbol{Power = 2.106 \cdot (wind\ speed)^3}$$

Where: the units of power are in Watts and the units of wind speed are in miles per hour

Energy Calculation

$$Energy = Power \cdot Time \cdot Overall\ Efficiency$$

Estimated Overall Efficiency

$$Overall\ Efficiency = (Rotor\ Loss) \cdot (Transmission\ Loss) \cdot (Generator\ Loss) \cdot (Power\ Conditioning, Yawing, and\ Gusts\ Loss)$$

$$Overall\ Efficiency = 0.4 \cdot 0.9 \cdot 0.9 \cdot 0.9 = 0.29$$

Therefore:

$$Energy = 0.611 \cdot (wind\ speed^3) \cdot (time)$$

Equation 1: Wind Turbine Energy Output

Analysis

Table 4 uses this equation to estimate the energy produced per hour, per day, per month, and per year and various average wind speeds.

Table 4: Estimated Energy Produced by Appledore Wind Turbine at Various Average Wind Speeds

	Energy Produced (kWh)			
Wind Speed (mph)	Per Hour	Per Day	Per Month	Per Year
5	0.08	1.83	54.99	669.05
10	0.61	14.66	439.92	5352.36
15	2.06	49.49	1484.73	18064.22
20	4.89	117.31	3519.36	42818.88
30	16.50	395.93	11877.84	144513.72
40	39.10	938.50	28154.88	342551.04
50	76.38	1833.00	54990.00	669045.00

Table 5 shows real average wind speeds and estimated energy outputs for various months at Appledore Island. These particular months were chosen because they had the most wind speed data available.

Table 5: Estimated Energy Output by Appledore Wind Turbine Using Actual Wind Speed Data

		Energy Produced (kWh)	
Month/Year	Wind Speed (mph)	Per Hour	Per Month
Oct-08	16.13	2.56	76.92
Dec-08	20.64	5.37	161.17
Jun-09	13.41	1.47	44.20
Dec-09	24.26	8.72	261.72
Mar-10	21.06	5.71	171.21

Recommendation

Purchase and install a meter so that the wind turbine energy output can be accurately recorded year-round and further studied by future interns. This meter will also aid in considering the wind turbine as a source of energy for wintertime researchers.

Waste Gray Water Solution

Background

The Kingsbury House, built in 2001, has its own gray water system, which leaches through a Frickle Filter (Figure 9) and then out into a small leach field. Two of the three toilets are connected to a large composter (Clivus Multrum M10) and the remaining toilet is connected to a small composter (Clivus Multrum M1/M2). The M10 was installed in 2007 and the M1/M2 in 2008. The liquid end product from the composting toilets goes through the Frickle Filter to the leach field. In 2008, it was discovered that there was no foam media in the Kingsbury House Frickle Filter so foam media was added to it.

Until 2009, the rest of the island's wastewater was chlorinated, de-chlorinated, and discharged into the ocean. SML now has two leach fields, one for Bartels and one for Kiggins Commons, Founders, Hamilton, and the Grass Lab. They are outside Bartels and the Commons respectively. The gray water system is shown in Figure 8. The 2009 engineering interns found that the Commons' leach field was not working properly, so more sand was added to the sides. A layer of clay was added to the slope of the three exposed sides of both leach fields in 2009.

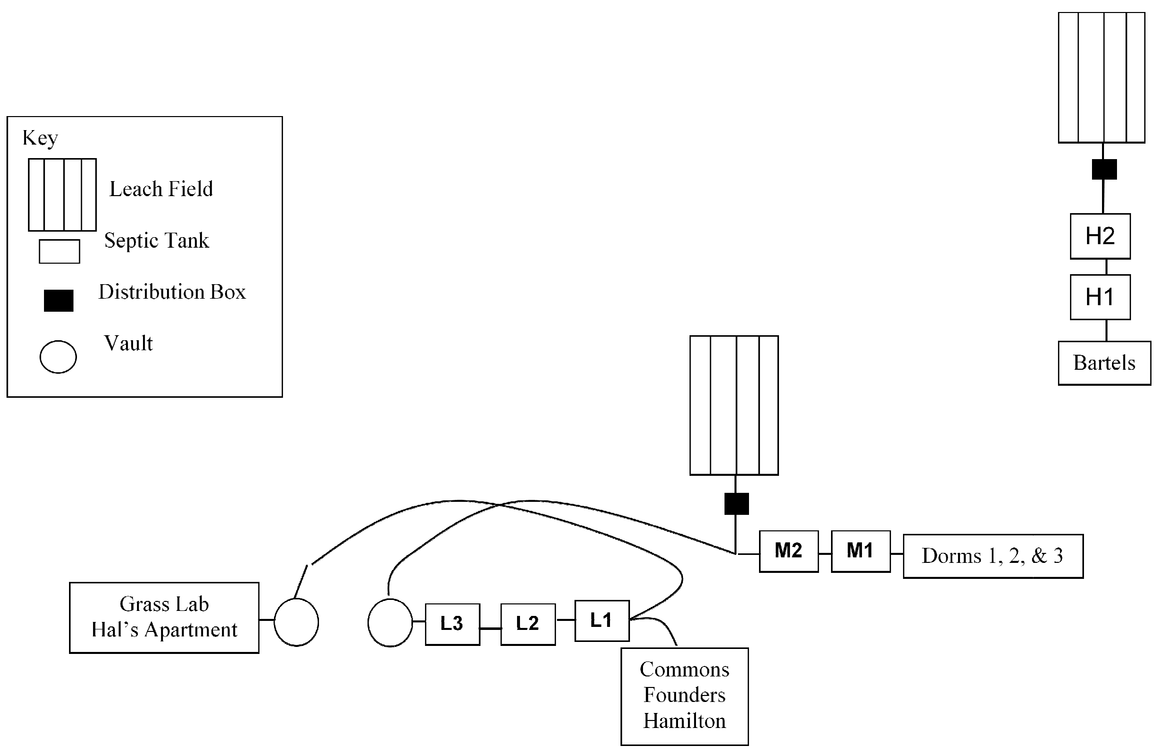

Figure 8: Main Waste Water System

Both Bartels and the Commons have septic tanks to collect the solids before discharging the liquid to the leach field. Core samples were taken from each of the septic tanks to determine the percentage of solid in the tanks. This is an indication of how full these septic tanks are. This data will act as a baseline for a yearly assessment of the amount of solids in the tanks. This will allow island staff to know when they need to pump the septic tanks. It will also enable future interns to determine the effect that the composting toilets that are to be added to the Commons at the end of this season have on reducing solid waste.

The 2009 engineering interns tested the Kiggins Commons leach field to determine the fecal coliform levels and found that the field was not working up to its full potential. They mentioned that the fields' performance should improve over the years as they grow biological mats to filter the water.

From analysis of the fluid from the Kingsbury House composting toilets, they found the M10 composter might not be working properly because it had much more fecal coliform than the M1/M2 composter.

Objective

Determine the effectiveness of the Kingsbury House's composting toilets and the leach fields outside Bartels and Kiggins Commons. Determine the percentage of solids in the septic tanks.

Data Collection

Bartels

In order to test the leachate from the Bartels leach field, we needed to know where the water was leaching out of the field, so we poured Rhodamine dye into the distribution box and checked the edges of the field for the dye every day thereafter.

Kiggins Commons

We took samples from the distribution box and sent them to Eastern Analytical Incorporated (EAI), the same lab as last year, to be tested for five-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), and fecal coliform. BOD_5 is the amount of oxygen consumed in the sample in a five-day period. Discharging high levels of BOD into the environment is not desirable because it can rid bodies of water of dissolved oxygen so that nothing can grow. TSS is a measure of the non-dissolved solid material in the sample. TKN is the sum of the organic nitrogen, ammonia, and ammonium concentrations. High levels of nitrogen that are discharged into the environment can get into bodies of water and cause eutrophication, the excessive growth of plants and algal blooms. These consume all of the oxygen in the water and inhibit other growth, much like BOD. Fecal coliform bacteria indicate the presence of pathogens in the water.

We did not perform the same tests as the 2009 interns because the test wells were dry.

Kingsbury House

For the composting toilets at the Kingsbury House, we extracted samples from the pipe that carry the liquid end product from the large composter to the Frickle Filter and used a pump to receive a sample from inside the smaller composter. As for the Frickle Filter, we tested the entrance and the exit areas. These were also sent to EAI, to be tested for BOD, TSS, TKN, and fecal coliform. A diagram of the Frickle Filter can be seen in Figure 9.

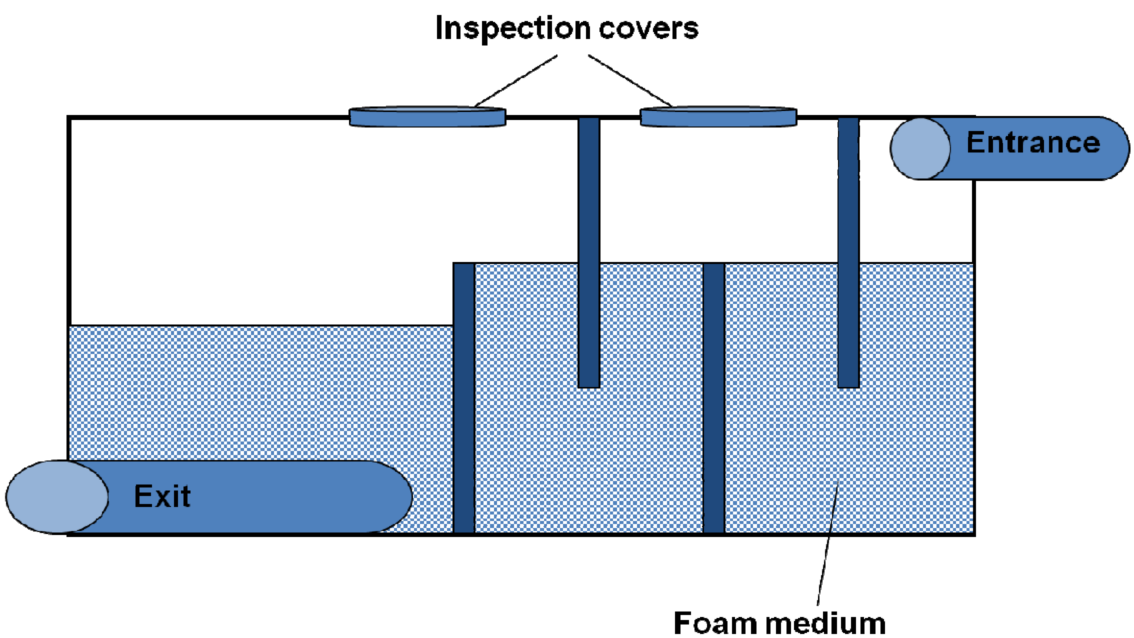

Figure 9: Frickle Filter Diagram

Septic Tanks

A core sample was taken from each of the septic tanks starting at 7:30 PM on July 7, 2010. The sampling was started at the highest septic tank by the wastewater pump. There are three septic tanks in this location and they were named from highest to lowest L1, L2, and L3 for lower 1, lower 2, and lower 3. These septic tanks are fed from Kiggins Commons, Founders, and the Grass Lab. The two septic tanks near the leach field by Kiggins Commons were sampled next. These samples were named from highest to lowest M1 and M2 for middle 1 and middle 2. These two septic tanks are fed from dorms. The two septic tanks near Bartels were sampled last. These samples were named from highest to lowest H1 and H2 for high 1 and high 2. These two septic tanks are fed from Bartels.

Samples were taken using a core sampler. The height of solid in each sample was estimated by looking at the amount of dark substance in the core sampler. The core sample was then discharged into a bucket and stirred. A 45 ml test tube was then used to scoop the sample from this bucket. These samples were then placed in a glass container of known mass and placed in a drying oven between 103 degrees Celsius and 105 degrees Celsius. These samples were then left in the drying oven for 24 hours and then moved to a cooling chamber. After the samples cooled they were re-weighed to determine the dry weight of the sample. The percentage of solids in the septic tanks was then calculated from this data.

Analysis

Bartels

We looked for the dye once or twice a day for two weeks and never found it. According to Al Frick, the designer of the leach fields, wastewater should move through the soil at two inches per hour. This number remains valid regardless of the rainfall because the wastewater flow, not the rainfall, is the main driver of flow through the leach field. This means that although we had almost no rain during the observation period, we should have seen the dye within three or four days. Wastewater on the surface of the soil is not a good thing, so the disappearance of the dye could mean that the leach field is working, but it could also mean that the wastewater is dropping straight down through the rocks. To find out, we recommend that next year's interns get in touch with Al Frick and do further tests.

Kiggins Commons

The lab results from EAI for BOD, TKN, and TSS for the Commons distribution box are displayed in Table 6. Last year's fecal coliform result is also included. Unfortunately, there were not enough bottles to test fecal coliform this year, so no comparisons can be made. No tests were done last year for BOD, TKN, or TSS at the leach fields.

Table 6: Kiggins Commons Distribution Box Test Results

Year	BOD (mg/L)	F. coliform (MPN/100mL)	TKN (mg/L)	TSS (mg/L)
2009	Not tested	1,830,000	Not tested	Not tested
2010	590	Not tested	60	76

Kingsbury House

The lab results from EAI for BOD, fecal coliform, TKN, and TSS in the composting toilet liquid are shown in Tables 7 and 8. Unfortunately, SML does not have the specifications for the composters, so the data from the lab cannot be compared to a standard. Joe Ducharme, SML's contact at Clivus, has been contacted for specifications, but none have been received yet. Table 7 shows the results for the entrance and exit of the Frickle Filter. It should be noted that the Frickle Filter is filled with small pieces of foam, which may inflate the total suspended solids number.

Table 7: Clivus Multrum M10 liquid end product results from 2008, 2009, and 2010

Year	BOD (mg/L)	F. coliform (MPN/100mL)	TKN (mg/L)	TSS (mg/L)
2008	65	300,000	1,200	53
2009	<60	>1,600	730	80
2010	<60	14	1,000	38

For both composters, EAI reported that "though several dilutions were run, oxygen depletion was not great enough to calculate a valid BOD result. An elevated detection limit has been reported." The numbers are ambiguous, but it looks like in the larger composter, the Clivus Multrum M10, the BOD improved somewhat from 2008 to 2009 and then stayed the same from 2009 to 2010. The fecal coliform improved dramatically each year. The drop from 300,000 MPN/100mL to just 14 is most likely due to the addition of peat in 2009. The TKN has hovered around 1,000 mg/L, decreasing by 39% between 2008 and 2009 and then increasing by 27% between 2009 and 2010. The total suspended solids increased by 51% from 2008 to 2009 and then decreased by 53% from 2009 to 2010. The M10 seems to be doing well.

Table 8: Clivus Multrum M1/M2 liquid end product results from 2009 and 2010

Year	BOD (mg/L)	F. coliform (MPN/100mL)	TKN (mg/L)	TSS (mg/L)
2009	89	<2	670	94
2010	<300	>1,600	1,200	310

In the smaller composter, the Clivus Multrum M1/M2, the BOD may have gone up by as much as 237%, but the lab result is ambiguous, so it may even have gone down. The fecal coliform went up very significantly. The TKN and TSS also went up, by 79% and 230% respectively. The TSS number could be an overestimate because we may have stirred up suspended solids from the bottom or sucked them into the sample with the pump we used to take the sample.

The liquid from the Kingsbury House composters goes to a Frickle Filter before entering a small leach field. The test results from the entrance and exit of the Frickle Filter are shown in Table 9.

Table 9: Results for entrance and exit of Frickle Filter from 2010

	BOD (mg/L)	F. coliform (MPN/100mL)	TKN (mg/L)	TSS (mg/L)
Entrance	150	>1,600	50	92
Exit	260	Not tested	60	990
Septic Tank Effluent Standard*	118-189	10^6 to 10^7	29-63	38-85

*Standards are from Inspectapedia, http://www.inspectapedia.com/septic/sludgescum.htm. Septic tank standards may vary.

There were not enough bottles to test the exit of the Frickle Filter for fecal coliform. However, BOD, TKN, and TSS all went up between the entrance and the exit, by 73%, 20%, and 976% respectively. TKN and fecal coliform meet Inspectapedia's septic tank effluent standards, but BOD and TSS do not. The increase in TSS is probably severely inflated because some of the foam medium ended up in our sample. The concentrations at the entrance could be low because an influx of gray water from a shower or a load of laundry diluted the effluent. It was also noted that the Frickle Filter is missing a splash plate and skim layer that are in the plans.

Septic Tanks

The observational results of the testing are shown in Table 10. The empirical results from the drying test are shown in Table 11.

Table 10: Observational Results from the Septic Core Samples

Sample	Notes	% Solids by Volume
L1	4.5 feet total, 4.5 feet solids	100
L2	4.5 feet total, 1.2 feet solids	27
L3	2.5 feet total, 0.5 feet of solids, scum at top	20
M1	2.5 feet total, 0.5 feet solids, clear above	20
M2	2.5 feet total, 2.5 feet clear	0
H1	2 feet total, 0.25 feet solid, 1 foot clear, 0.75 feet grease	12.5
H2	2 feet total, 2 feet clear	0

Table 11: Empirical Results from Drying Test

Sample	Weight of Container (g)	Weight of Container with Wet Sample (g)	Weight of Dried Sample (g)	mg Total Solids/L	% of Solids
L1	113.72	162.67	114.82	24,444	2.25
L2	326.92	377.47	327.33	9,111	0.81
L3	322.91	372.64	323.17	5,778	0.52
M1	117.09	167.85	117.40	6,889	0.61
M2	115.93	167.50	116.06	2,889	0.25
H1	315.70	364.30	315.99	6,444	0.60
H2	115.84	166.70	115.89	1,111	0.098

Septic tanks need to be pumped when approximately 25% to 33% of the liquid capacity of the tank is solid by volume before drying. In a multiple septic tank system like the current system, the septic tanks need to be emptied when the last septic tanks in the series is approximately 25% to 33% solid by volume. Using the sludge judge, the L1 septic tank was determined to be 100% full, the L2 septic tank 27% full, and the L3 septic tank 20% full as shown in Table 10. The last septic tank L3 is very close to the 25% threshold which is suggested as the lower limit of volume percent solids before emptying. These tanks will most likely need to be pumped at the end of the season and should be monitored until then.

The M1 septic tank is 20% full and the M2 tank is 0% full. The second septic tank in this series is completely empty so the solids can still spill over into this tank without any danger of solids clogging the leach lines. These septic tanks do not need to be emptied.

The H1 septic tank is 12.5% full and the H2 tank is 0% full. The second septic tank in this series is also completely empty so the solids can still spill over into this tank without any danger of solids clogging the leach lines. These septic tanks do not need to be emptied.

The drying test was done to quantify the actual amount of solids in the tank so that the effect of the new composting toilets to be installed at Kiggins Commons has on the solid buildup in the septic tanks can be measured in future years. The installation of the composting toilets will also affect the buildup of solids in the other septic tanks because island residents can be instructed to preferentially use the composting toilets to poop.

Recommendation

Bartels

We recommend using a more rigorous method to find where the wastewater goes so that it can be sampled. Al Frick has suggested inserting a suction cup lysimeter 12 inches into the soil on a diagonal to intercept the wastewater flow.

Kiggins Commons

We recommend to continue testing the distribution box and to continue the 2009 interns' tests of the test wells if they have water in them. Hopefully the addition of composting toilets at Kiggins Commons this fall will improve the condition of the water in the distribution box.

Kingsbury House

The M10 composter test results are acceptable. The fecal coliform and TKN numbers are high for the M1/M2 composter indicating that peat should be added to this composter. The BOD and TSS numbers are inconclusive for the M1/M2 composter.

The Frickle Filter appears to increase the concentration of BOD, TKN, and TSS, but these results may have error due to stirring up suspended solids with the pump and dilution of the entrance concentrations due to a shower or a load of laundry at the wrong time. We recommend further investigation of both composters and especially the Frickle Filter. We also recommend looking into the missing splash plate and skim layer in the Frickle Filter.

Septic Tanks

From the sludge judge it was determined that the lower septic tanks fed by Kiggins Commons, the Grass Lab, and Founders are nearing their maximum capacity. These tanks should be monitored at the end of this season and the beginning of next season to see how much of the solids have decomposed and whether these tanks need to be pumped before the start of next season. The middle and upper septic tanks are not near their full capacity and do not need to be pumped.

With the installation of the composting toilets the buildup of solids in future seasons will be slower in all the septic tanks because island residents can be instructed to preferentially use the composting toilets. The decrease in the rate of solid buildup in all of the septic tanks should be reinvestigated next year after these toilets are installed. We also recommend that island residents be instructed to preferentially use the composting toilets to poop so the septic tanks do not fill up and require pumping.

Increase Freshwater Supply to Well

Background

The 2009 engineering interns determined that siphoning water from Crystal Lake at a rate of 5400 gallons/day for nine days only decreased the water level of Crystal Lake by ¼”. They also noted that this was a very wet summer and Crystal Lake was constantly being refilled by rain water. We wanted to repeat this siphoning experiment and monitor the water level of Crystal Lake during a dry summer like the summer of 2010.

Pipe was also laid from Crystal Lake to the area around the fresh water well in preparation of the approval of the Crystal Lake draining permit. This pipe was primed and water was drained from Crystal Lake to the area around the fresh water well for approximately 24 hours to test the prime and determine whether the draining system functioned correctly. A flow meter was placed in the pipe to determine how much Crystal Lake water has flowed from Crystal Lake to the area around the fresh water well. The water level of the well was monitored in comparison to the normal decrease in water level due to island usage after the drainage test to determine roughly how long it takes for the water to seep through the ground and into the well and roughly how much water actually makes it into the well. The level of Crystal Lake was also being constantly monitored to make sure it did not drain to an unacceptable level.

Objective

Determine the effect on the water level of Crystal Lake by draining Crystal Lake at a flow rate comparable to the daily water use of the island.

Data Collection

Two meter sticks were placed in Crystal Lake to monitor the water level. Two readings were used so they could be compared to each other for accuracy. Water was siphoned from Crystal Lake with hoses starting at 5:40 PM on June 25, 2010 at a flow rate of 1.14 gallons per minute or 1642 gallons per day. The flow rate was determined by taking the average of three trials of filling a five gallon bucket with the siphoned water.

The hose became clogged sometime between 7:20 PM on June 27 and 8:30 AM on June 28. The hose was then re-primed and the siphoning began again. The hose clogged again at 11:00 AM on June 28 and a screen was made for the hose to prevent debris from clogging the hose again. The hose was then re-primed and the siphon begun again at a flow rate of 1.06 gallons per minute or 1521 gallons per day.

This siphon was then stopped at 1:43 PM on June 30, 2010 because the weather was very dry and the water level was dropping rapidly. The permit for draining water from Crystal Lake to the area around the fresh water well was pending and we did not want to waste water that could be used for that. The siphon we created drained a rough total of 6730 gallons of water from Crystal Lake over four and a half days. The level of Crystal Lake continued to be monitored to determine whether or not the water level of the lake would recover after the siphoning stopped.

Pipe was laid from Crystal Lake to the area around the fresh water pump. This pipe was primed and water began draining from Crystal Lake via this pipe to the fresh water pump at 9:30 AM on June 7, 2010. This was only a test that the system worked and the flow from Crystal Lake was stopped at 8:08 AM on June 8, 2010. This drained a total of 5144 gallons of water at a flow rate of 3.8 gallons per minute. The water level of Crystal Lake continued to be monitored. The water level of the well was also monitored in comparison to the normal decrease in water level due to island usage after the drainage test to determine roughly how long it takes for the water to seep through the ground and into the well and roughly how much water actually makes it into the well.

Analysis

The results of the water level readings from Crystal Lake are shown in Table 12. A commented graph of this data is shown in Figure 10.

Table 12: Water Level Readings from Crystal Lake

Date and Time	Meter Location #1	Meter Location #2	Notes
6/25/2010 17:40	21.1	16.1	
6/26/2010 8:30	20.8	16	
6/27/2010 11:30	20.4	15.6	
6/27/2010 19:20	20.2	15.5	Flow stopped at night, re-primed pump and unclogged hose in morning.
6/28/2010 8:30	20.3	15.5	
6/28/2010 11:00	20.3	15.5	Re-primed pump and unclogged hose.
6/28/2010 13:00	20.1	15.5	
6/28/2010 15:00	20	15.5	
6/28/2010 17:00	20.2	15.5	
6/28/2010 19:00	20	15.4	
6/28/2010 21:00	20	15.5	
6/29/2010 9:00	19.75	15.1	
6/29/2010 17:00	19.7	15	
6/29/2010 19:00	19.8	15	
6/29/2010 21:00	19.8	15	
6/30/2010 10:25	19.5	14.7	
6/30/2010 13:43	19.5	14.5	Stopped siphon. 6730 total gallons drained.
7/1/2010 9:00	19	14	
7/2/2010 9:00	18.75	13.75	
7/3/2010 8:40	18.5	13.5	
7/4/2010 8:40	18.1	13.1	
7/5/2010 8:40	18	13	
7/6/2010 7:20	17.8	12.8	
7/7/2010 8:00	17.5	12.5	Started draining at 9:30 AM on 7/7.
7/7/2010 21:00	17	12	
7/8/2010 8:40	16.8	11.8	Stopped draining at 8:08 AM on 7/8. 5144 total gallons drained.
7/9/2010 9:20	16.7	11.7	
7/10/2010 8:40	16.1	11.1	Ross drained roughly 500 gallons for water buffalo.
7/10/2010 20:40	17	12	Rained hard from 1:00 PM to 5:00 PM, first time it has rained since we have been here.
7/11/2010 9:30	17.1	12.1	
7/12/2010 8:40	16.8	11.8	

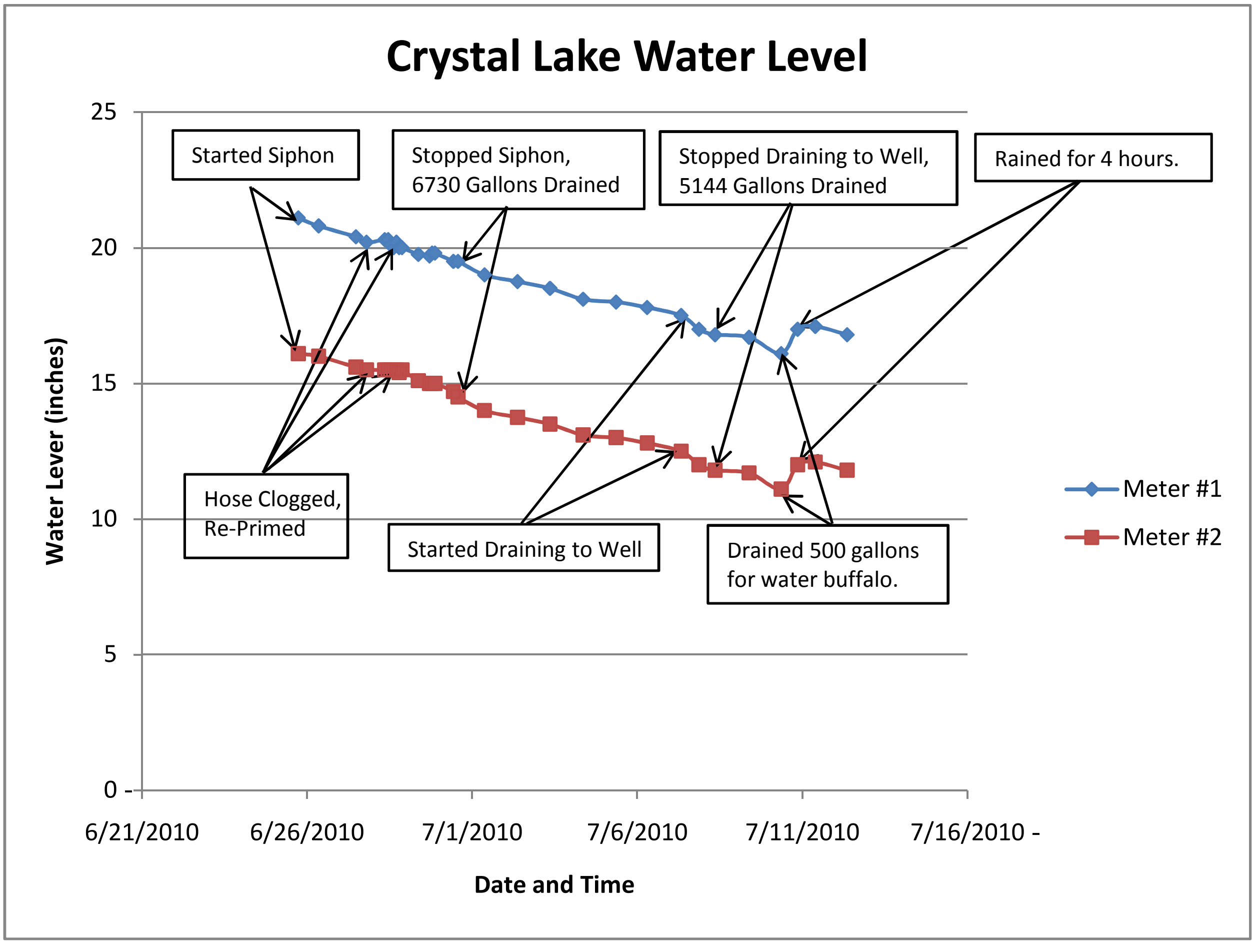

Figure 10: Commented Water Level Readings from Crystal Lake

The water level of Crystal Lake has gone down a total of five inches from June 25, 2010 to July 10, 2010 before recovering about an inch because of the four hour rain fall. This was the only rain fall there has been during the collection of data. Crystal Lake drained 0.7 inches when it was drained 5144 gallons from July 7, 2010 to July 8, 2010. This is a significant decrease in the water level of Crystal Lake and if the level of Crystal Lake can only be lowered six inches per the issued permit, only 44000 gallons of water can be drained from Crystal Lake without any rainfall to replenish it. It would take 8.5 days to drain Crystal Lake six inches at a flow rate of 3.8 gallons per minute without rainfall to replenish it. It was estimated that the island uses roughly 1400 gallons a day from previous water usage data. This means that assuming 100% of the water drained from Crystal Lake ends up in the well Crystal Lake can provide 31 days of water to the island without any rainfall to replenish the lake.

The evaporation rate of water from Crystal Lake was calculated to be 1343 gallons per day. This evaporation rate was already factored into the above calculations of water level decrease in Crystal Lake.

The well water level data is shown in Table 13 and graphed in Figure 11.

Table 13: Well Water Level Data after Crystal Lake Drainage to Well

Date and Time	Well Water Level (inches)	Notes
7/7/2010 10:30	152	Started draining Crystal Lake into area around well.
7/7/2010 20:30	152	
7/8/2010 8:30	152	Stopped draining Crystal Lake into area around well.
7/9/2010 9:00	151	
7/9/2010 19:30	149.5	
7/10/2010 8:25	151	
7/10/2010 20:30	150	Rained hard from 1:00 PM to 5:00 PM, first time it has rained since we have been here.
7/11/2010 9:10	150.5	
7/12/2010 8:40	148	
7/12/2010 7:30	148	

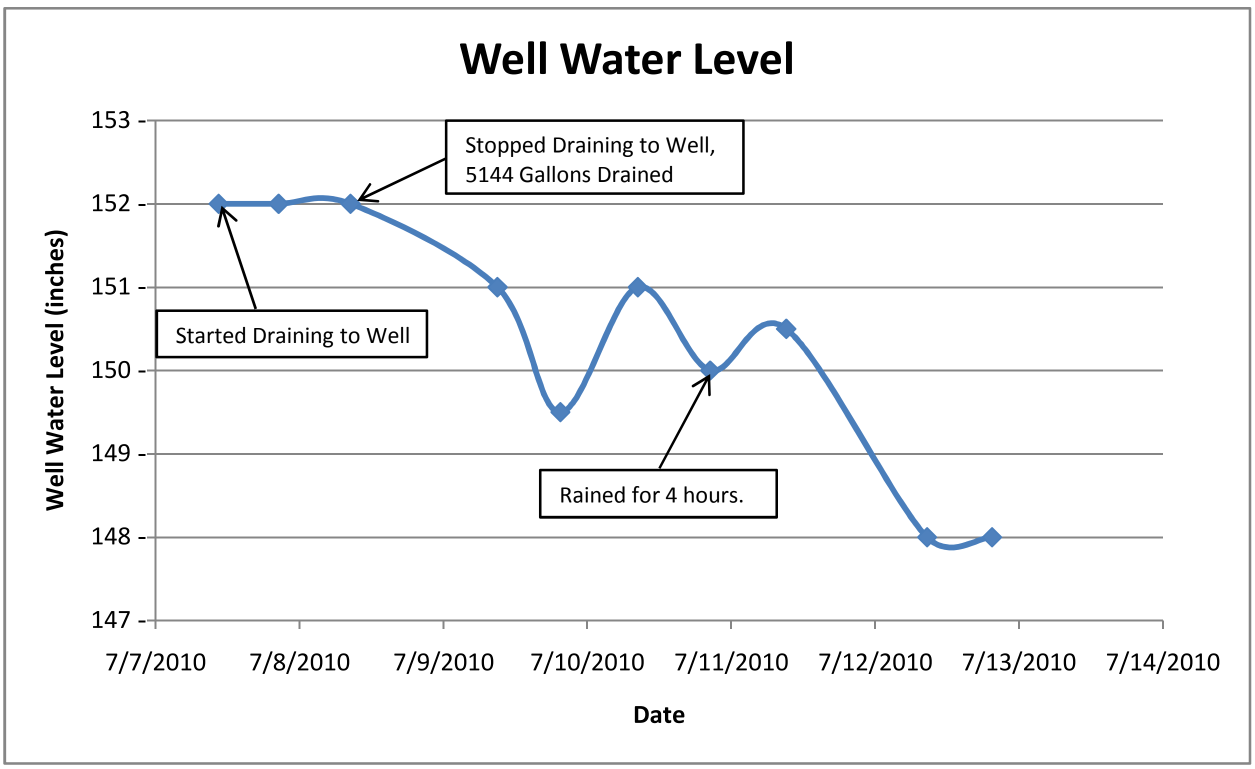

Figure 11: Well Water Level after Crystal Lake Drainage to Well

The well water level goes down an average of 9 inches a week estimated from previous well water level data from the 2010 season. The five days we took data the well water level has only decreased 4 inches. In addition to draining 5144 gallons of water from Crystal Lake to the area around the well in these five days, it also rained for four hours. Both these events have an effect on the water level of the well. It is not conclusive but preliminary data suggests that the water drained from Crystal Lake to the area around the well is showing up in the well.

Recommendation

The water level of Crystal Lake should be consistently monitored as the water is drained to the well area especially in dry seasons because it only takes 8.5 days to drain Crystal Lake six inches at flow rate of 3.8 gallons per minute provided by the pipe installed. This equates to approximately 44000 gallons of total water drained from Crystal Lake which is enough to provide 31 days of water to the island at a daily use of 1400 gallons per day. Supplemented with rainfall and the existing well water stored from the winter, this should be enough water to supply the island with fresh water for the entire season without having to run the reverse osmosis machine.

The interns next year should continue to monitor the water level of Crystal Lake further as draining begins. They should also monitor the water level of the well to determine an estimate of how much water drained from Crystal Lake actually makes it into the well.

Energy Conservation

Background

Shoals Marine Lab has limited energy and water available for usage so it is imperative that it is not wasted. Lights in the SML labs and academic buildings are frequently left on when the rooms are vacant. Many lights around Kiggins Commons and inside the Kiggins Commons' bathrooms are left on 24/7. To save energy, motion sensor lights have been newly installed on the second floor of Laighton.

The small storage water heaters in Laighton and PK sustain a continuous hot water source all day, every day. It is assumed that the two buildings use a large amount of electricity and supply a small amount of hot water though the amounts of power and water used by the water heaters has not yet been measured. There are 11 refrigerators on Appledore Island excluding the reach-in and walk-in refrigerators in the kitchen, most with much less occupied volume compared to the available volume. The electricity consumption of the refrigerators has not yet been measured either.

There are three pump systems: freshwater, wastewater, and saltwater. For the freshwater pump system, there is a well pump and a cistern pump. For the wastewater pump system, there are two pumps that are used alternately on the same pipe for increased efficiency. For the saltwater pump system, there is a single pump. Meters were installed on the well and cistern pumps to determine their average energy consumption. These meters were read at roughly the same time every day and the energy use of each individual pump was calculated per day.

The amount of propane bottles used is recorded every time an empty bottle is replaced by a new one. Propane is mainly used in the kitchen and its varying usage theoretically should be related to the varying population of the island. This data has not yet been correlated.

Recently a motion sensor light switch was installed in the upstairs classroom of Laighton. In addition, three LED light bulbs have been installed in various locations.

Objective

Determine the efficiency and usage of electricity in common locations, refrigerators, small storage tank water heaters in the laboratories, water pumps, and propane so as to recommend solutions that will reduce energy, water, and propane consumption.

Water Pumps

Data Collection

The energy consumption of each individual pump was determined by having two people stand in the fresh water pump room and two people stand by the generator output. Radios were used to communicate between the two groups. A reading from the generator output was taken immediately before a pump was turned on and immediately after. The difference in the generator output is roughly the energy draw of that particular pump. A reading from the generator output was then taken immediately before a pump was turned off and immediately after. That difference is also roughly the power of that particular pump. This process was repeated five times for each pump resulting in ten values for pump power. These values were then averaged to determine the average power of each pump. The results of the well pump trials are shown in Table 14 and the results of the cistern pump trials are shown in Table 15.

Table 14: Power Calculation for Well Pump

Generator Output (kW)			Generator Output (kW)		
Off	On	Difference (kW)	On	Off	Difference (kW)
16.91	18.26	1.35	18.38	16.96	1.42
16.99	18.17	1.18	18.29	16.9	1.39
16.87	18.27	1.4	18.31	17.06	1.25
17.07	18.4	1.33	18.12	16.98	1.14
18.84	20.15	1.31	20.29	18.82	1.47
Average Power:		**1.32 kw**			

Table 15: Power Calculation for Cistern Pump

Generator Output (kW)			Generator Output (kW)		
Off	On	Difference (kW)	On	Off	Difference (kW)
17.49	18.58	1.09	18.6	17.49	1.11
17.36	18.55	1.19	19.52	18.51	1.01
17.94	19.07	1.13	18.84	17.56	1.28
17.41	18.52	1.11	18.72	17.61	1.11
17.38	18.46	1.08	18.67	17.54	1.13
Average Power:		**1.12 kw**			

Energy Usage of the Well and Cistern Pumps

The average power of each pump was then multiplied by the hours a day the pump is used to determine the average energy use of each pump per day. The results of this are shown in Table 16 for all the data that is available. The energy usage of the well pump and cistern pumps are graphed in Figures 12 and 13 respectively.

Table 16: Energy Usage of Well and Cistern Pumps per Day

Date	Well Pump (hours)	Difference (hours)	Kilowatt Hours Used per Day	Cistern Pump (hours)	Difference (hours)	Kilowatt Hours Used per Day
5/15/2010	64.0			63.1		
5/16/2010	67.7	3.7	4.88	65.0	1.9	2.13
5/17/2010	69.1	1.4	1.85	66.0	1.0	1.12
5/18/2010	70.9	1.8	2.38	66.9	0.9	1.01
5/19/2010	72.8	1.9	2.51	67.8	0.9	1.01
5/20/2010	72.8	0.0	0.00	67.9	0.1	0.11
5/21/2010	74.6	1.8	2.38	68.7	0.8	0.90
5/22/2010	76.5	1.9	2.51	69.6	0.9	1.01
5/23/2010	77.7	1.2	1.58	70.5	0.9	1.01
5/24/2010	79.1	1.4	1.85	71.5	1.0	1.12
5/25/2010	80.5	1.4	1.85	72.4	0.9	1.01
5/26/2010			2.20			1.10
5/27/2010	83.8	3.3	2.20	74.4	2.0	1.10
5/28/2010	85.3	1.5	1.98	75.4	1.0	1.12
5/29/2010	87.1	1.8	2.38	76.4	1.0	1.12
5/30/2010	88.7	1.6	2.11	77.3	0.9	1.01
5/31/2010	90.4	1.7	2.24	78.3	1.0	1.12
6/1/2010	92.2	1.8	2.38	79.3	1.0	1.12
6/2/2010	93.9	1.7	2.24	80.4	1.1	1.23
6/3/2010	95.5	1.6	2.11	81.5	1.1	1.23
6/4/2010	98.5	3.0	3.96	83.2	1.7	1.90
6/5/2010	100.2	1.7	2.24	84.2	1.0	1.12
6/6/2010	102.5	2.3	3.04	86.1	1.9	2.13
6/7/2010	104.7	2.2	2.90	87.0	0.9	1.01
6/8/2010	106.3	1.6	2.11	87.9	0.9	1.01
6/9/2010	109.3	3.0	3.96	89.8	1.9	2.13
6/10/2010	110.8	1.5	1.98	90.8	1.0	1.12
6/11/2010	113.8	3.0	3.96	92.6	1.8	2.02
6/12/2010	115.3	1.5	1.98	93.6	1.0	1.12
6/13/2010	118.3	3.0	3.96	95.4	1.8	2.02
6/14/2010	119.7	1.4	1.85	96.3	0.9	1.01
6/15/2010	121.3	1.6	2.11	97.3	1.0	1.12
6/16/2010	124.2	2.9	3.83	99.1	1.8	2.02
6/17/2010	125.9	1.7	2.24	100.1	1.0	1.12
6/18/2010	128.8	2.9	3.83	102.0	1.9	2.13
6/19/2010	130.5	1.7	2.24	103.0	1.0	1.12
6/20/2010	131.9	1.4	1.85	103.9	0.9	1.01
6/21/2010	134.9	3.0	3.96	105.8	1.9	2.13
6/22/2010	136.5	1.6	2.11	106.8	1.0	1.12
6/23/2010			2.90			1.60
6/24/2010	141.0	4.5	2.80	109.6	2.8	1.50
6/25/2010	143.9	2.9	3.83	111.4	1.8	2.02

6/26/2010	145.5	1.6	2.11	112.3	0.9	1.01
6/27/2010	146.9	1.4	1.85	113.3	1.0	1.12
6/28/2010	149.9	3.0	3.96	115.1	1.8	2.02
6/29/2010	151.5	1.6	2.11	116.1	1.0	1.12
6/30/2010	153.0	1.5	1.98	117.1	1.0	1.12
7/1/2010	155.3	2.3	3.04	119.0	1.9	2.13
7/2/2010	157.6	2.3	3.04	119.9	0.9	1.01
7/3/2010	159.5	1.9	2.51	121.8	1.9	2.13
7/4/2010	162.2	2.7	3.56	122.8	1.0	1.12
7/5/2010	164.2	2.0	2.64	124.7	1.9	2.13
7/6/2010	166.7	2.5	3.30	125.6	0.9	1.01
7/7/2010	168.4	1.7	2.24	126.7	1.1	1.23
7/8/2010	172.5	4.1	5.41	128.6	1.9	2.13
7/9/2010	175.3	2.8	3.70	130.4	1.8	2.02
7/10/2010	176.8	1.5	1.98	131.8	1.4	1.57
7/11/2010	178.3	1.5	1.98	132.3	0.5	0.56
Average		**2.08**	**2.64**		**1.26**	**1.36**

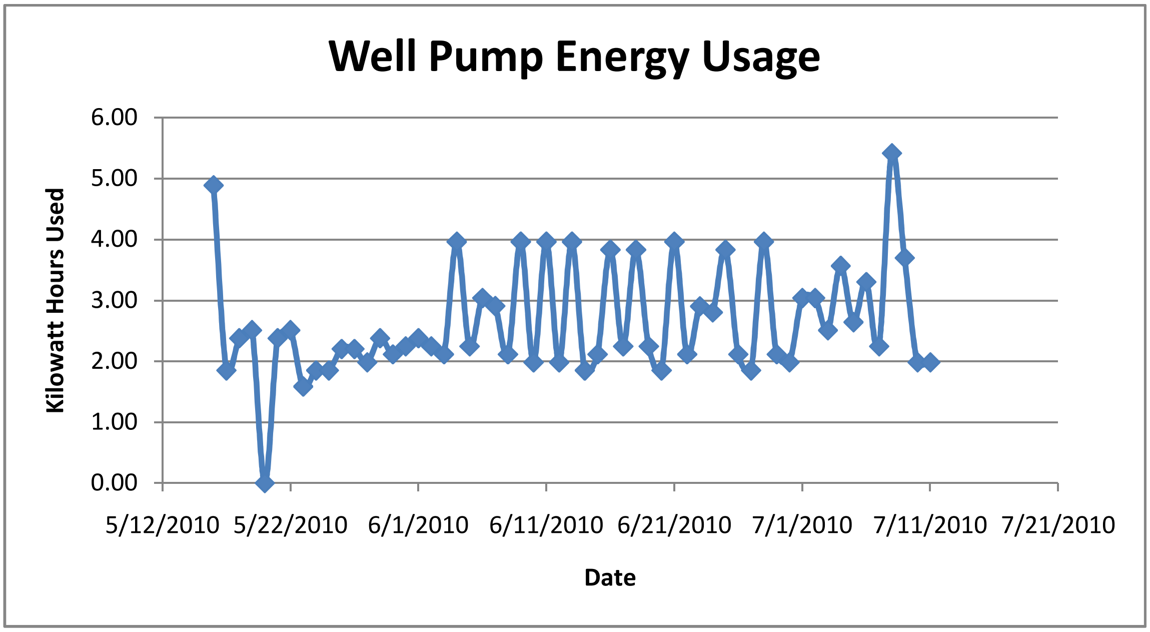

Figure 12: Energy Usage of Well Pump per Day

The average energy usage for the well pump is 2.64 kWh per day. On the 20th of May, 2010, the well pump must have been turned to the off position because it used no energy on that day. The energy usage of the well pump varies based on the water demand for that day.

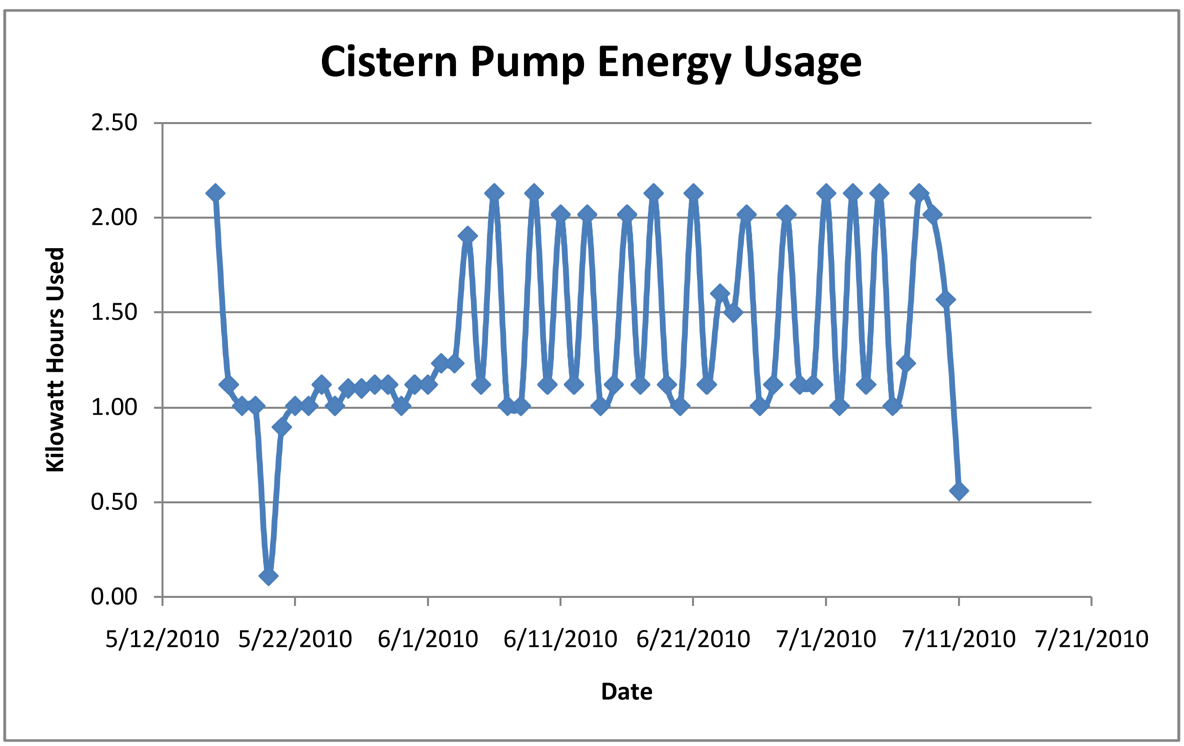

Figure 13: Energy Usage of Cistern Pump per Day

The average energy usage for the well pump is 1.36 kWh per day. On the 20th of May, 2010, the cistern pump must have been turned to the off position because it used very little energy on that day. The energy usage of the cistern pump varies based on the water demand for that day.

Energy Usage of Wastewater Pumps

Meters were installed on the two wastewater pumps to determine their average energy consumption. These meters were read at roughly the same time every day and the energy use of each individual pump was calculated per day.

Determining the Power of Each Wastewater Pump

The energy consumption of each individual pump was determined by having two people stand in the wastewater pump room and two people stand by the generator output. Radios were used to communicate between the two groups. A reading from the generator output was taken immediately before a pump was turned on and immediately after. The difference in the generator output is roughly the energy draw of that particular pump. A reading from the generator output was then taken immediately before a pump was turned off and immediately after. That difference is also roughly the power of that particular pump. This process was repeated five times for each pump resulting in ten values for pump power. These values were then averaged to determine the average power of each pump. The results of the pump one trials are shown in Table 17 and the results of the pump two trials are shown in Table 18.

Table 17: Power Calculation for Wastewater Pump One

Generator Output (kW)			Generator Output (kW)		
Off	On	Difference (kW)	On	Off	Difference (kW)
16.81	18.09	1.28	18.6	16.56	2.04
16.67	18.18	1.51	18.23	16.85	1.38
17.79	19.13	1.34	19.66	17.78	1.88
16.13	18.35	2.22	18.08	16.38	1.7
16.25	17.75	1.5	18.1	16.18	1.92
Average Power:		**1.68**			

Table 18: Power Calculation for Wastewater Pump Two

Generator Output (kW)			Generator Output (kW)		
Off	On	Difference (kW)	On	Off	Difference (kW)
16.32	17.91	1.59	18.25	16.19	2.06
16.05	17.71	1.66	18.01	16.12	1.89
16.24	17.96	1.72	19.4	17.72	1.68
17.72	19.29	1.57	19.54	17.58	1.96
17.73	19.27	1.54	20.05	17.78	2.27
Average Power:		**1.79**			

Energy Use of the Wastewater Pumps

The average power of each pump was then multiplied by the hours a day the pump is used to determine the average energy use of each pump per day. The results of this are shown in Table 19 for all the data that is available. The energy usage of wastewater pumps 1 and 2 are graphed in Figures 14 and 14 respectively.

Table 19: Energy Usage of Wastewater Pumps per Day

Date	Wastewater Pump 1 (hours)	Difference (hours)	Kilowatt Hours Used per Day	Wastewater Pump 2 (hours)	Difference (hours)	Kilowatt Hours Used per Day
6/26/2010	8.0			9.8		
6/27/2010	8.2	0.2	0.34	10.0	0.2	0.36
6/28/2010	8.4	0.2	0.34	10.2	0.2	0.36
6/29/2010	8.6	0.2	0.34	10.4	0.2	0.36
6/30/2010	8.8	0.2	0.34	10.6	0.2	0.36
7/1/2010	9.0	0.2	0.34	10.9	0.3	0.54
7/2/2010	9.2	0.2	0.34	11.1	0.2	0.36
7/3/2010	9.3	0.1	0.17	11.4	0.3	0.54
7/4/2010	9.6	0.3	0.50	11.7	0.3	0.54
7/5/2010	9.8	0.2	0.34	12.0	0.3	0.54
7/6/2010	9.9	0.1	0.17	12.2	0.2	0.36
7/7/2010	10.1	0.2	0.34	12.4	0.2	0.36
7/8/2010	10.3	0.2	0.34	12.7	0.3	0.54
7/9/2010	10.6	0.3	0.50	13.0	0.3	0.54
7/10/2010	10.7	0.1	0.17	13.1	0.1	0.18
7/11/2010	10.9	0.2	0.34	13.3	0.2	0.36
Average		**0.19**	**0.32**		**0.23**	**0.42**

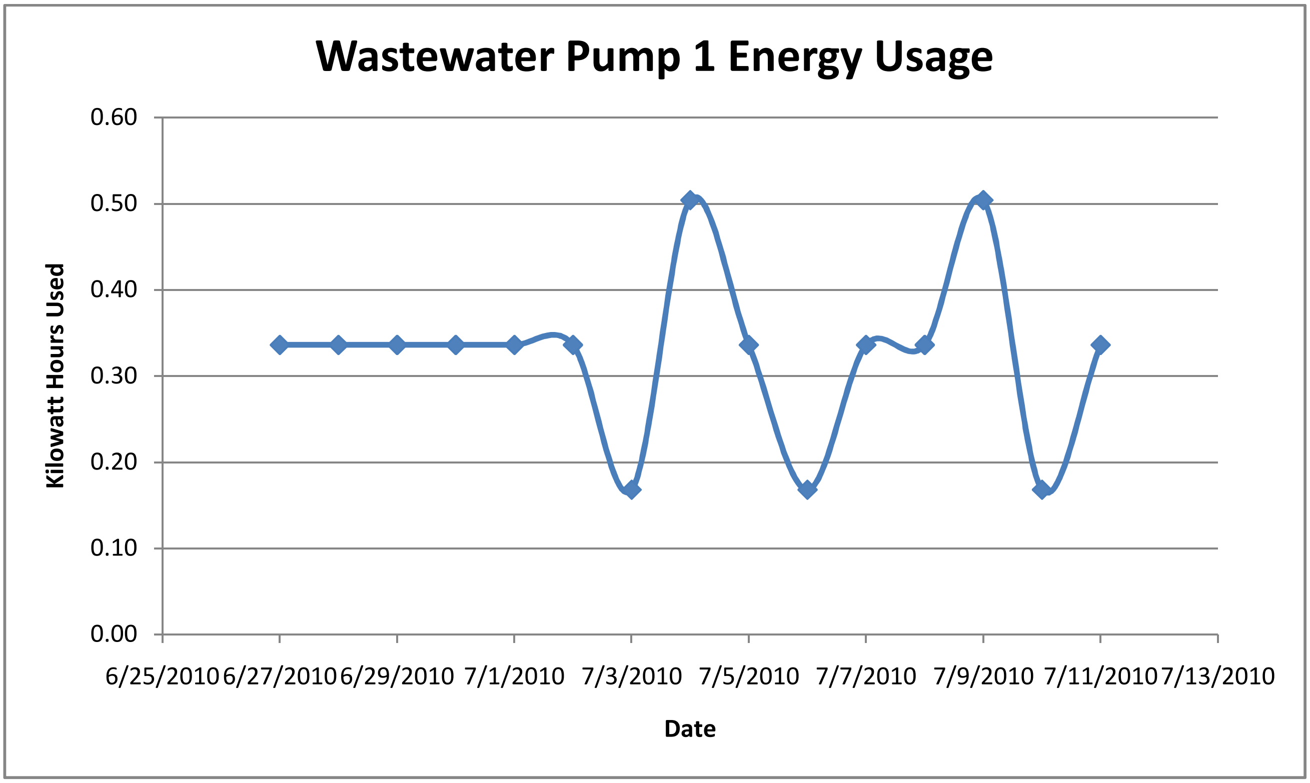

Figure 14: Energy Usage of Wastewater Pump 1 per Day

The average energy usage for the well pump is 0.32 kWh per day. The energy usage of the wastewater pump varies based on the sewage produced for that day.

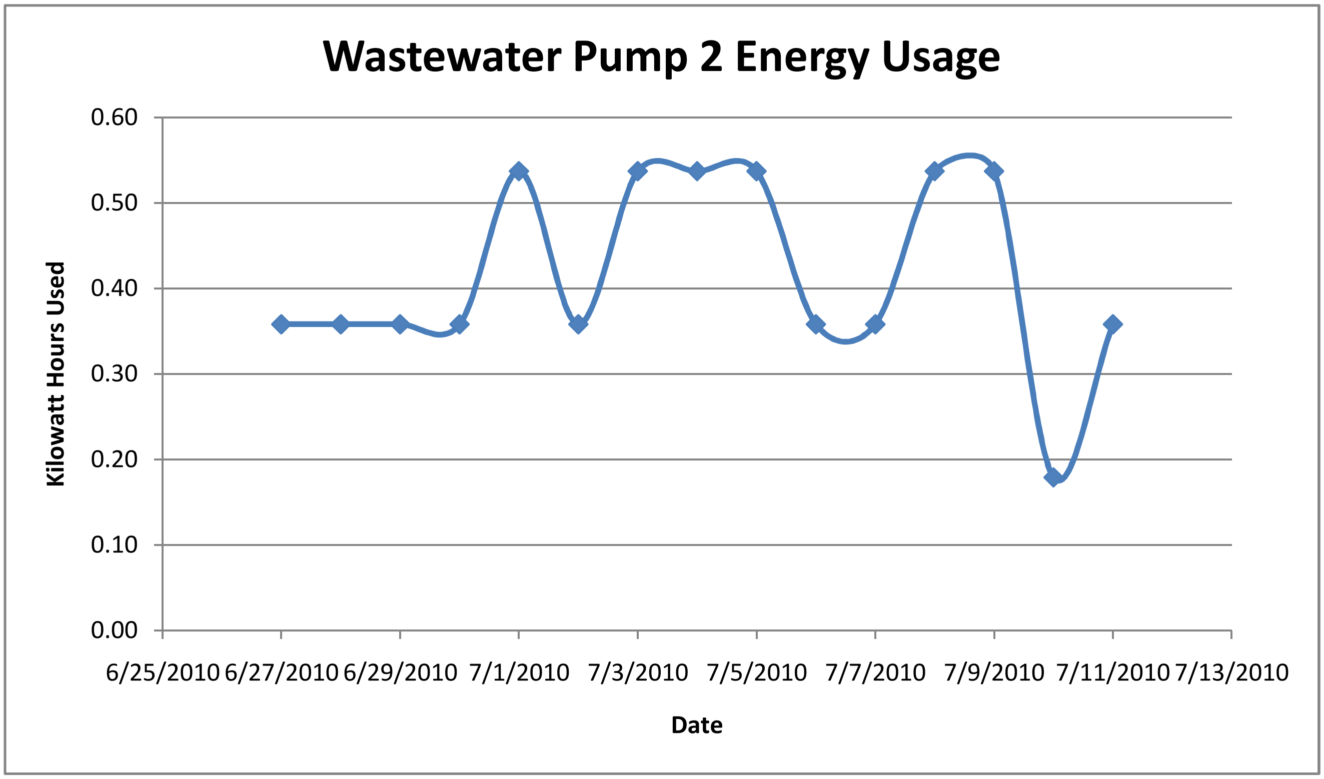

Figure 15: Energy Usage of Wastewater Pump 2 per Day

The average energy usage for the well pump is 0.42 kWh per day. The energy usage of the wastewater pump varies based on the sewage produced for that day.

Water Heaters

Energy Usage of Water Heaters

Energy meters and flow rate meters were installed on two water heaters in Laighton and Palmer-Kinne to determine their average energy consumption per day and per gallon of water used. These meters were read at roughly 9:30 PM every day and the energy use of each heater was calculated per day. To convert from the U.S. gallons shown on the meters to kWh, the maximum wattage found on the water heaters was used. This value was 2000 watts for the Laighton water heater and 1500 watts for the PK water heater.

Energy Use of the Electric Water Heaters

The results of the energy and hot water usage per day of the electric water heater in Laighton and Palmer-Kinne are shown in Tables 20 and 21 respectively. These results are graphed in Figure 16 and 17 respectively.

Table 20: Energy and Water Usage of Laighton Electric Water Heater per Day

Date	Laighton Water Heater (hours)	Difference (hours)	Difference (kWh)	Laighton Water Level (U.S. gallons)	Difference (U.S. gallons)	Energy Use per Gallon (kWh)	Cost of Energy per Gallon ($)
6/22/2010	34.6			32.42			
6/23/2010	35.3	0.7	1.4	32.43	0.01	140.00	36.40
6/24/2010	35.9	0.6	1.2	32.435	0.005	240.00	62.40
6/25/2010	36.8	0.9	1.8	32.44	0.005	360.00	93.60
6/26/2010	37.5	0.7	1.4	32.45	0.01	140.00	36.40
6/27/2010	38.1	0.6	1.2	32.46	0.01	120.00	31.20
6/28/2010	38.9	0.8	1.6	32.48	0.02	80.00	20.80
6/29/2010	39.6	0.7	1.4	32.56	0.08	17.50	4.55
6/30/2010	40.3	0.7	1.4	32.59	0.03	46.67	12.13
7/1/2010	41.2	0.9	1.8	32.6	0.01	180.00	46.80
7/2/2010	42.1	0.9	1.8	32.62	0.02	90.00	23.40
7/3/2010	42.8	0.7	1.4	32.65	0.03	46.67	12.13
7/4/2010	43.6	0.8	1.6	32.66	0.01	160.00	41.60
7/5/2010	44.3	0.7	1.4	32.68	0.02	70.00	18.20
7/6/2010	44.9	0.6	1.2	32.68	0	Infinite	Infinite
7/7/2010	45.6	0.7	1.4	32.68	0	Infinite	Infinite
7/8/2010	46.3	0.7	1.4	32.7	0.02	70.00	16.80
7/9/2010	47.1	0.8	1.6	32.7	0	Infinite	Infinite
7/10/2010	47.7	0.6	1.2	32.72	0.02	60.00	14.40
7/11/2010	48.3	0.6	1.2	32.72	0	Infinite	Infinite
Average		**0.72**	**1.44**		**0.02**	**121.39**	**31.39**

Table 21: Energy and Water Usage of Palmer-Kinne Electric Water Heater per Day

Date	PK Water Heater (hours)	Difference (hours)	Difference (kWh)	PK Water Level (U.S. gallons)	Difference (U.S. gallons)	Energy Use per Gallon (kWh)	Cost of Energy per Gallon ($)
6/22/2010	43.1			79.68			
6/23/2010	46.3	3.2	4.8	84.63	4.95	0.97	0.25
6/24/2010	47.3	1	1.5	87.59	2.96	0.51	0.13
6/25/2010	48	0.7	1.05	88.05	0.46	2.28	0.59
6/26/2010	48.7	0.7	1.05	89.5	1.45	0.72	0.19
6/27/2010	50.3	1.6	2.4	92.43	2.93	0.82	0.21
6/28/2010	50.8	0.5	0.75	93.58	1.15	0.65	0.17
6/29/2010	51.3	0.5	0.75	95.77	2.19	0.34	0.09

6/30/2010	52.1	0.8	1.2	96.42	0.65	1.85	0.48
7/1/2010	54.1	2	3	99.34	2.92	1.03	0.27
7/2/2010	55.3	1.2	1.8	101.48	2.14	0.84	0.22
7/3/2010	56.7	1.4	2.1	104.27	2.79	0.75	0.20
7/4/2010	57.3	0.6	0.9	106.75	2.48	0.36	0.09
7/5/2010	58.2	0.9	1.35	107.67	0.92	1.47	0.38
7/6/2010	58.6	0.4	0.6	108.75	1.08	0.56	0.14
7/7/2010	59	0.4	0.6	109.95	1.2	0.50	0.13
7/8/2010	59.6	0.6	0.9	110.07	0.12	7.50	1.95
7/9/2010	60	0.4	0.6	111.05	0.98	0.61	0.16
7/10/2010	60.4	0.4	0.6	111.3	0.25	2.40	0.62
7/11/2010	61.1	0.7	1.05	112.06	0.76	1.38	0.36
Average		**0.95**	**1.42**		**1.70**	**1.34**	**0.35**

Note: Cost of energy per gallon was calculated with the cost of energy at $0.26 per kWh. This was calculated using the cost of diesel purchased in 2009.

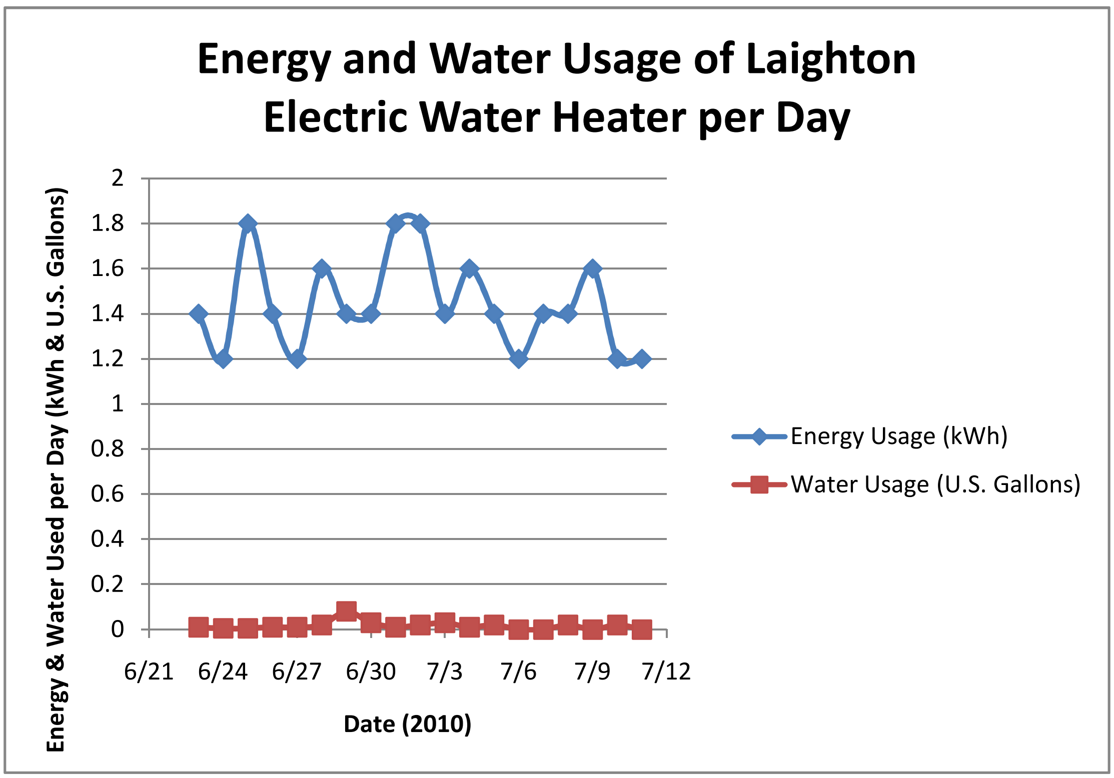

Figure 16: Energy and Water Usage of Laighton Electric Water Heater per Day

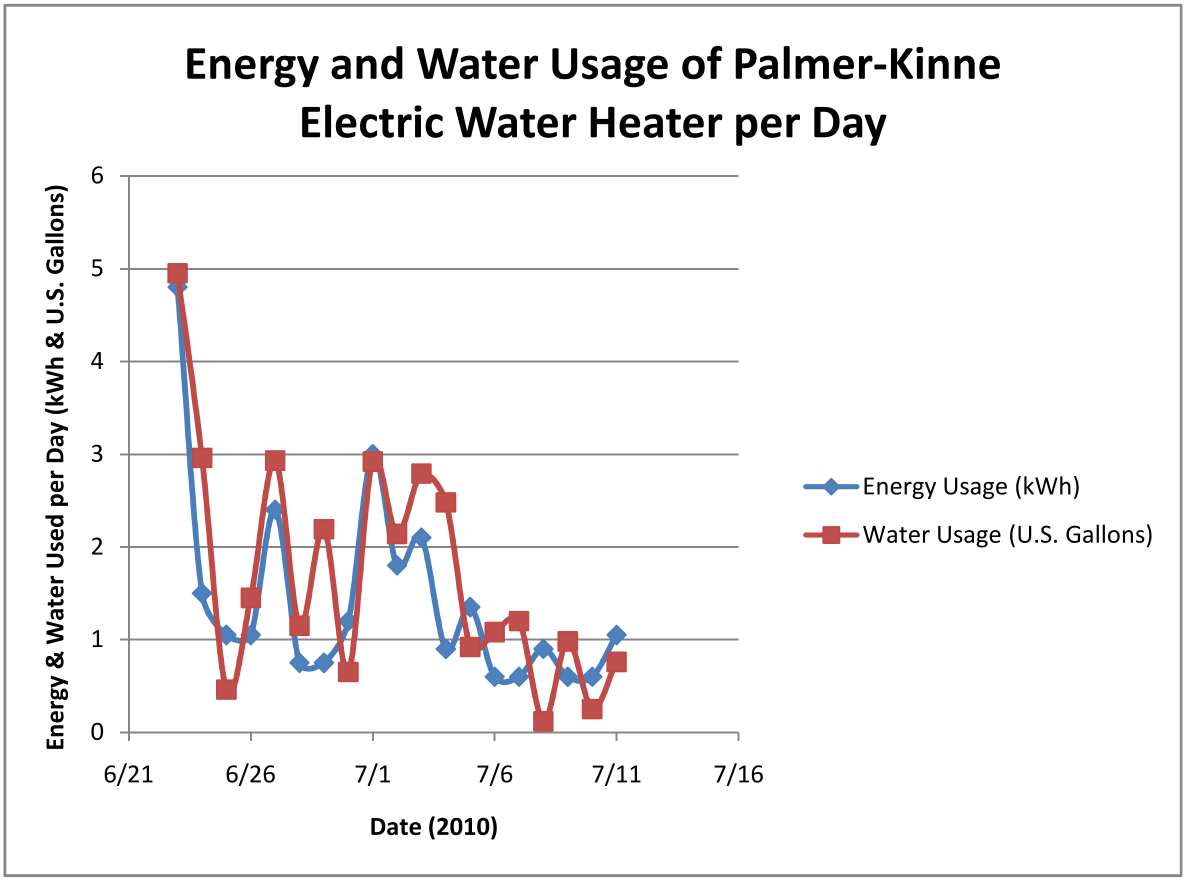

Figure 17: Energy and Water Usage of Palmer-Kinne Electric Water Heater per Day

Analysis

The energy and monetary cost of these electric water heaters per gallon of water used is very high because the demand for hot water in Laighton and Palmer-Kinne is low to non-existent. We have interviewed students, professors, and the laboratory manager Heather-Anne about whether or not they actually need hot water in these buildings and the results have been mixed. Some professors and students insist on hot water for cleaning lab equipment and instruments while some believe cold water and soap is sufficient for cleaning. Heather-Anne has said that she does not need hot water often, but it is a necessity.

The hot water usage data from Laighton would suggest that hot water is not a necessity for this building as the hot water usage on most days is less than 0.02 U.S. gallons. This means that energy is being used the entire day to heat the same water that no one is using. It can be seen in Figure 16 that because so little hot water is being used in Laighton that the energy used per day is independent of the water usage. This could be due to the fact that during the time period we collected the data the Laighton lab was not being heavily used by classes.

The Palmer-Kinne lab uses approximately 2 U.S. gallons of water per day. This is also a very small amount of water. It can be seen in Figure 17 that although this is a small amount of water, the energy used per day is dependent on the water usage meaning that hot water is being used and new water is being heated. More energy is used to heat water on days when more hot water is required.

This is how the hot water heater is intended to be used, but because the total amount of water used is still very small a lot of energy is wasted keeping the same water heated. An assessment of the hot water needs should be completed. If it is assessed that hot water is not needed, these water heaters should be permanently turned off.

If hot water truly is a necessity, other types of water heaters should be explored to replace these electric water heaters. The energy and monetary cost of these different types of water heaters are compared in Table 22.

Table 22: Energy and Monetary Cost of Different Types of Water Heaters

Type	Cost of Installation ($)	Energy Use per Gallon (kWh)	Cost of Energy per Gallon ($)
Laighton - Storage	0	121.389	31.56
Palmer-Kinne - Storage	0	1.344	0.35
Instantaneous Electric	270	0.133	0.03
Solar with Electric Backup	4800	0.022	0.01

Note: Cost of energy per gallon was calculated with the cost of energy at $0.26 per kWh. This was calculated using the cost of diesel purchased in 2009.

Instantaneous Electric Water Heater

The smallest instantaneous electric water heaters suitable for a single faucet application draw roughly 12 kW when they are used. This results in a significant energy savings in total energy usage, but is not feasible because 12 kW is too high of an instantaneous load for the small generator and will cause the small generator to shut down.

Solar Electric Water Heater

Installing a solar electric water heater is not feasible for the current usage of hot water at Laighton and the PK buildings. It costs a lot to install such a system and then the water is stored in a tank. Because these buildings don't use much hot water, there would still be a significant cost in electricity to maintain the tank at a specified temperature.

Instantaneous Propane Water Heater

While still energy demanding we found that an on demand propane water heater would be the best option to heat water in these buildings. An on demand propane water heater would only consume energy in the form of a small pilot light in addition to the time when hot water is used. The costs of these heaters are relatively inexpensive ($369) but would also require ventilation.

Recommendation

After our analysis and research we recommend that Shoals reassess the hot water needs in the PK and Laighton buildings. Perhaps the water heaters could be shut off and then turned on during times of lab cleaning.

If hot water is determined to be necessary we recommend that a propane on-demand hot water heater be installed in PK. If hot water is needed for cleaning of Laighton lab supplies they could go the small distance to PK to use their hot water.

Lighting

Informally walking around at night and observing what lights were on most frequently, it was concluded that the light outside of Kiggins Commons, lights in the kitchen/snack area of Kiggins Commons, the bathroom lights of Kiggins Commons, and outdoor lights lining the pathways are always on. In the Kiggins Commons' bathrooms, the light-switches are not accessible to the extent that they cannot be found by the regular bathroom-user so they are on 24/7. The outdoor lights lining the pathways are always on but are so occasional that they are not a noteworthy electricity draw.

The majority of the lights on Appledore Island were recently switched from incandescent light bulbs to compact fluorescent light bulbs (CFLs). This change has saved the island around $630 per 50,000 hours of usage according to Table 23. Table 23 is only a rough estimate of energy and monetary savings but gives a general idea. The cost of electricity will vary as will the cost of bulbs from retailer to retailer. The incandescent to CFL exchange was undoubtedly a step in the right direction; however LED light bulbs should be installed in common locations for further savings. The initial cost of an LED light bulb is about $30 more expensive than a CFL bulb, but in the long run, about $90 will be saved for every 50,000 hours of electricity used per bulb.

Table 23: Cost Comparison between LEDs, CFLs, and Incandescent Light Bulbs

	LED	CFL	Incandescent
Light bulb projected lifespan	50,000 hours	10,000 hours	1,200 hours
Watts per bulb	6	14	60
Cost per bulb	$35.95	$3.95	$1.25
KWh of electricity used over 50,000 hours	300	700	3000
Cost of electricity (@0.26 per KWh)	$78	$182	$780
Bulbs needed for 50k hours of use	1	5	42
Equivalent 50k hours bulb expense	$35.95	$19.75	$52.50
Total Cost for 50k hours	$113.95	$201.75	$832.50

http://eartheasy.com/live_led_bulbs_comparison.html

A motion-detector light was newly installed in the upstairs classroom of Laighton. It was observed that this automatic feature is never used and the switch is only seen in the on or off setting.

It was also observed that the lights in Kiggins Commons are very often left on in the day time when they are not needed. They are very difficult to turn off so they are left on and waste a considerable amount of energy each day.

Recommendations

The outdoor lights of Kiggins Commons located above the porch on the dorm-side and the indoor lights in the Kiggins Commons kitchen/snack area should be replaced with LED light bulbs/tubes as they are on throughout the night. The bathroom lights of Kiggins Commons should be replaced by LED bulbs and the location of the switch should be emphasized to all residents of the island. Another option would be to reroute the wires and put a light switch by the doors of the bathrooms.

There are no locations in particular where motion detector lights should be installed because it was noticed that the one already installed is not effective and never in-use.

It is also recommended that it be emphasized to all island residence that the Kiggins Commons lights be turned off in the day and when not in use.

Laighton Computers

The computers in Laighton are regularly left on when not being used. The energy usage of the computers and printer in Laighton is shown in Table 24.

Table 24: Energy Usage of Computers in Laighton Computer Lab in Sleep Mode

Device	Energy Used per Hour for Each Computer & Monitor (kWh)	Energy Saved by Turning Off Devices From 12 AM - 7 AM (kWh)	Money Saved by Turning Off Devices From 12 AM - 7 AM ($)	Money Saved per Season by Turning Off Devices ($)
Dell Computer (3)	0.0418	0.29	0.08	7.99
iMac (4)	0.0312	0.22	0.06	5.96
Mac (2)	0.0203	0.14	0.04	3.88
Printer	0.0075	0.05	0.01	1.43
Total	0.2983	2.09	0.54	**57.01**

It can be seen from Table 24 that the energy usage of the computers in sleep mode is small. All the computers and printer combined only use 2.09 kWh in sleep mode for seven hours. Estimating that a season is 105 days long, the computers and printer use 219 kWh overnight in sleep mode costing $57.01. Although this is not a lot of energy it is energy being wasted as there is no reason for the computers to be on at night when no one is using them. It is recommended that these computers be automatically shut down at midnight every night.

Refrigerator Energy Consumption

Shoals Marine Lab has multiple refrigerators and freezers used for both preservation of specimens and food. Knowing the high cost to produce 1 kWh of energy here on Appledore we investigated the energy consumption of the refrigerators and freezers to see if there was any that drew an exceedingly large proportion of energy.

Data Collection

We obtained a meter (Watts Up) that measures the energy consumption of household appliances. We found the average energy draw for each individual refrigerator by plugging the various refrigerators and freezers into the Watts Up meter for a period over one hour. We chose this method because most of the refrigerators did not show energy consumption until the compressor automatically turned on. This enabled us to overcome variances in how often the individual compressors turned on.

Our data showed that the energy use among the refrigerators and freezers is relatively uniform. The two peaks in the chart below (Figure 18) are from a refrigerator in the basement of the commons and a freezer at PK. We were amazed to see that the Galaxy refrigerator in the basement of the commons used so much energy as it is the newest refrigerator on the island. Looking at the "Watts Up" meter we found that although this specific refrigerator was small, it constantly runs a fan at 65 Watts. The other large energy consumer is the large freezer at PK, used to maintain specimens.

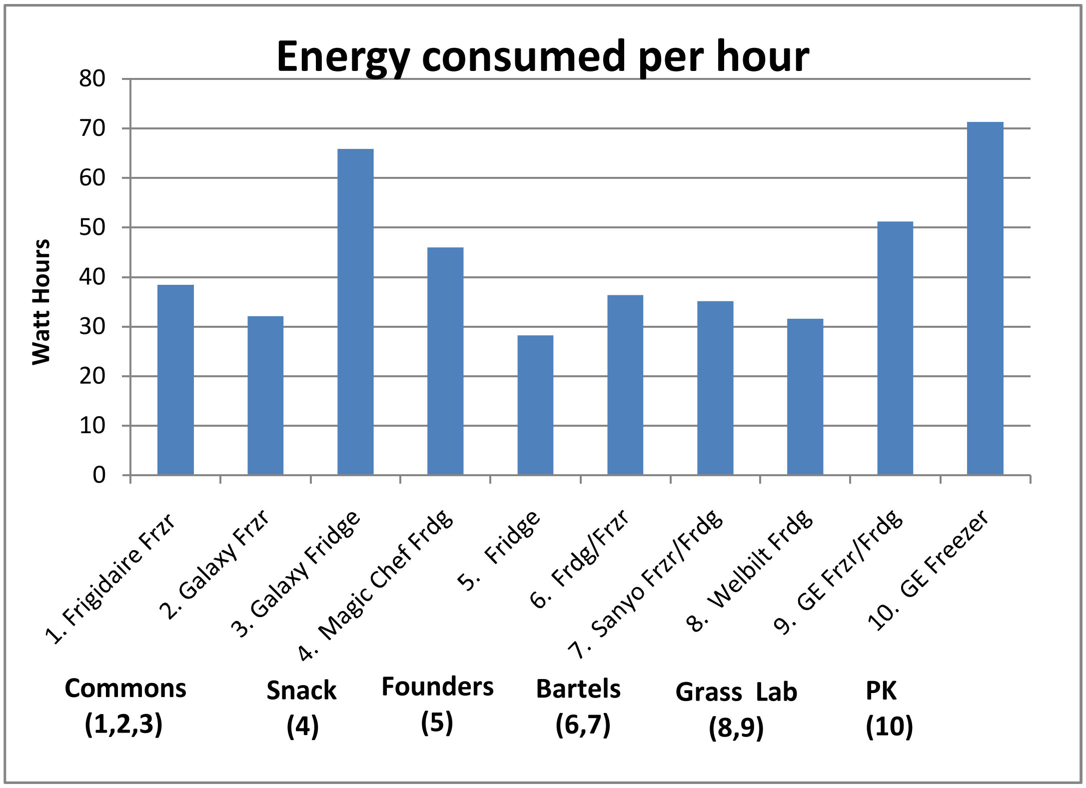

Figure 18: Energy consumed by campus refrigerators and freezers

Table 25: Refrigerator and Freezer data

REFRIGERATOR/FREEZERS		Name	Serial #	Watts/hr	kW/month
Commons	Basement	Frigidaire Freezer	WB72646495	38.36	27.62
	Basement	Galaxy Freezer	WB05120122	32.1	23
	Basement	Galaxy Refrigerator	20091501422	65.86	47.6
	Snack Area	Magic Chef	IE19280686	46.03	33.1
Founders	3rd Floor		60300047	28.26	20.3
Bartels	Kitchen	Kenmore 22	9512780	36.4	26.1
	Kitchen	Sanyo	607478.00	35.14	25.2
Grass Lab	1st Floor	Welbilt	198609048661	31.59	22.7
	2nd Floor	GE Freezer/Refrigerator	AH703115	51.24	37.2
PK	Outside	GE Freezer	DT141251	71.28	51.1

Recommendation

During our data collection we were pleased to note that there were no refrigerators turned on without there being something inside. We suggest that refrigerator usage be discussed during a routine staff meeting to determine who is using the refrigerator and if they need them on. Perhaps the refrigerators could be shared among researchers or staff such as the three refrigerators/freezers underneath Kiggins Commons.

Propane Usage

It is recorded in a logbook by the island engineers every time the propane tanks are changed. Island population was also estimated based on the estimates given to the cooks. Using these two data sets, we correlated propane usage of each month with the average daily population of the island. We correlated the values for the season of 2009 and for May and June of the 2010 season. Figure 19 represents a graph of these values while Table 26 gives the specific numbers. From the graph June 2010 had a higher propane usage per average daily population but this may be due to the variance in changes (which is shown by a lower value for May 2010). This data should continue to be kept and correlated so that a better view will be obtained in the future of how Shoals propane use varies in accordance with the daily population average.

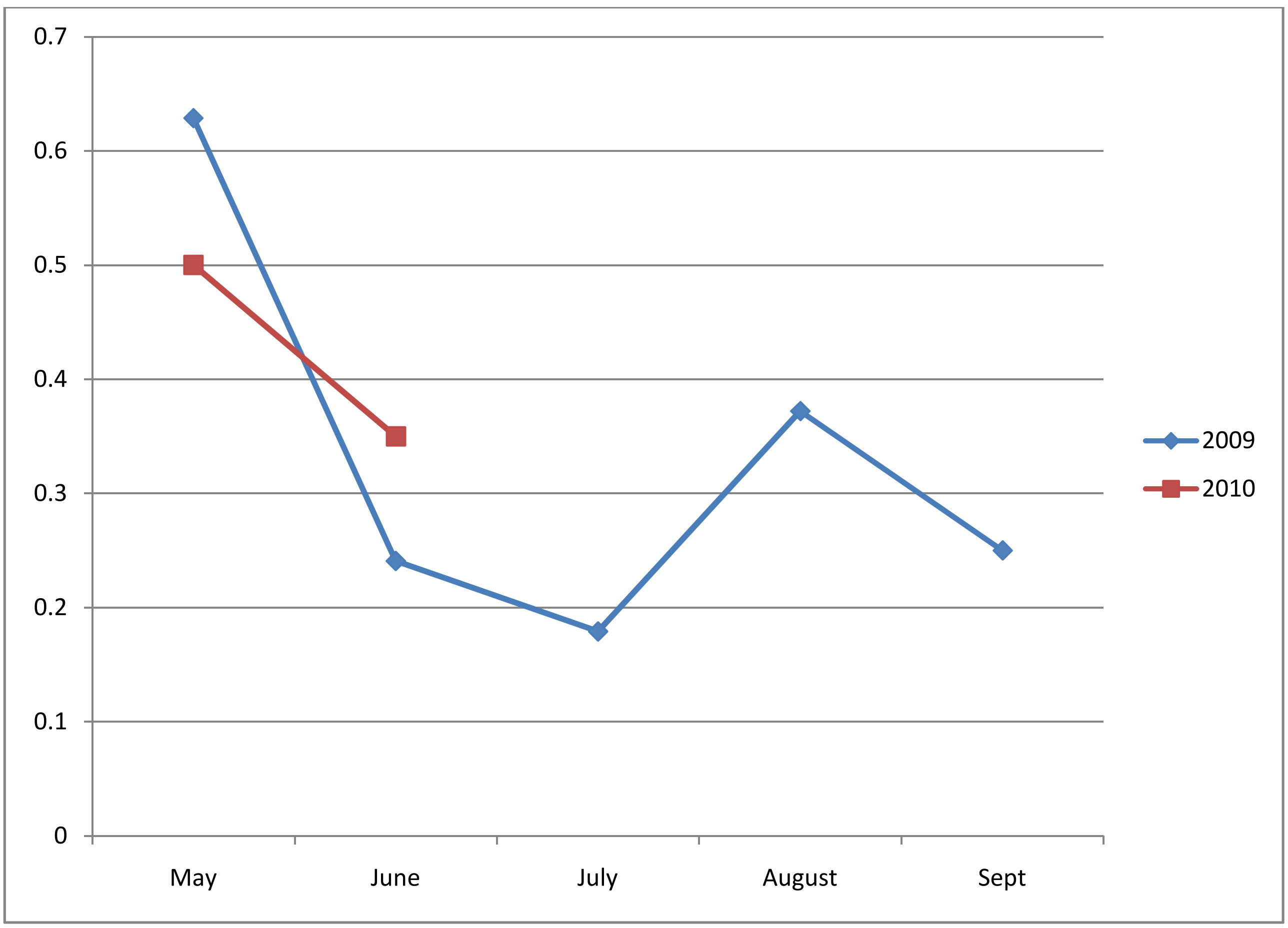

Figure 19: Propane bottles changed/average daily island population

Table 26: Propane barrels changed per month, Average daily population, and correlation of the two

2010	People/day	Propane changed	Propane per average daily population
May	28	14	0.5
June	60	21	0.35
2009	People/day	Propane changed	Propane per average daily population
May	35	22	0.628571
June	54	13	0.240741
July	67	12	0.179104
August	43	16	0.372093
Sept	12	3	0.25

Boat Trips and Fuel Consumption

After a short time here at Appledore we began to notice that there was consistently a Shoals boat leaving the island for the shore. We began to ask what the uses of the trips are and obtained how often a trip to Portsmouth is made. We found that the routine trip schedule is:

Monday: Kingsbury, 1 round trip

Tuesday: Heiser, 2 round trips

Wednesday: Kingsbury, 1 round trip

Thursday: No planned trips

Friday: Heiser, 1 round trip

Saturday: Heiser, 1 round trip

Sunday: Heiser, 1 round trip

We were amazed to see how often these trips are made and realize that many of these trips are necessary for activities such as food run, beginning and ending classes, and other transportation needs. In order to get a better perspective of the cost of each round trip we calculated the fuel consumption of each boat with a gasoline price of $2.69. These calculations are shown below.

Fuel Costs:	Time:
Heiser: 16 gallons/hr Round trip: 24 gallons	Heiser: 1.5 hrs (round trip)
Kingsbury: 4 gallons/hr Round trip: 12 gallons	Kingsbury: 3 hrs (round trip)

When the days and trips are labeled according to costs the values appear as below.

Monday: Monday – $32

Tuesday – $129

Wednesday – $32

Thursday – $0

Friday – $65

Saturday – $65

Sunday -- $65

We believe that a round trip could be reduced for at least one day a week and thereby reduce the expense of fuel and other unseen costs. For example, one less round trip on Saturday or Sunday would save $65 a week. We suggest that the lab reduce the round trips made between Portsmouth and Appledore and therefore save lab funds.

Another possible solution is to use the Miss Christine to shuttle people to and from the island when the weather is nice and very few people or supplies need to be transported.

Fuel Costs:	Time:
Miss Christine: 4 gallons/hr Round Trip: 3.32 gallons	Miss Christine: 0.83 hrs (round trip)

This means the Miss Christine only cost **$8.93** to run per round trip. This is roughly one quarter the cost of running the Kingsbury and one eighth the cost of running the Heiser. The Miss Christine should be run whenever possible instead of either the Kingsbury or the Heiser.

Saltwater System Pump Energy Conservation

Background

SML has an extensive saltwater system to feed the sea tales in the laboratories. The saltwater has to flow continuously so that the specimens are in a water environment that is similar to the ocean. This requires running an electric pump continuously. The present pump is the largest single user of electricity on the island. The current pump in use is a Gould 5AB1K2H0, 3656, 1 ½ x 2 -8, with a 6 1/8 inch impeller. Shoals Marine Lab has a similar pump that is used as a backup.

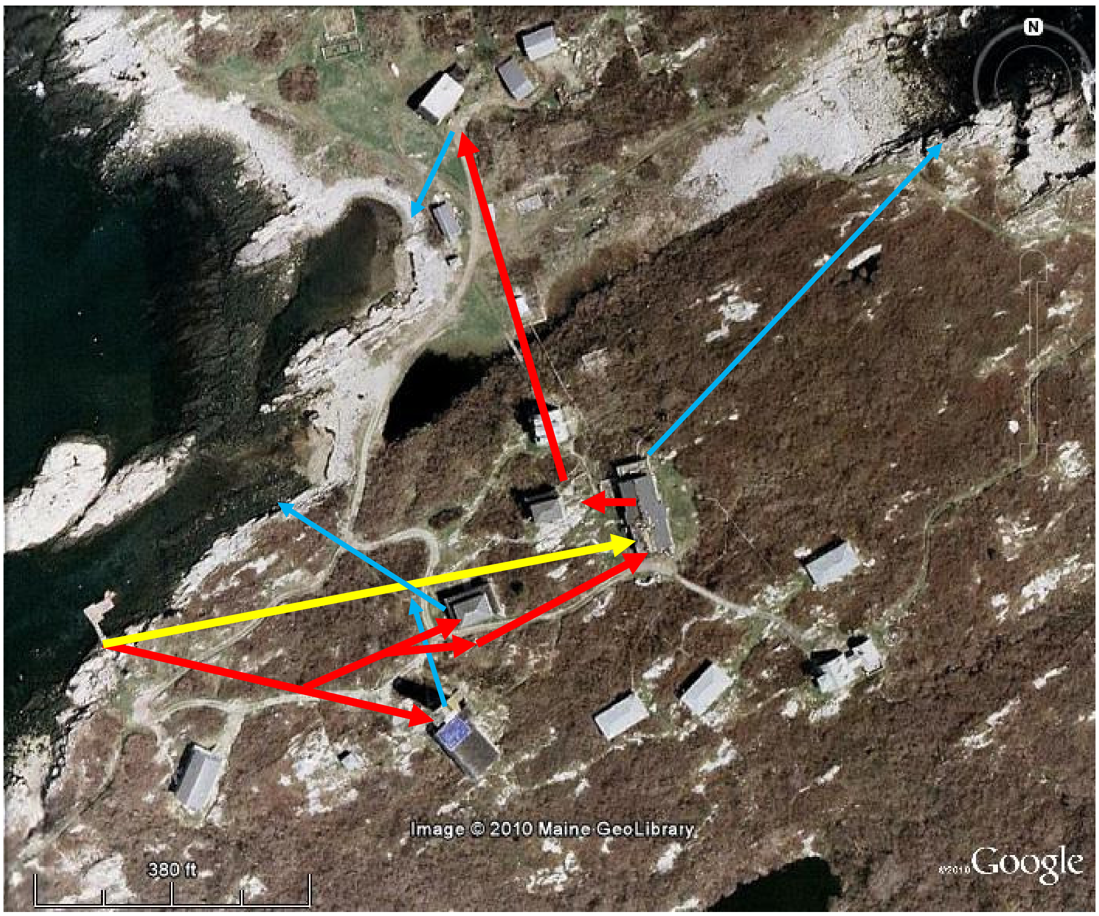

Figure 20: Map of Current Salt Water System

Key
- Pipe 1 Intake
- Pipe 2 Intake
- Discharge

Elevation Changes:

Ocean to Center of pump (tide of 1.09ft) = 20.74 ft.

Pump to PK = 46 ft

Objective

Reduce the amount of electricity needed to pump sea water for the saltwater system.

Analysis

It was discovered that salt water was being delivered unnecessarily to many empty sea tables. This struck interest in the behaviors of students and faculty regarding the seawater usage. To determine the students' attitude and usage of the sea tables we talked with students who have taken courses here at Shoals. We found that students are rarely involved in changing the flow rate of the sea tables. Another interesting theme was that most students replied to have at one point used the sea tables, though not often by any means.

Once we found out the students' use of the sea tables, we talked with the teachers and other staff members during our time on the island. While the Forensics class was not involved in any use of the sea tables, another teacher during the week of June 27 to July 3, 2010 seemed to be very aware of the usage and conservation of the salt water to the sea tables. From these responses and the observed behavior we believe that the constant rotation of teachers changes the consumption of salt water feeding the sea tables. In addition, we believe that the professors feel responsible for the sea table they are running and are hesitant to touch the flow of sea tables that they have not turned on themselves.

When we arrived at Shoals, we found that there were four sea tables running water through them although they were not being used. After speaking with a staff member about their use we found that they had been on all season. On June 29, after speaking with Ross about these unused sea tables their individual valves were turned off. After this, we heard no complaints that the sea tables were off. From these conversations and observations we believe that currently the sea water is seen as a valuable commodity where the cost of its use is not highly considered.

From these conclusions we suggest that signs be place near the sea tables to remind the teachers, new and returning, to conserve the flow of the sea tables. By doing so, the flow rate will be lowered consistently throughout the duration of the season. In addition to physical reminders it is suggested that one person be in charge of all the sea tables and understand the cost included of having sea tables running and thereby insure that sea tables are not running without use.

Data Collection

We calculated the maximum flow rate with the help of Heather Anne. We began measuring the flow rate at the pump house of the sea tables already running, the ones underneath Kiggins Commons (outside, under the deck), the three Laighton, then proceeded to turn on each sea table throughout the island. We then took the maximum flow rate of all the sea tables and added the flow rate of a fire hose. As found in Table 27, we recorded the maximum flow rate for all the current salt water applications at 59.5 Gallons per Minute (GPM).

Table 27: Flow Rate from Salt Water Pump

	Flow (gallons/min)	Difference (gallons/min)	Flow (L/min)	Difference (L/min)
Initial	41		155	
PK North Side Table On	50	9	190	35
PK South Table On	53	3	201	11
Kiggins On	56	3	212	9
Grass Lab On	56	0	212	0
Salt Water Faucet in Grass Lab On	56.5	0.5	214	2
Fire Hose On	56	3	212	9
Fire Hose Off	53	3	201	9
Total (All Sea tables + Fire Hose)	**59.5**			

Total Dynamic Head

Another important aspect in determining the correct size of pump is the Total Dynamic Head. We found that previous years interns had determined the total head of the system to be 111 ft (See Final Report 2007 pg 24). We found this to be a good estimate after using Google Earth to determine that the elevation rise from the pump (18 ft above sea level) to PK (64 feet above sea level) is 46 ft, assuming the remaining total head is due to friction losses. Using Google Earth and finding the neap tide record for Gosport Harbor (-3.5 ft.) we calculated the elevation rise from the neap tide to the pump was about 21.5 ft. In calculating the total dynamic head we were careful to remember the pressure requirements for the fire hoses and were instructed to keep a minimum pressure of 25 psi (57.765 ft of head) for the fire hoses. The total dynamic head plus the minimum pressure requirement equate to 168.765 ft of head.

Net Positive Suction Head (NPSHa)

Perhaps the most important factor with downsizing the current salt water pump is the amount of suction lift that the pump has to perform. We concluded that a more precise elevation difference from the pump to the lowest low tide was needed then the results mentioned above. This information is necessary in order to determine the Net Positive Suction Head Available (explained in Equation 2).

$$NPSHa = Ha - Hz - Hf + Hv - Hvp$$

Equation 2: Equation for Net Positive Suction Head Available (NPSHa)

Ha = Absolute Pressure of the liquid at elevation
Hz = Vertical distance from centerline of the pump to the lowest level of the liquid
Hf = Friction losses
Hv = Velocity head at the pump suction
Hvp = Vapor Pressure of the liquid

After consulting with Ross Hansen we used a transit to accurately find the height difference from the ocean to the pump. We took our measurements at 2:32 PM on July 9, 2010. Using the transit we found that the elevation change from the water level to the center of the pump was 244.125 inches. We then used a tide chart for Gosport Harbor which gave us the difference from the level of the sea at 2:31 PM and the low tide of the day (1.09 ft.). The difference was calculated to be 4.8 inches and therefore a total distance of 248.925 inches for the low tide of July 9.

To ensure that we found the maximum height difference that the pump would have to lift, we took the extreme low tide for Gosport harbor (-3.5 ft.) and took the difference of this tide from the low tide of July 9, which equated to 4.59 ft. We added this record low tide to our previous calculation of the elevation of the pump in order to ensure a safe estimate. In inches, this calculation becomes

248.925 + 55.08 (4.59*12) = 304.005 (or 25.338 ft.).

(distance from the pump to the low tide of July 9) + (depth of record low tide below the tide on July 9) = (Furthest distance we expect from the ocean to the pump)

We calculated the values for the NPSHa equation (see Figure 20) as follows:

Ha = 33ft (H20) (1 atm at sea level),
Hz = 25.38 ft,
Hf = 3.6 ft,
Hv = neglected due to little and variable velocity
Hvp =.80 ft,
NPSHa = 9.16585 ft.

This means that when exploring the options of a smaller pump the NPSH required of the pump should not be more than our value of 9.17 ft. In the even more conservative scenario, using the lowest ever recorded tide data of -3.5 ft., the NPSHa would = 7.66585.

When looking at various pumps we were cautious to ensure that the NPSH required (NPSHr) of the pumps were more than our calculated NPSHa. Doing so helps to protect a future pump from experiencing cavitation and ultimately pump failure.

In the process of researching we found that the NPSHr is often given at a rate where the pumps performance will be degraded by 3% which with suction lift will result in cavitation and eventually pump failure.

Researched Possibilities

Variable Frequency Drive (VFD) pump

A variable frequency drive pump would allow the sea tables to receive their necessary flow and would respond to a decrease in flow by reducing the impeller speed and thereby the total energy consumed. We found that energy savings would still be significant when a large portion of the head comes from static head, as in our situation.

Table 28: Power Consumption

Flow (GPM)	Flow (%)	Throttled	VFD			
			0 ft. static head	60 ft. static head	140 ft. static head	210 ft. static head
170	50%	19.70 kW	3.20 kW	6.35 kW	10.44 kW	14.08 kW
204	60%	20.95	5.46	8.7	12.7	16.02
238	70%	22.21	8.68	11.75	15.42	18.3
272	80%	23.47	13.06	15.58	18.61	20.9
306	90%	24.73	18.83	20.31	22.31	23.77
340	100%	25.99	26.19	26.02	26.52	26.89

(These tests used a two-pole, 3,560 rpm, 40-hp, totally enclosed fan-cooled motor with a NEMA nominal nameplate efficiency of 94.1% matched with a pump having a 3-in. suction, 2-inch discharge and 8-inch impeller. The VFD was rated at 40-hp. Both the drive and motor are three-phase 460 VAC. The system curves represent 0, 60, 140 and 210 feet of static head. Each curve intersects the pump curve at approximately 340 GPM.) (see http://www.plantservices.com/articles/2005/491.html?page=2).

The VFD motor appears attractive in its energy conservation but they are not well suited for pumps that have a high suction lift. In a VFD the RPM range changes as a result of flow demands upstream. In our situation we need to maintain a high RPM no matter the flow rate in order to maintain the large suction lift. If a submersible pump is chosen, then a VFD pump would help to significantly lower the energy costs according to the above table.

Submersible Pump

A submersible pump would overcome our current concern with our high suction lift but would present new cautions from the open ocean water. We found some pumps that are made to withstand the aggressive nature of ocean water. A submersible pump would allow us to use a lower horsepower and a variable frequency drive motor. While these features are attractive, the cost of such materials would be very expensive and the cost of unexpected destructive ocean elements would not make a submersible pump the best option. In the specific situation of the salt water pump on Appledore, we recommend that a more cautious approach be taken. This will decrease the variables of weather and intertidal organisms. (An example of an anti corrosion material can be found at http://www.us.grundfos.com/web/download.nsf/Pages/AE3491FCF7342D34882569D800763C1E/$File/L-CI-TL-002.pdf).

Cost: $3,900 (6” diameter pump – made for a 6’’ well and a 4” diameter motor, 5 HP, 230/v/3 phase)

Smaller Pump

5hp motor--Gould 3656 9BF 1J1F0, 1x2-8

After consulting with a technician at Gould pumps we found a pump (Gould 3656 9BF 1J1F0, 1x2-8) that would be able to maintain suction even at the lowest tide we receive here at the island. This pump is made out of cast-iron with the impeller made of brass being able to withstand corrosion. Cost: $2,468 (6 3/16" impeller diameter, 5 HP)

Using the data of the 2007 interns combined with the desired pressure for the fire hoses (168 ft. of total dynamic head) we see on the pump curve (Figure 21) the 9BF pump would be operating between 45 – 50% efficient and would be able to keep a pressure of 25 psi at a flow of 54 GPM. Reducing the flow under this level would put additional stress on the fixed speed motor because it would be working under its desired capacity.

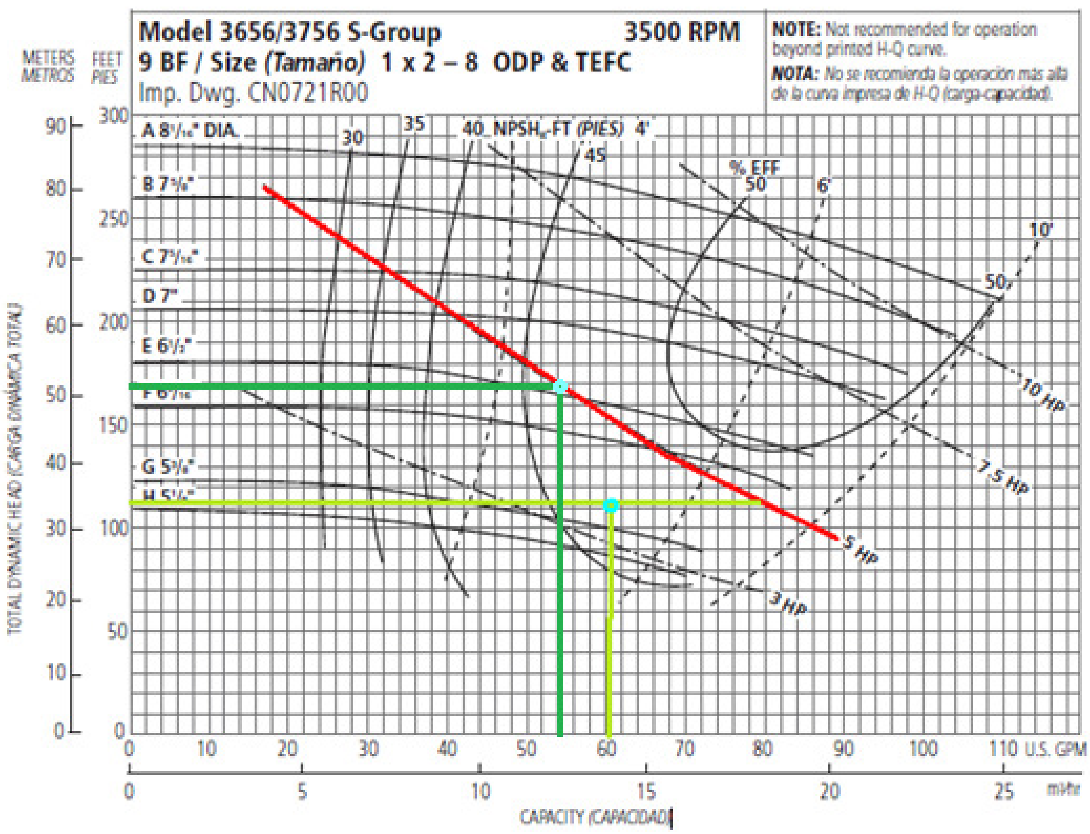

Figure 21: Pump Curve (Gould 3656 9BF 1J1F0, 1 x 2-8)

(Red: The pump capacity of 5hp; Light Green: Pump conditions of 111 ft of total dynamic head and a flow of 61 GPM; Dark Green: Pump conditions for 170 ft of total head and a flow of 54 GPM; Blue Dots: Where the pump would be operating under specified conditions).

3hp motor-- Gould 3656, 3BF, 1 ½ x 2 – 6

Another option is an even smaller pump. The Gould 3656, 3BF, 1 ½ x 2 – 6 would sustain a 65 GPM load at a total dynamic head of 111 ft, which does not include the desired pressure for the fire hoses. At these levels of flow and total head the pump only requires 6 ft of NPSH. As seen in the pump curve below (Figure 22), the pump would be operating betweeen 60 – 65% efficient at that point. This pump would feed the water tables but would not give enough pressure for the firehoses.

Cost: $1561 (6 1/8" impeller diameter, 3hp)

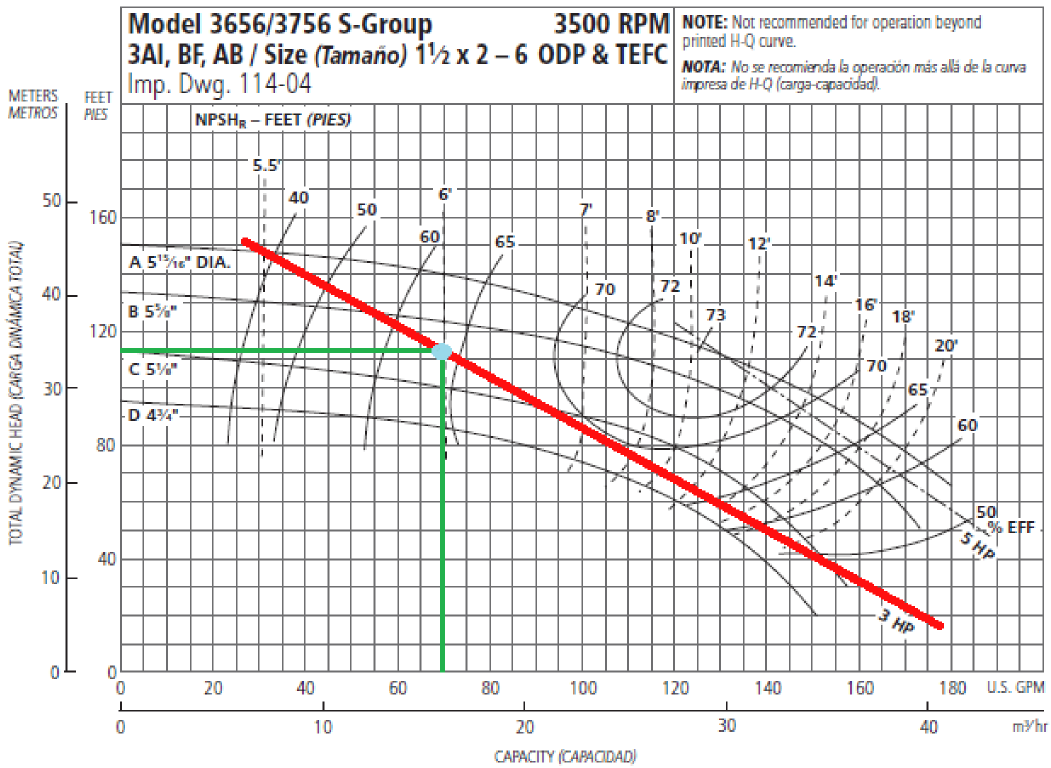

Figure 22: Gould 3656 3BF 1H1B0, 1 ½ x 2 – 6 pump curve

(Red: The pump capacity of 3hp; Green: Maximum pump conditions of 111 ft of total dynamic head and a flow of 66 GPM; Blue: Where the pump would be operating under specified conditions).

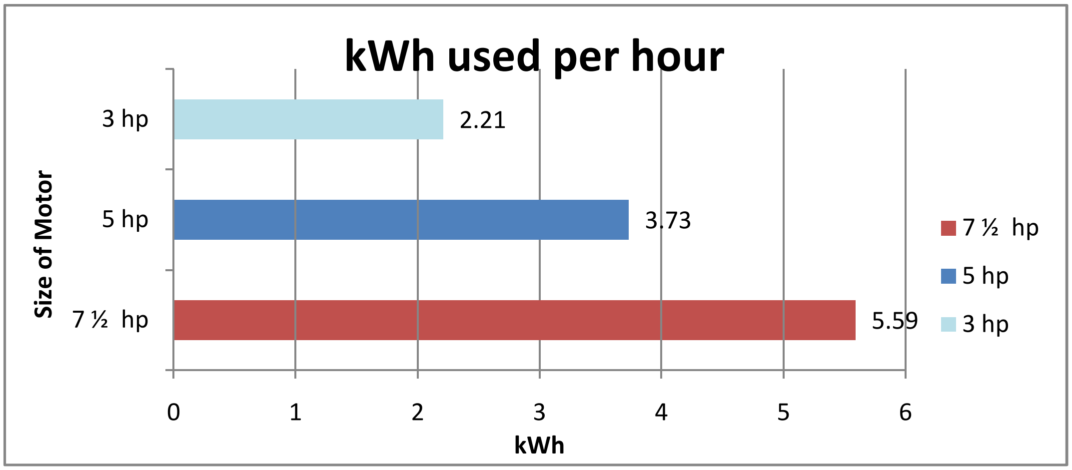

Figure 23: Energy Consumption Comparison (7 ½ hp, 5 hp, 3 hp)

We calculated an estimate for the cost to produce 1 kWh of energy. To do this we monitored the amount of fuel burned and the amount of energy produced during the 2010 season. We received the cost paid per gallon of fuel during September of 2009. We found that the cost for 1 kWh is equal to $0.26. This is a low estimate, given the additional expenses of oil changes and maintenance but worked to give us an idea of the cost. Using this estimate we compared the savings for a 3hp motor versus a 5hp motor (Figure 23).

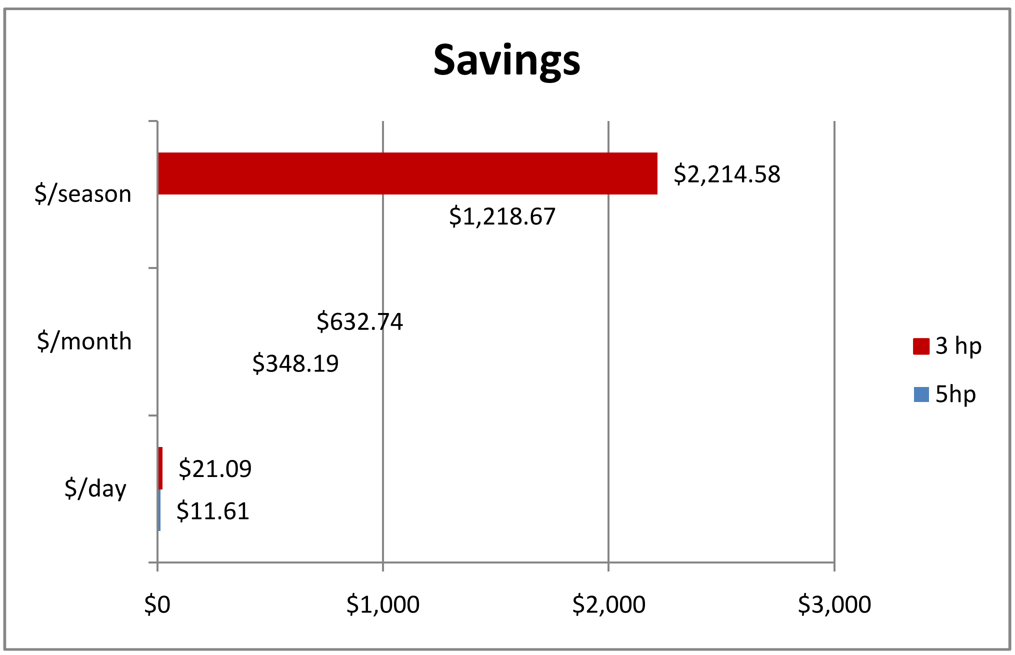

Figure 24: Savings compared from a 3hp to a 5 hp motor

Pumps in Parallel

There are many configurations for pumps in parallel. These applications can be utilized for situations where a minimum pressure is required or a minimum flow rate is necessary. We suggest that for a situation with one small pump and a larger pump that a simple setup be installed. In this scenario the lab preparation coordinator and professors would have to correlate with island engineers if a higher flow rate were necessary.

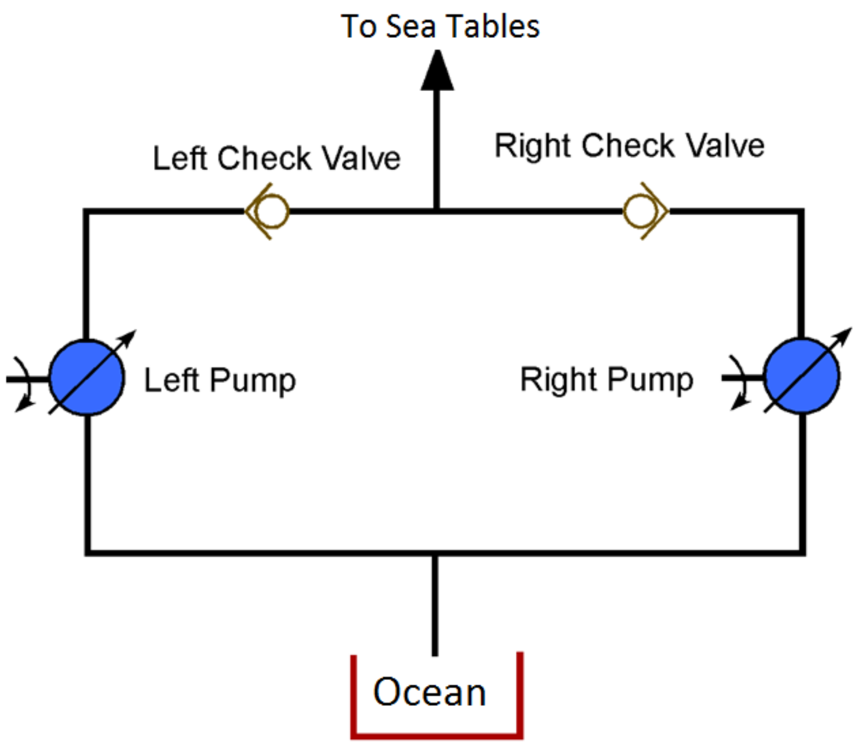

Figure 25: Pumps in Parallel Configuration

Safety Precaution

We found that Gould makes a Load Monitor that would help prevent overload or under load conditions and thereby help avoid pump damage or failure.

Final Suggestions

After much research on the current salt water system we recommend that the Shoals Marine Lab continue to use the model of pump currently in operation. Although the 7 ½ hp motor costs significantly more in energy production, the pump has been working consistently even with the high suction lift demand.

The current saltwater pump has the capacity to feed all of the sea tables and even more if desired. We believe that any sea table beneath PK or the Commons would easily receive flow without significantly changing the flow or work from the salt water pump.

Kiggins Acoustic Improvement

Background

The upper level of Kiggins Commons is primarily used as a cafeteria and a workspace between meal times. Hardwood ceilings and floors, glass, and a complex pointed ceiling geometry cause a cacophony of sound during meal times making it very difficult to intelligibly understand table conversations. Conversations from across the room can be heard and understood just as well as neighboring conversations. There are very few absorptive surfaces like rugs or sofas in the room. There are also fans hanging from the ceiling, blinds on the west side of the room, and hard chairs which affect the travel of sound around the room.

Objective

Quantify the acoustical characteristics of the Kiggins Commons dining room in order to suggest solutions that are appropriate for the room and its intended usage.

Data Collection

Theoretical

Speaking with Willie Bemis we strove to find the desired use for the commons area. We found that the Kiggins Commons is used for multiple purposes but Willie's main concern was to provide a quieter atmosphere for "lunch." With this desired outcome we will provide better suggestions on how to decrease the noise level of the room during lunch.

A quantitative assessment of the room was done by taking background noise measurements when the room was completely empty except for the person measuring and spreading characteristic measurements when the room was in little use. This assessment was combined with the theoretical reverberation times calculated at different frequencies from the absorption coefficients and dimensions of the materials in the room. Frequencies with long reverberation times were then identified as problems and targeted for solutions.

Calibration

We used a Quest Electronics 215 handheld Sound Level Meter (SLM) along with a Quest Electronics OB-45 Octave Band Filter to measure the sound pressure level (SPL) in the dining room. We calibrated the SLM with a Quest Electronics CA-12 Sound Calibrator. For a constant noise source, we ran a ShopVac vacuum cleaner, which produced an A-weighted sound power level of 87dB with respect to 10^{-12} watts. All measurements were taken with all of the windows and exterior doors open and all of the fans turned on. The tables and chairs were arranged as they are during meals.

In order to find the power level (PWL) of the ShopVac, we took four SPL readings with the meter and ShopVac in the same spots, two meters apart but with the ShopVac facing four different directions, however the results were discarded. Instead we used a previously calculated power level of the Shop-Vac found by Al Russel. The experimental results were not used because the data was collected when the Shop-Vac was on a table and therefore the sound could not travel in a true hemispherical space. Al Russel's Shop-Vac power calibration was performed on the floor, increasing the accuracy relative to our collection, and the results are shown in Table 29 along with the background noise levels of the room. The Shop-Vac power level used for this project is 84 dB at 1000 Hz.

Next, we determined the background noise level in the dining room. We took measurements in the center of the unoccupied room with the exception of the person measuring. No noise sources were active except the outside noises, like gulls and wind, as well as various continuously left-on appliances, such as water heaters and refrigerators. We measured the SPL on the dBA scale, which represents the entire acoustic signal after "A" scale filtering. This scale is similar to what the human ear would hear.

We then quantified what a single noise source sounds like from different locations in the room by performing a dispersion test. We took dBA SPL readings at each table with the room in its mealtime configuration.

Table 29: Shop-Vac Power Level and Background Noise Readings

Octave Band Center Frequency		**Background Noise**
	PWL	**SPL**
	dB	**Db**
63	54	53
125	69	53
250	83	47
500	85	45
1000	84	41
2000	78	41
4000	70	37
8000	60	
dBA	87	48
Linear	89	55

We conducted a "walk away" or sound versus distance test. We observed how the sound level varied with distance away from the noise source. We performed this test twice to increase the accuracy of our investigation. We placed the ShopVac in the center of the buffet tables located at the front of the room, closest to the south-facing wall, and took SPL readings at measured distances from the ShopVac. We measured and recorded dBA and octave band readings: 125 through 4000. The octave bands 63 and 8000 were excluded due to their irrelevance as absorption data is not available for them. Once this data was collected, the room constant, R, values were calculated using Equation 4. In Equation 4 as in Equation 3, SPL represents the sound pressure level measurements taken by our sound level meter, PWL represents the calculated power level of the ShopVac, r represents the radius of the hemispherical space being measured, and R is the room constant to be solved for.

$$SPL - PWL = 10\, log\, [\frac{1}{2\pi r^2} + 4R]$$

Equation 3: Experimental Room Constant Equation

As a check for the experimental R value calculation, we theoretically calculated R by totaling the various materials in the room, multiplying those by the known sound absorption coefficients for each material, and using Equations 5. In Equation 5, R is the room constant value in meters, Sa is the total absorption, and a is the average absorption coefficient.

$$R = 0.0929(\frac{Sa}{1-a})$$

Equation 4: Theoretical Room Constant Equation

Along with the theoretical room constant, we calculated the theoretical reverberation times at each of the octave band frequencies using Equation 6. In this equation, T represents the reverberation time in seconds, VOL represents the volume of the room, and Sa represents the total absorption.

$$T = 0.05\frac{VOL}{Sa}$$

Equation 5: Theoretical Reverberation Time Equation

Meal Time Table Arrangement Test

The sound pressure level in Kiggins Commons was measured at lunch and dinner with the tables arranged in their normal configuration as shown in Figure 26. These measurements were taken at the locations shown in Figure 27. The tables were then rearranged in the arrangement shown in Figure 28 in the hope that sound would go directly out the windows instead of bouncing around the room and the sound pressure level was re-measured at the same locations.

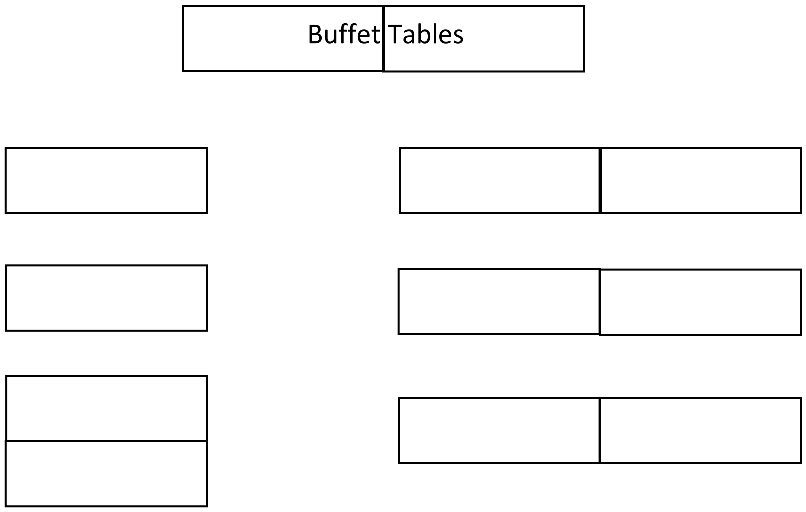

Figure 26: Normal Configuration of Tables in Kiggins Commons

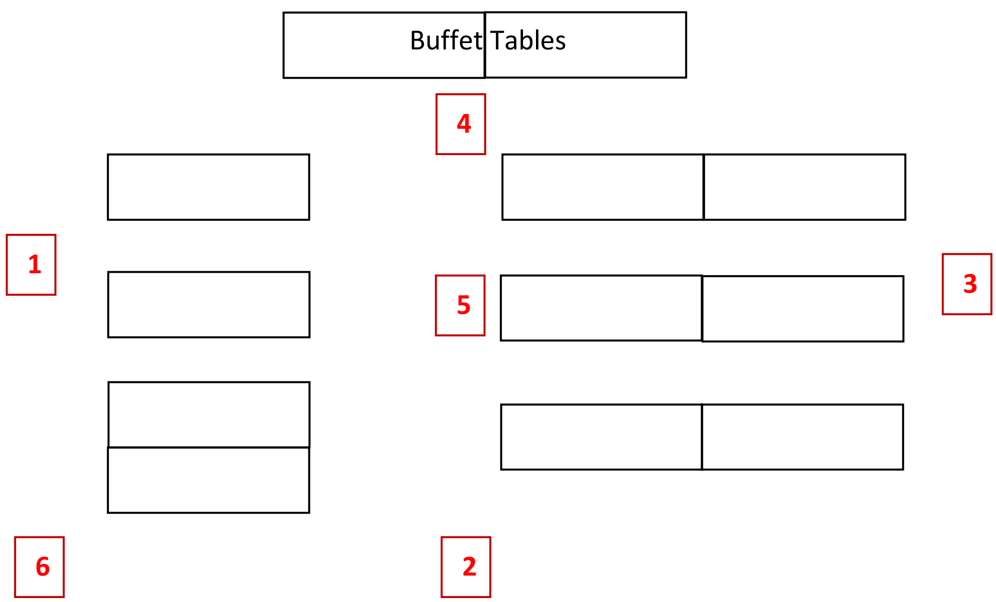

Figure 27: Sound Pressure Level Measurement Locations

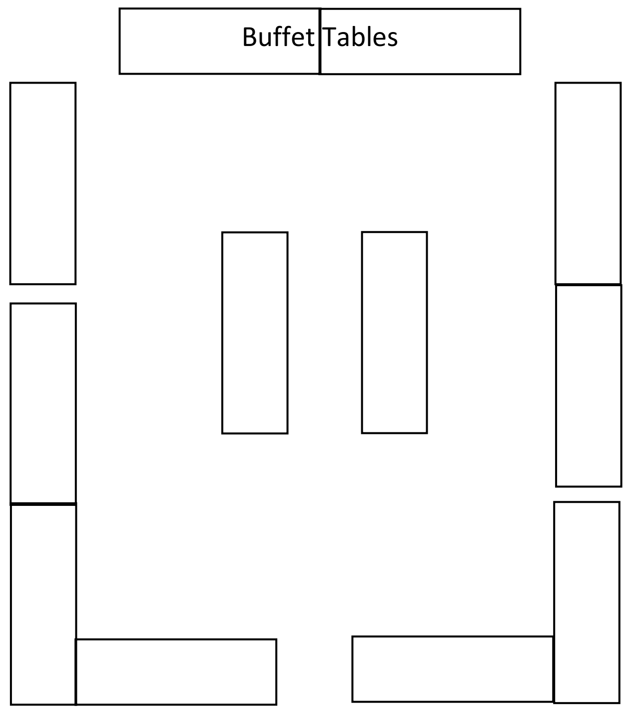

Figure 28: Rearranged Configuration of Tables in Kiggins Commons

Analysis

Theoretical

The reverberation time is defined as the amount of time it takes for a sound to decrease 60 decibels. A theoretical reverberation time can be calculated for each frequency. A longer reverberation time at a specific frequency means that that frequency of sound lingers in the room for a longer period of time. The building materials and furnishings of Kiggins Commons were analyzed using the Sound Absorption Data for Common Building Materials and Furnishings of ASTM C423 (see appendix). The absorption coefficients for each material and furnishing were looked up in this data and from those absorption coefficients the theoretical reverberation time of various frequencies of sound were calculated. The windows of Kiggins Commons can only be partially open so it was assumed that ¾ of the windows were fully open and ¼ were fully closed. Table 30 shows the absorption coefficients as well as reverberation times for various frequencies in an empty room. Table 31 shows the absorption coefficients as well as reverberation times for various frequencies in a room filled with people sitting in their chairs. This was done because people absorb a certain amount of sound and affect the reverberation times of the room.

Table 30: Absorption Coefficients and Reverberation Times of Unoccupied Kiggins Commons

ROOM ACOUSTICS: REVERBERATION TIME WORK SHEET

Unoccupied Kiggins Commons, existing configuration

6/24/10

SURFACE	MATERIAL	Area (sq ft)	Sound absorption coefficents (al) Octave Band Center Frequency 125	250	500	1000	2000	4000	Sound absorption (Si x al) Octave Band Center Frequency 125	250	500	1000	2000	4000
Floor	wood	1640	0.15	0.11	0.1	0.07	0.06	0.07	246	180	164	115	98	115
Ceiling	wood	1723	0.15	0.11	0.1	0.07	0.06	0.07	258	190	172	121	103	121
North	door	21	1	1	1	1	1	1	21	21	21	21	21	21
Facing	wood	29	0.4	0.9	0.8	0.5	0.4	0.3	12	26	23	15	12	9
	windows	495	0.35	0.25	0.18	0.12	0.07	0.04	173	124	89	59	35	20
	wood arch	42	0.15	0.11	0.1	0.07	0.06	0.07	6	5	4	3	3	3
East	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
Facing	wood	186	0.15	0.11	0.1	0.07	0.06	0.07	28	20	19	13	11	13
South	1" wood	170	0.19	0.14	0.09	0.06	0.06	0.05	32	24	15	10	10	9
Facing	open door	39	1	1	1	1	1	1	39	39	39	39	39	39
	wood	365	0.28	0.25	0.18	0.12	0.07	0.04	102	91	66	44	26	15
West	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
Facing	wood	186	0.15	0.11	0.1	0.07	0.06	0.07	28	20	19	13	11	13
Other	12 tables	288	0.15	0.11	0.1	0.07	0.06	0.07	43	32	29	20	17	20
	unoccupied chairs	70	0.15	0.19	0.22	0.39	0.38	0.3	11	13	15	27	27	21
	wood arches	236	0.15	0.11	0.1	0.07	0.06	0.07	35	26	24	17	14	17
	air (/1000 ft3)	20	0.9	0.9	0.95	1	1	1	18	18	19	20	20	0
	Total area, S	5706							125	250	500	1000	2000	4000
	Volume, VOL	20490	Total absorption, Sa (Sabines)						1122	878	753	560	460	442
			Average absorp coeff, a (radians)						0.25	0.15	0.13	0.10	0.08	0.08
			Reverbation time, T = 0.05VOL/Sa (sec)						0.91	1.17	1.36	1.83	2.23	2.32
			Room constant, R = Sa/(1-a) (sq ft)						1496	1038	868	621	501	479
			Room constant = 0.0929 R (sq meters)						139	96	81	58	47	44

Table 31: Absorption Coefficients and Reverberation Times of Occupied Kiggins Commons

ROOM ACOUSTICS: REVERBERATION TIME WORK SHEET — 6/24/10

Occupied Kiggins Commons, existing configuration

SURFACE	MATERIAL	Area (sq ft)	Sound absorption coefficents (al) Octave Band Center Frequency 125	250	500	1000	2000	4000	Sound absorption (Si x al) Octave Band Center Frequency 125	250	500	1000	2000	4000
Floor	wood	1640	0.15	0.11	0.1	0.07	0.06	0.07	246	180	164	115	98	115
Ceiling	wood	1723	0.15	0.11	0.1	0.07	0.06	0.07	258	190	172	121	103	121
North Facing	door	21	1	1	1	1	1	1	21	21	21	21	21	21
	wood	29	0.4	0.9	0.8	0.5	0.4	0.3	12	26	23	15	12	9
	windows	495	0.35	0.25	0.18	0.12	0.07	0.04	173	124	89	59	35	20
	wood arch	42	0.15	0.11	0.1	0.07	0.06	0.07	6	5	4	3	3	3
East Facing	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
	wood	186	0.15	0.11	0.1	0.07	0.06	0.07	28	20	19	13	11	13
South Facing	1" wood	170	0.19	0.14	0.09	0.06	0.06	0.05	32	24	15	10	10	9
	open door	39	1	1	1	1	1	1	39	39	39	39	39	39
	wood	365	0.28	0.25	0.18	0.12	0.07	0.04	102	91	66	44	26	15
West Facing	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
	wood	186	0.15	0.11	0.1	0.07	0.06	0.07	28	20	19	13	11	13
Other	12 tables	288	0.15	0.11	0.1	0.07	0.06	0.07	43	32	29	20	17	20
	occupied chairs	70	0.3	0.41	0.49	0.84	0.87	0.84	21	29	34	59	61	59
	wood arches	236	0.15	0.11	0.1	0.07	0.06	0.07	35	26	24	17	14	17
	air (/1000 ft3)	20	0.9	0.9	0.95	1	1	1	18	18	19	20	20	0
	Total area, S	5706												
	Volume, VOL	20490												

	125	250	500	1000	2000	4000
Total absorption, Sa (Sabines)	1132	894	772	591	495	479
Average absorp coeff, a (radians)	0.25	0.16	0.14	0.10	0.09	0.08
Reverbation time, T = 0.05VOL/Sa (sec)	0.90	1.15	1.33	1.73	2.07	2.14
Room constant, R = Sa/(1-a) (sq ft)	1509	1060	893	660	542	523
Room constant = 0.0929 R (sq meters)	140	98	83	61	50	49

The theoretical calculations of reverberation times show that an empty Kiggins Commons has an - average reverberation time between 500 Hz and 1000 Hz of 1.65 seconds. The theoretical calculations of reverberation times show that a fully occupied Kiggins Commons has an average reverberation time between 500 Hz and 1000 Hz of 1.58 seconds. The average reverberation time between 500 Hz and 1000 Hz is used because this frequency range is the most commonly heard frequency range by humans which is what we are interested in. Using the chart of recommended reverberation times for different room types, it was determined that the current reverberation times make Kiggins Commons more suited for churches, high school auditoriums, or opera (see appendix). Although the chart has no cafeteria reverberation time recommendation, it was determined that Kiggins Commons was to mimic the sound levels of the lecture and conference room category. The recommended range of reverberation times for lecture and conference rooms was between 0.7 seconds and 1.1 seconds. This means that the current reverberation time of an occupied Kiggins Commons needs to be lowered from 1.58 seconds to this level. To lower the reverberation time by half the existing absorption of the room needs to be doubled. Therefore to reach the goal of deadening the sound of Kiggins Commons to that of a lecture or conference room, the absorption of the materials in the room must be increased 44 % to 125 %.

Experimental

Walk Away Test

Two trials of a "walk away" test from the ShopVac sound source were completed to determine the experimental room constants. The results of trial one and two are shown in Tables 32 and 33 respectively. The room constants for trial one and two are calculated in Tables 34 and 35 respectively. Figure 29 shows the walk away test result calibrated to the ShopVac power level at 1000 Hz. The experimental room constant was found to be 25 m^2. This value was then compared to the calculated theoretical room constants.

Reference: Compendium of Materials for Noise Control, NIOSH 1975

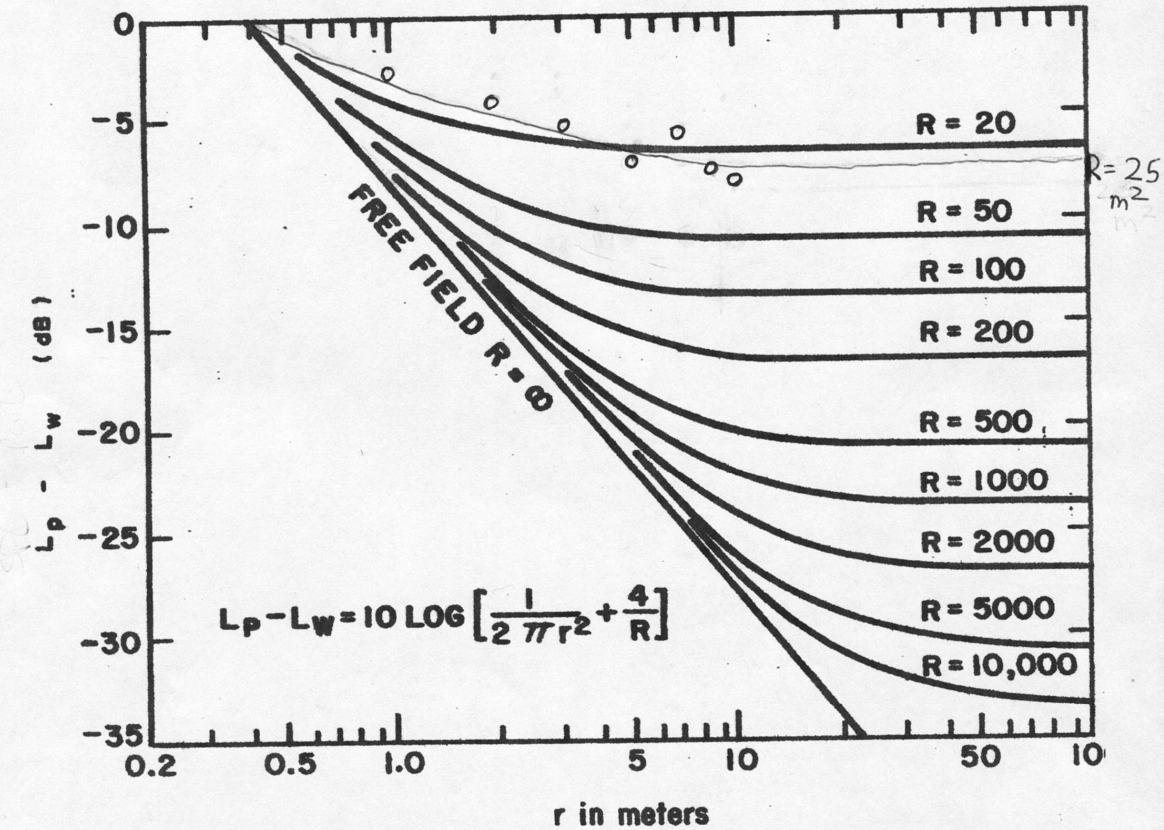

FIGURE I-17.—Relative Sound Pressure Level versus Distance from the Source for Sem reverberant Fields. *r* **=distance from acoustic center;** *R* **=room constant.**

Figure 29: Walk Away Test Results

Table 32: Sound Pressure Level Readings at Various Frequencies and Distances Away from ShopVac Sound Source Trial 1

Octave	Pos #1	Pos #2	Pos #3	Pos #4	Pos #5	Pos #6	Pos #7
Distance (m)	1	2	3	5	7	9	10
Band CF	SPL	SPL	SPL	SPL	SPL	SPL	SPL
Hz	dB	dB	dB	dB	dB	dB	dB
125	74	66	66	66	65	65	64
250	80	85	86	72	86	79	72
500	85	81	80	80	84	83	80
1000	83	78	78	77	77	78	76
2000	83	80	77	78	76	77	77
4000	77	75	74	72	71	71	71
dBA	87	84	83	84	84	82	84
LINEAR	89	87	88	83	89	86	83

Octave	Pos #1	Pos #2	Pos #3	Pos #4	Pos #5	Pos #6	Pos #7
Distance (m)	1	2	3	5	7	9	10
Band CF	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL
Hz	dB	dB	dB	dB	dB	dB	dB
Distance (m)	1	2	3	5	7	9	10
125	5	-3	-3	-3	-4	-4	-5
250	-3	2	3	-11	3	-4	-11
500	0	-4	-5	-5	-1	-2	-5
1000	-1	-6	-6	-7	-7	-6	-8
2000	5	2	-1	0	-2	-1	-1
4000	7	5	4	2	1	1	1
dBA	0	-3	-4	-3	-3	-5	-3
LINEAR	0	-2	-1	-6	0	-3	-6

Table 33: Sound Pressure Level Readings at Various Frequencies and Distances Away from ShopVac Sound Source Trial 2

Octave	Pos #1	Pos #2	Pos #3	Pos #4	Pos #5	Pos #6	Pos #7
Distance (m)	1	2	3	5	7	9	10
Band CF	SPL	SPL	SPL	SPL	SPL	SPL	SPL
Hz	dB	dB	dB	dB	dB	dB	dB
125	71	66	64	65	64	65	66
250	72	86	86	78	85	75	83
500	80	81	77	75	82	75	81
1000	81	80	78	77	78	77	76
2000	80	78	78	78	76	78	76
4000	76	74	74	73	72	72	72
dBA	89	85	83	82	84	83	83
LINEAR	101	88	85	82	88	82	85

Octave	Pos #1	Pos #2	Pos #3	Pos #4	Pos #5	Pos #6	Pos #7
Distance (m)	1	2	3	5	7	9	10
Band CF	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL	SPL - PWL
Hz	dB	dB	dB	dB	dB	dB	dB
125	2	-3	-5	-4	-5	-4	-3
250	-11	3	3	-5	2	-8	0
500	-5	-4	-8	-10	-3	-10	-4
1000	-3	-4	-6	-7	-6	-7	-8
2000	2	0	0	0	-2	0	-2
4000	6	4	4	3	2	2	2
dBA	2	-2	-4	-5	-3	-4	-4
LINEAR	12	-1	-4	-7	-1	-7	-4

Table 34: Room Constants Calculated from Trial 1 at Various Frequencies

Frequency (Hz)	Room Constant
125	8.3
250	2.0
500	11.2
1000	17.1
2000	2.6
4000	1.3
dBA	10.5
LINEAR	6.8

Table 35: Room Constants Calculated from Trial 2 at Various Frequencies

Frequency (Hz)	Room Constant
125	17.0
250	30.0
500	45.0
1000	25.0
2000	1.0
4000	0.0
dBA	16.0
LINEAR	15.0

A higher room constant at a certain frequency results in a smaller reverberation time at that frequency. Comparing the theoretical room constants that were calculated, it can be seen that the experimental room constants are much smaller than the theoretical values meaning that the room actually reverberates much more sound than theory would predict. For example the theoretical room constant value at a frequency of 500 Hz was calculated to be 734 square feet, but in trial one of the experimental "walk away" test the room constant was only calculated to be 301 square feet. Increasing the absorption of materials in the room would increase the room constant at specific frequencies and thus decrease the reverberation times at specific frequencies.

Another interesting phenomenon is that there appear to be points in the room where the geometry of the room focuses the sound. At 2-3 meters and 7 meters away from the ShopVac sound source in both trials, the sound level increases from the sound level at distances closer to the sound source. These appear to be focal points of sound in the room. The sound pressure level at a frequency of 250 Hz is roughly 15 decibels higher at these focal points than at other distances away from the ShopVac sound source.

Meal Time Table Arrangement Test

The results of the meal time table arrangement test are shown in Table 36.

Table 36: Sound Pressure Level at Various Locations during Lunch and Dinner

	Old Arrangement		New Arrangement	
	Lunch	Dinner	Lunch	Dinner
	39 people	38 people	53 People	61 People
Position #	SPL (dBA)	SPL (dBA)	SPL (dBA)	SPL (dBA)
1	72	68	68	74
2	70	72	66	67
3	72	72	68	76
4	65	73	66	66
5	76	72	70	68
6	70	67	67	70

It can be seen from the results that although there were 10 to 20 less people when we measured the sound pressure levels in the old table arrangement, the decibel readings were less in position 1, 2, 3, 5, and 6 at lunch and position 2, 4, and 5 at dinner. This is not conclusive evidence that the new arrangement is better, but it would seem that more sound travels out the windows in the new arrangement decreasing the decibel level at the various positions.

Recommendation

The current average reverberation time between 500 Hz and 1000 Hz for Kiggins Commons when it is occupied is 1.53 seconds. Our goal is to reduce this to anywhere between 0.7 to 1.1 seconds. This decision was based on the Optimum Reverberation Time graph in M. David Egan's, "Architectural Acoustics." For Kiggins Commons' purposes, we categorized it as a, "lecture and conference room."

Echo Eliminator™

Our first recommendation is to hang Echo Eliminator™ WALL PANELS on the east and west facing walls. Three 3 lb. pack of 14 one-inch thick panels, totaling to 336 square feet, can be purchased for around $1344. The panels will arrive as 24” by 48” rectangles but can be cut to the desired size fairly easily as they are made of recycled cotton. We recommend hanging a white 30” by 12” sized panel above each window on the two side walls to keep the room’s symmetry and visual appeal. The panels come in a variety of colors: charcoal, marble light blue, and white, plus 7 other colors with the addition of $112 to the cost. Our recommendation entails having 22.5 square feet of the paneling on the east and the west walls resulting in 291 square feet of Echo Eliminator™ WALL PANELS left over which we suggest putting in an aesthetically appealing arrangement on the south facing wall. This proposal is somewhat costly but raises the room constant and lowers the reverberation time to the desired range, as seen in Table 37. **These wall panels lowered the average reverberation time between 500 Hz and 1000 Hz from 1.65 seconds to 1.03 seconds.**

http://echoeliminator.com/soundproofing_material/acoustic_wall_panels.htm

Custom Picture Sound Panels

A more creative way to implement sound tiling is to make custom sound tiling with pictures printed on them and place them on the east and west facing walls above the windows. These could be pictures of old classes, directors, or donors. 384 square feet of paneling costing $4880 would need to be purchased to lower the reverberation time to the desired range as shown in Table 38. The cost of this makes it an unrealistic option. **These custom picture sound panels lowered the average reverberation time between 500 Hz and 1000 Hz from 1.65 seconds to 0.94 seconds.**

http://www.soundproofcow.com/acoustic-panels/custom-print-acoustic-panels.html

Table 37: Absorption Coefficients and Reverberation Times of Kiggins Commons with Echo Eliminator™ WALL PANELS

ROOM ACOUSTICS: REVERBERATION TIME WORKSHEET 7/2/10

Unoccupied Kiggins Commons, existing configuration, Recommendation 1

SURFACE	MATERIAL	Area (sq ft)	Sound absorption coefficents (al) Octave Band Center Frequency 125	250	500	1000	2000	4000	Sound absorption (Si x al) Octave Band Center Frequency 125	250	500	1000	2000	4000
Floor	wood	1640	0.15	0.11	0.1	0.07	0.06	0.07	246	180	164	115	98	115
Ceiling	wood	1723	0.15	0.11	0.1	0.07	0.06	0.07	258	190	172	121	103	121
North Facing	door	21	1	1	1	1	1	1	21	21	21	21	21	21
	wood	29	0.4	0.9	0.8	0.5	0.4	0.3	12	26	23	15	12	9
	windows	495	0.35	0.25	0.18	0.12	0.07	0.04	173	124	89	59	35	20
	wood arch	42	0.15	0.11	0.1	0.07	0.06	0.07	6	5	4	3	3	3
East Facing	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
	1" 3 lb. panel	45	0.08	0.31	0.79	1.01	1	0.99	4	14	36	45	45	45
	wood	224	0.15	0.11	0.1	0.07	0.06	0.07	34	25	22	16	13	16
South Facing	1" wood	170	0.19	0.14	0.09	0.06	0.06	0.05	32	24	15	10	10	9
	1" 3 lb. panel	291	0.08	0.31	0.79	1.01	1	0.99	23	90	230	294	291	288
	open door	39	1	1	1	1	1	1	39	39	39	39	39	39
	wood	365	0.28	0.25	0.18	0.12	0.07	0.04	102	91	66	44	26	15
West Facing	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
	1" 3 lb. panel	45	0.08	0.31	0.79	1.01	1	0.99	4	14	36	45	45	45
	wood	186	0.15	0.11	0.1	0.07	0.06	0.07	28	20	19	13	11	13
Other absorbers	12 tables	288	0.15	0.11	0.1	0.07	0.06	0.07	43	32	29	20	17	20
	unoccupied chair	70	0.15	0.19	0.22	0.39	0.38	0.3	11	13	15	27	27	21
	wood arches	236	0.15	0.11	0.1	0.07	0.06	0.07	35	26	24	17	14	17
	air (/1000 ft3)	20	0.9	0.9	0.95	1	1	1	18	18	19	20	20	0
	Total area, S	6125												
	Volume, VOL	20490												

	125	250	500	1000	2000	4000
Total absorption, Sa (Sabines)	1158	1001	1058	947	844	821
Average absorp coeff, a (radians)	0.25	0.16	0.17	0.15	0.14	0.13
Reverbation time, T = 0.05VOL/Sa (sec)	0.88	1.02	0.97	1.08	1.21	1.25
Room constant, R = Sa/(1-a) (sq ft)	1544	1196	1279	1121	978	949
Room constant = 0.0929 R (sq meters)	143	111	119	104	91	88

Table 38: Absorption Coefficients and Reverberation Times of Kiggins Commons with Custom Picture Sound Panels

ROOM ACOUSTICS: REVERBERATION TIME WORKSHEET

Unoccupied Kiggins Commons, Recommendation 2

6/24/10

			Sound absorption coefficents (al) Octave Band Center Frequency						Sound absorption (Si x al) Octave Band Center Frequency					
SURFACE	MATERIAL	Area (sq ft)	125	250	500	1000	2000	4000	125	250	500	1000	2000	4000
Floor	wood	1640	0.15	0.11	0.1	0.07	0.06	0.07	246	180	164	115	98	115
Ceiling	wood	1723	0.15	0.11	0.1	0.07	0.06	0.07	258	190	172	121	103	121
North Facing	door	21	1	1	1	1	1	1	21	21	21	21	21	21
	wood	29	0.4	0.9	0.8	0.5	0.4	0.3	12	26	23	15	12	9
	windows	495	0.35	0.25	0.18	0.12	0.07	0.04	173	124	89	59	35	20
	wood arch	42	0.15	0.11	0.1	0.07	0.06	0.07	6	5	4	3	3	3
East Facing	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
	wood	186	0.15	0.11	0.1	0.07	0.06	0.07	28	20	19	13	11	13
South Facing	1" wood	170	0.19	0.14	0.09	0.06	0.06	0.05	32	24	15	10	10	9
	open door	39	1	1	1	1	1	1	39	39	39	39	39	39
	wood	365	0.28	0.25	0.18	0.12	0.07	0.04	102	91	66	44	26	15
West Facing	windows	98	0.35	0.25	0.18	0.12	0.07	0.04	34	25	18	12	7	4
	wood	186	0.15	0.11	0.1	0.07	0.06	0.07	28	20	19	13	11	13
Other absorbers	12 tables	288	0.15	0.11	0.1	0.07	0.06	0.07	43	32	29	20	17	20
	unoccupied chairs	70	0.15	0.19	0.22	0.39	0.38	0.3	11	13	15	27	27	21
	wood arches	236	0.15	0.11	0.1	0.07	0.06	0.07	35	26	24	17	14	17
	air (/1000 ft3)	20	0.9	0.9	0.95	1	1	1	18	18	19	20	20	20
	custom picture pane	384	0.25	0.89	1.17	1.16	1.1	1.08	96	342	449	445	422	415
	Total area, S	6090												
	Volume, VOL	20490												

	125	250	500	1000	2000	4000
Total absorption, Sa (Sabines)	1218	1220	1202	1005	883	876
Average absorp coeff, a (radians)	0.25	0.20	0.20	0.17	0.14	0.14
Reverbation time, T = 0.05VOL/Sa (sec)	0.84	0.84	0.85	1.02	1.16	1.17
Room constant, R = Sa/(1-a) (sq ft)	1623	1526	1498	1204	1032	1023
Room constant = 0.0929 R (sq meters)	151	142	139	112	96	95

Pro Audio Sound Specialists Sound Absorbing Baffles

After considering the setup and main use of Kiggins Commons we considered several options for reducing the reverberation time of the room. In reviewing the options we had to remember the fire safety of our choices. One option is to hang sound absorbing baffles from the ceiling. We talked with Mike from Pro Audio Sound Specialists who recommended that we place 80 white baffles from the ceiling, each baffle sizing at 2" thick, 2' feet wide, and 4' feet long. The cost of the baffles, grommets, and shipping and handling would be $3,207.20. This option greatly reduces the reverberation time as shown in Figure 30, but is very costly. **These baffles would lower the reverberation time to 0.55 seconds.**

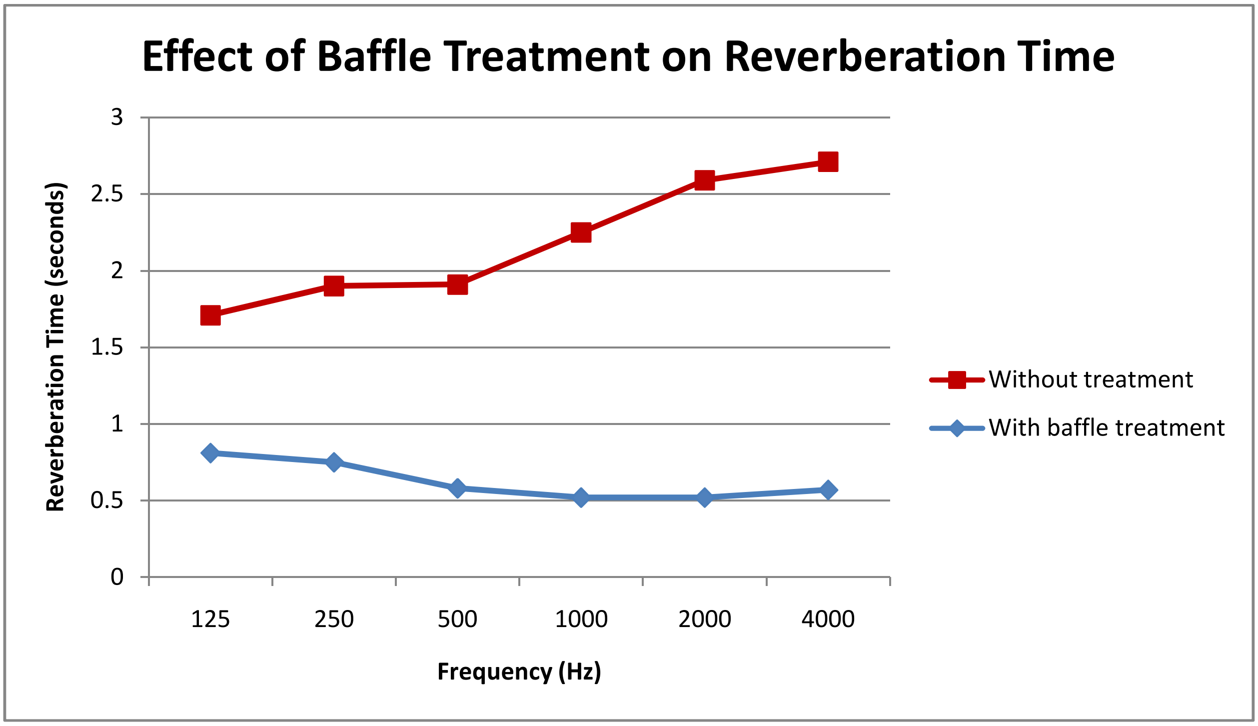

Figure 30: Effect of Baffle Treatment on Kiggins Commons Reverberation Time at Various Frequencies

Constructing Homemade Sound Panels

The most cost effective way of creating sound absorbing space is to construct them yourselves. The panels could be constructed using materials found at common hardware stores. When constructing the panels it would be necessary to cover them with a material that is loosely woven to allow a better sound absorption. These panels could be placed on the South wall (with the Screen) and could be placed in an aesthetically pleasing design. This would be a great place to have a large square footage of sound absorbing materials. In doing research, we have found the most important factor in sound absorption is how much area is covered by the sound absorbing materials. In addition, we recommend that panels be built and put above the windows on the east and west facing walls.

We found some construction techniques on the website http://home.comcast.net/~audio-worx/page2DIYpanels.html and have attached instructions in the appendix. This would only cost as much as the materials and time of the engineers and would lower the reverberation time to the necessary levels if enough sound panels are constructed.

The total cost of these DIY Panels amounts to $276. The amount of materials shown in Table 39 will provide enough to cover the recommended 376 square feet.

Table 39: DIY Panel Cost Analysis

Material	Dimensions (in.)	Amount	Cost ($)
Kraft Paper	24" x 12000"	6	120
Hardware Cloth	24" x 60"	12	60
Dacron Batting	30" x 72"	12	60
Cotton Muslin	58" x 36"	12	36

Final Suggestion

After considering all the solutions, we recommend that the most cost efficient solution be considered.

1. Make sure the windows and the screen are open.

2. Place tables in an arrangement where the tables are closer to the windows so that sound can easier escape outside.

3. Construct sound absorbing panels and place them in the commons remembering to maximize the area covered by these panels. Instruction on how to create panels can be found in the appendix.

Adapt Kingsbury House for Year Round Use

Background

Shoals Marine Lab (SML) is only open from April to the end of September, and all of the island systems, including electricity, freshwater, saltwater, and wastewater are shut down in the winter. So far, people have stayed in the apartment above the Grass Laboratory in the off season to start up and close down the island and to come out for maintenance work. The Grass Lab apartment fits up to eight people. If the Kingsbury House could be habitable during the winter, then more people could come out to do research year round. The Kingsbury House can fit about 10 people comfortably, and more beds could be brought in if necessary. The Kingsbury House is the newest building on the island, so it has some modern features like double-glazed windows and a propane furnace. Its water and electricity come from the SML system, so there would have to be an alternative if people were to stay there in winter.

The current insulation includes six-inch fiberglass batts faced with a vapor barrier in the upstairs walls and in most of the attic, but significant sections of the attic are uncovered. Fiberglass batts are not ideal for attic insulation because they allow air to pass through them, so the air space above them negatively impacts their effectiveness. There is no insulation between the upstairs and the basement or on the basement walls or floor. The windows are double-glazed with low emissivity. Three of the exterior doors are insulated PVC exterior doors with a double-glazed half panel, and the fourth is a PVC exterior French door. The existing heat loss conditions are detailed in Table 39.

Objective

Determine the necessary additions and improvements to make the Kingsbury House suitable for use in winter for several days at a time.

Data Collection

Measurements of the temperature in the above-ground basement and the upstairs of the Kingsbury House were taken from December 2009 to June 2010 with Dickson Pro Series SP125 USB temperature sensors. We compared the temperatures inside to the outdoor temperature for the same time periods, shown in Figures 31 and 32. Figure 31 shows the indoor basement temperatures along with the outside temperatures over the 7 month span. Figure 32 similarly shows the indoor upstairs temperatures with the outside temperatures. There is barely any difference between the temperature inside and outside the house, so the current insulation is not enough to make the house comfortable in the winter without using a large amount of propane.

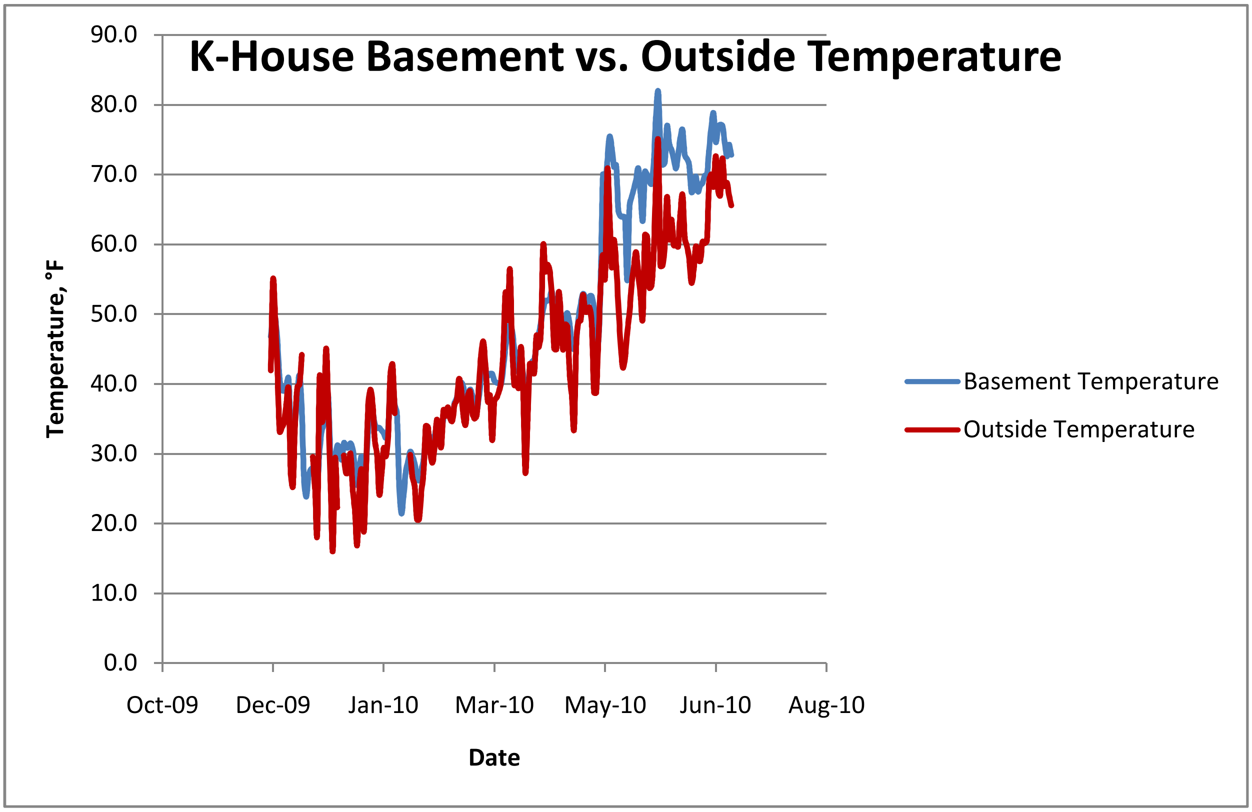

Figure 31: Basement Temperatures versus Outside Temperatures

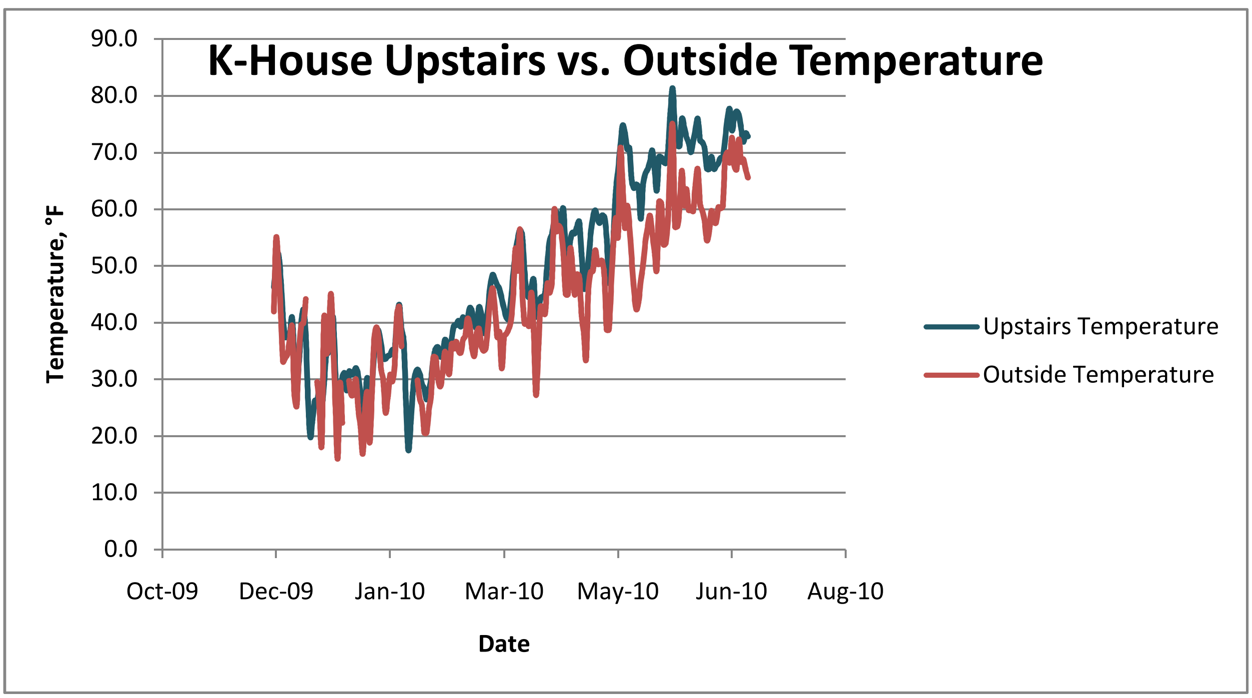

Figure 32: Upstairs Temperatures versus Outside Temperatures

The upstairs walls have six-inch fiberglass batt insulation between 24-inch on-center framing made of pressure-treated spruce. The floor of the attic has fiberglass open to the air with a vapor barrier facing, and the ceiling of the basement is not insulated. We researched materials and prices for several possible options for improving the insulation of the Kingsbury House, detailed in Tables 43 through 49.

To find the numbers in these tables, we did a heat loss calculation using the area of each type of surface in the house (ceiling, floor, framing, insulated wall, doors, windows), taken from the Kingsbury House architectural plans, and the R values for each material, from Appendix 4D and Tables 4.20, 4.22, and 4.23 in More Other Homes and Garbage (1981, Sierra Club Books) and from the R Value Table at http://www.allwallsystem.com/design/RValueTable.html.

$$Heat\ Loss = \frac{A \cdot \Delta T}{R}$$

Equation 6: Heat Loss Equation

where heat loss is measured in British thermal units per hour, A is the area of the surface in square feet, ΔT is the temperature difference across the surface in degrees Fahrenheit, and R is the thermal resistance of the material (hr-SF-°F/Btu).

To find out what the heat loss means in terms of propane usage, we need to consider the characteristics of propane. It has an energy content of about 92,000 Btu/gallon, and its conversion to Btu delivered is about 89% efficient. Equation 8 shows the conversion from heat loss in Btu/hr to gallons of propane required per day.

$$Propane\ usage = \frac{HL \cdot 24 \cdot E}{EC}$$

Equation 7: Propane Usage Equation

where propane usage is in gallons per day, HL is heat loss in Btu/hr, the conversion factor is 24 hr/day, E is efficiency (89%), and EC is energy content (92,000 Btu/gal).

In addition to keeping warm, any winter occupants of the Kingsbury House will need electricity. We performed an energy audit on the appliances and other energy draws to see how much power would be needed.

The residents will also need water. Estimated volumes of water required for various necessary usages for 10 people were made and a water tank size was chosen accordingly.

Kingsbury House's existing conditions are shown in Table 40. The current total daily heat loss is 2,071,219 Btu/day and requires 25.3 gallons of propane per day for the house to stay at the design indoor temperature, 65°F if the outside temperature is 10°F. It is worth noting that the heat loss and propane required are very optimistic because the fiberglass batts in the attic are open to the air, so cold air can pass straight through, and parts of the attic are not covered at all. Through testing improvements and additions using the formatted Excel spreadsheet, courtesy of James Petersen, it has been seen that slight changes to the house can significantly alter the amount of needed propane and heat loss per day.

Ventilation and infiltration were not accounted for any of the calculations as they were unknown, so these heat loss estimates are optimistic. Estimating these would require a blower door test. Since ventilation and infiltration are left out of all of the calculations, the comparison is still valuable. The losses through ventilation and infiltration would probably improve with the addition of insulation, so there would be more improvement than our comparisons show.

Table 40: Existing Insulation Condition Heat Loss Worksheet

Kingsbury House, Appledore Island June, 2010

Existing Conditions: Fiberglass batts in the upstairs walls and most of the attic	
Input values are shown in blue	
	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.2	0.109	7.3	55.0	400
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	3.2	0.317	140.1	55.0	7,703
Doors	80	3.3	0.308	24.6	55.0	1,354
Floor (Basement Ceiling)	2,296	1.9	0.532	1,221.2	55.0	67,168
Upstairs Ceiling	2,335	18.7	0.053	124.7	55.0	6,857

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	1,569	[Btu/hr-°F]
Total Hourly Heat Loss	86,301	[Btu/hr]
Load per Ft^2	38	[$Btu/hr/ft^2$]
Total Daily Heat Loss	2,071,219	[Btu/day]
Daily propane required	25.3	[gal/day]

Analysis

Energy Consumption

The results of the energy audit of the appliances of Kingsbury House are shown in Table 41. The microwave is the largest current energy draw of the house followed closely in second by the dishwasher. Every appliance is used in moderation for varying periods of time except the three composting toilets and the printer. Each of the composting toilets consumes a constant 3 watts totaling to 9 watts for all of them and the printer consumes 18 watts constantly on standby. If every appliance in the house is on, the power draw is 5510 watts. We did not measure the power draw of the lights, but a typical compact fluorescent light bulb draws about 15 watts, so each light that is turned on adds that much to the power draw of the house. Any computers, cell phone chargers, and other devices that people plug in will also add to the energy consumption.

We have a few options for energy sources. There is a small Honda generator, which runs on unleaded gasoline and generates five kilowatts. This generator is typically used to start up and close down the island, so it would be relatively easy to install. The occupants of the house would have to be careful not to start appliances while lots of other things are running to avoid generator failure. If lots of people were staying in the Kingsbury House, and they were going to do laundry, run the microwave, charge phones and computers, and make coffee all day long, a slightly bigger generator might be a good idea. For a greener but more expensive and complicated option, a stand-alone solar array could be set up for the Kingsbury House. Hooking the Kingsbury House up to the existing green grid is not an option because sometimes the batteries run low as it is, and the AIRMAP data collection could be negatively affected. Wiring the Kingsbury House to the green grid would also be difficult and expensive.

Table 41: Energy Audit of Appliances

Appliance	In Use Energy Consumption, watts	Standby E consumption, watts
Microwave	1600	0
Dishwasher	1200	0
Coffee Maker	880	0
Booster Pump for Freshwater	713	0
Printer	445	18
Dryer	196	0
Washer	165	0
Refrigerator	115	0
Fan 2	96	0
Fan 1	42	0
Composting Toilets (3)	39	9
Composting toilets Fan (3)	19	0
Total potential power draw	5510	27

Note: The washer and dryer energy consumption numbers look low because they are heated with propane. Lights, computers, and cell phone chargers will add to the power draw.

Water Consumption

In the past, if a few people have come out for a day or two, they have brought a few 2.5-gallon jugs of water from the mainland. Since we are now thinking about having 10 people, we will need a source of water on the island. Turning on the whole freshwater system is not worth it and maybe not even feasible since the system is designed for the summer.

There is a space in the basement for a water tank. To decide how big it should be, we made rough estimates of the expected water use. Table 42 shows the different uses of water per person per day and then the total for 10 people for two weeks.

Table 42: Water Usage

Use	Amount per person per day, gallons	Amount used by 10 people, gallons
Showers	4.286	600
Cooking/washing dishes	1	140
Toilets	0.0469	6.56
Drinking	0.25	35
Total	**5.58**	**781.56**

Ten people staying in the Kingsbury House for two weeks would use approximately 782 gallons - of water. To be conservative, we recommend a 1,000-gallon tank.

If the walls of the basement are insulated, the tank can just sit in the basement. If the ceiling of the basement is insulated instead, a small super-insulated enclosure for the water tank and the larger composter (necessary for a group of 10) would have to be built. Having the composter and the tank enclosed would make it less convenient for the engineers to work on them, and the structure would add to the material costs and the time and labor required to winterize the Kingsbury House.

Thermal Blinds

The first recommendation is the addition of thermal blinds to all of the windows except for the two in the attic. Speaking with Dan Carroll of Portsmouth Blind and Shade, it was found out that Hunter Douglas Duette 3/4” Honeycomb semi-opaque shades are very efficient thermal blinds with an R value of 7.18. These thermal blinds are great for reflecting heat in the summer and retaining heat in the winter. It was estimated that these blinds would cost about $28/square feet of window, and Kingsbury House has 441 square feet of window, meaning this suggestion would total to approximately $12,353. In comparison to the following recommendations, the cost relative to the heat loss for thermal blinds may not be worth it on a limited budget. Shown in Table 43, adding thermal blinds lowers the daily heat loss to 1,942,796 Btu/day, lessening it from the existing condition by 128,423 Btu/day. It also takes the required daily propane down from 25.3 gal/day to 23.73 gal/day, a difference of 1.57 gal/day.

Table 43: Heat Loss Worksheet with addition of Thermal Blinds

Kingsbury House, Appledore Island June, 2010

Add thermal blinds to all of the windows except the attic windows	
Input values are shown in blue	
	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp (99.6%)	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.1	0.110	7.3	55.0	403
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	10.3	0.097	42.7	55.0	2,349
Doors	80	3.3	0.308	24.6	55.0	1,354
Floor (Basement Ceiling)	2,296	1.9	0.532	1,221.2	55.0	67,168
Upstairs Ceiling	2,335	18.7	0.053	124.7	55.0	6,857

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	1,472	[Btu/hr-°F]
Total Hourly Heat Loss	80,950	[Btu/hr]
Load per Ft^2	35	[$Btu/hr/ft^2$]
Total Daily Heat Loss	1,942,796	[Btu/day]
Daily propane required	23.73	[gal/day]

Closed-Cell Spray Foam

The second recommendation is the addition of closed-cell foam. This has an R-Value of 6.9 per inch. Closed-cell foam integrates an insulating gas that is retained within cells and has one of the highest R-values among available insulation. Since it is sprayed at some pressure, it fills any cracks and holes more effectively than any other material. It also resists air flow and moisture, so it provides an effective air barrier and has low moisture vapor permeability. Closed-cell foam can be added in a few different ways that will yield varying heat loss outcomes.

Something to consider is that any spray foam insulation contractor would have to bring equipment out to the island. One contractor we spoke with, Scott Ray would bring out a 16-foot trailer, which might fit on the Kingsbury. He said his trailer was the smallest operation we would find, so any other contractor would need at least as much space, and for some, a barge might have to be rented, so that fee should be considered when looking at the various options.

The first option is to spray closed-cell foam on the floor (basement ceiling). The floor is roughly 2300 square feet and an insulation thickness of 5 inches is recommended. After contacting insulation contractor, Doug Colby, it was discovered that it would cost around $4.50 per square foot, which amounts to $10,350 to insulate 2300 square feet of the basement ceiling. For this scenario, portrayed in Table 44, the daily heat loss would be reduced to 542,555 Btu/day, a difference of 1,528,664 Btu/day, and the required daily propane would be brought down to 6.63 gal/day, a change of 18.67 gal/day.

The second option is to spray closed-cell foam on the upstairs ceiling (attic). The existing fiberglass batts would be removed for the spraying and then returned on top of the foam. With the air barrier of the foam, they would add significant insulation, an R value of 19 hr-SF-°F/Btu in addition to the 38 provided by the foam. The upstairs ceiling is slightly larger in area than the floor at 2335 square feet and 4.5 inches of foam is recommended so it is estimated that this will cost around $4.50 per square foot, which makes $10,508 along with the cost of the barge. As seen in Table 45, this would decrease the daily heat loss to 1,968,576 Btu/day, reducing it from the existing conditions by 102,643 Btu/day. The needed propane would go down by 1.26 gal/day, meaning 24.04 gal/day would be required.

The third option is to spray the closed-cell foam on the basement inside walls. This alternative is shown in Table 46. 5.5 inches of the foam is recommended for the 1035 square feet of wall above the cinderblock and between the framing. 3 inches of foam is recommended for the cinderblocks. This amount of foam would cost around $5,740 (at $2.50/SF) as well as the barge fee. Spray foam on the basement walls would decrease the daily heat loss to 964,562 Btu/day, a change of 1,106,657 Btu/day. Also, the daily required propane would drop to 11.78 gal/day, a difference of 13.52 gal/day.

The fourth option is to spray the closed-cell foam on basement ceiling floor and walls. This option would almost certainly be combined with insulation for the walls of the basement. Only 2 inches of foam is recommended to this 2300 square foot floor area because the temperature difference between the desired 65°F and the 50°F of the ground is much smaller than for the other options, in which the heat loss is to the air. A 5 inch thickness is recommended to 1500 square foot wall area. This volume of foam would total to about $10,434 (at $2.50/SF) plus the barge fee. This addition would bring the daily heat loss down 1,493,992 Btu/day to 577,227 Btu/day, and the daily propane needed down to 7.05 gal/day, a change of 18.25 gal/day from the current condition. This option is depicted in Table 47.

Table 44: Heat Loss Worksheet with addition of Closed-Cell Foam on Floor

Kingsbury House, Appledore Island June, 2010

Spray basement ceiling with closed-cell foam

Input values are shown in blue

	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.1	0.110	7.3	55.0	403
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	3.2	0.317	140.1	55.0	7,703
Doors	80	3.3	0.308	24.6	55.0	1,354
Floor (Basement Ceiling)	2,296	36.4	0.027	63.1	55.0	3,469
Upstairs Ceiling	2,335	18.7	0.053	124.7	55.0	6,857

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	411	[Btu/hr-°F]
Total Hourly Heat Loss	22,606	[Btu/hr]
Load per Ft^2	10	[Btu/hr/ft^2]
Total Daily Heat Loss	542,555	[Btu/day]
Daily propane required	6.63	[gal/day]

Table 45: Heat Loss Worksheet with addition of Closed-Cell Foam on Upstairs Ceiling

Kingsbury House, Appledore Island — June, 2010

Spray the attic with closed-cell foam	
Input values are shown in blue	
	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.2	0.109	7.3	55.0	400
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	3.2	0.317	140.1	55.0	7,703
Doors	80	3.3	0.308	24.6	55.0	1,354
Floor (Basement Ceiling)	2,296	1.9	0.532	1,221.2	55.0	67,168
Upstairs Ceiling	2,335	49.8	0.020	46.9	55.0	2,580

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	1,491	[Btu/hr-°F]
Total Hourly Heat Loss	82,024	[Btu/hr]
Load per Ft^2	36	[$Btu/hr/ft^2$]
Total Daily Heat Loss	1,968,576	[Btu/day]
Daily propane required	24.04	[gal/day]

Table 46: Heat Loss Worksheet with addition of Closed-Cell Foam on Basement Walls

Kingsbury House, Appledore Island — June, 2010

Spray closed-cell foam to the walls of the basement	
Input values are shown in blue	
	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp (99.6%)	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.2	0.109	7.3	55.0	400
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	3.2	0.317	140.1	55.0	7,703
Doors	80	3.3	0.308	24.6	55.0	1,354
Basement Walls- Cinderblocks	421	22.7	0.044	18.6	55.0	1,021
Basement Walls- Framing	35	7.7	0.130	4.5	55.0	250
Basement Walls- Other	1,035	38.8	0.026	26.7	55.0	1,468
Basement Floor	2,296	1.9	0.532	1,221.2	15.0	18,319
Upstairs Ceiling	2,335	18.7	0.053	124.7	55.0	6,857

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	1,619	[Btu/hr-°F]
Total Hourly Heat Loss	40,190	[Btu/hr]
Load per Ft^2	18	[Btu/hr/ft^2]
Total Daily Heat Loss	964,562	[Btu/day]
Daily propane required	11.78	[gal/day]

Table 47: Heat Loss Worksheet with addition of Closed-Cell Foam on Basement Floor and Walls

Kingsbury House, Appledore Island — June, 2010

Spray closed-cell foam to the floor and walls of the basement	
Input values are shown in blue	
	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.2	0.109	7.3	55.0	400
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	3.2	0.317	140.1	55.0	7,703
Doors	80	3.3	0.308	24.6	55.0	1,354
Basement Walls- Cinderblocks	421	22.7	0.044	18.6	55.0	1,021
Basement Walls- Framing	35	7.7	0.130	4.5	55.0	250
Basement Walls- Other	1,035	38.8	0.026	26.7	55.0	1,468
Basement Floor	2,296	15.8	0.063	145.3	15.0	2,180
Upstairs Ceiling	2,335	18.7	0.053	124.7	55.0	6,857

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	543	[Btu/hr-°F]
Total Hourly Heat Loss	24,051	[Btu/hr]
Load per Ft^2	10	[$Btu/hr/ft^2$]
Total Daily Heat Loss	577,227	[Btu/day]
Daily propane required	7.05	[gal/day]

Blown-In Cellulose

The third recommendation is the application of blown-in cellulose to the upstairs ceiling. Blown-in cellulose is great for places where other types of insulation are difficult to install, such as small attics. It is composed of small, broken down materials that fill in hard-to-reach cavities once blown in. Because Kingsbury House has a cathedral ceiling, certain measures would need to take place. The cellulose would just fall off the raised, slanted cathedral part of the ceiling, and then that section would only have fiberglass batts unless another material was added to that section. A more major and less easily solved problem with blown-in cellulose is that the high winds on Appledore in the winter would blow into the attic from the sides and blow the cellulose away from the edges of the attic and into the center, leaving the edges not insulated. Also, after blown-in cellulose had been added, the attic would no longer be accessible. The attic in Kingsbury House has enough space where blown-in insulation is not the only option, so this recommendation may not be as helpful as others. Blown-in cellulose is very impractical for a cathedral ceiling, and, moreover, it would not insulate the Kingsbury House very well because of the wind on Appledore.

Rigid Foam Board

The fourth recommendation is rigid foam board. Four inches would be installed, giving an R value of 20. The foam comes in 2” x 2’ x 8’ sheets that cost $14.77 each at the North Hampton Home Depot. Since moisture can get in between the beads of foam, a vapor barrier is required. Home Depot sells six-millimeter plastic in 10’ x 100’ rolls for $59.98 per roll. This means that insulating the attic with rigid foam would cost approximately $2250 for the foam plus $180 for the vapor barrier, giving a total of $2430. This can be seen in Table 48. Insulating the basement walls would cost $1500 for the foam plus $180 for the vapor barrier, which totals to $1680. The analysis for adding rigid foam board to the basement walls is shown in Table 49. One advantage of rigid foam is that the island engineers or volunteers could install it instead of having to hire a contractor as with spray foam. It is also cheaper than spray foam, but it is somewhat less effective and can’t be installed in the basement ceiling because of all of the pipes hanging down in the way. Another disadvantage is that the installation would take a lot of time and effort and would have to be done very meticulously to be effective.

Table 48: Heat Loss Worksheet with addition of Rigid Foam Board on Upstairs Ceiling

Kingsbury House, Appledore Island — June, 2010

Add Rigid Foam Board to the Upstairs Ceiling	
Input values are shown in blue	
	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.1	0.110	7.3	55.0	403
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	3.2	0.317	140.1	55.0	7,703
Doors	80	3.3	0.308	24.6	55.0	1,354
Floor (Basement Ceiling)	2,296	1.9	0.532	1,221.2	55.0	67,168
Upstairs Ceiling	2,335	38.7	0.026	60.3	55.0	3,316

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	1,505	[Btu/hr-°F]
Total Hourly Heat Loss	82,763	[Btu/hr]
Load per Ft^2	36	[$Btu/hr/ft^2$]
Total Daily Heat Loss	1,986,316	[Btu/day]
Daily propane required	24.26	[gal/day]

Table 49: Heat Loss Worksheet with addition of Rigid Foam Board on Basement Walls

Kingsbury House, Appledore Island — June, 2010

Add Rigid Foam to the Basement Walls

Input values are shown in blue

	[sf]
Total Conditioned Floor Area (inside of wall)	2,296
	[°F]
Indoor Design Temp	65
Outdoor Design Temp	10
	[%]
Framing Effect	6.25

	Area [SF]	R-Value [hr-SF-°F/Btu]	U-Value [Btu/hr-SF-°F]	UA-Value [Btu/hr-°F]	ÄT [°F]	Heat Loss [Btu/hr]
Upstairs Walls- Framing	67	9.2	0.109	7.3	55.0	400
Upstairs Walls- Insulated	998	19.5	0.051	51.3	55.0	2,819
Windows	441	3.2	0.317	140.1	55.0	7,703
Doors	80	3.3	0.308	24.6	55.0	1,354
Basement Walls- Cinderblocks	421	22.0	0.046	19.2	55.0	1,054
Basement Walls- Framing	35	7.7	0.130	4.5	55.0	250
Basement Walls- Other	1,035	20.8	0.048	49.7	55.0	2,732
Basement Floor	2,296	1.9	0.532	1,221.2	15.0	18,319
Upstairs Ceiling	2,335	18.7	0.053	124.7	55.0	6,857

Propane has an energy content of 92,000 Btu/gallon, and conversion to Btu delivered is about 89% efficient.

Building UA-Value	1,642	[Btu/hr-°F]
Total Hourly Heat Loss	41,487	[Btu/hr]
Load per Ft^2	18	[$Btu/hr/ft^2$]
Total Daily Heat Loss	995,679	[Btu/day]
Daily propane required	12.16	[gal/day]

Using Grass Lab Instead

The fifth recommendation is to use the Grass Lab and the apartment above it during the winter months for research instead of attempting to winterize Kingsbury House. The apartment in the Grass Lab fits up to four people without having to squeeze in too tight. It would be very feasible to move a bed or two into the room downstairs, and in a pinch, more people could squeeze in on the floor upstairs.

The temperature conditions in the Grass Lab in its current state are shown in Figures 33 and 34. Figure 3 shows the inside downstairs temperatures from December 2009 to June 2010 along with the outside temperatures for that duration. Figure 4 likewise shows data of the temperatures of the inside upstairs temperatures with the outside temperatures.

When looking at these graphs, it is seen that the lowest the temperature ever dropped to was slightly less than 30°F in the upstairs in January 2010. Glancing back at the Kingsbury House temperature graphs, Figures 1 and 2, it is apparent that the Grass Lab in its existing condition is more habitable in the winter than Kingsbury House.

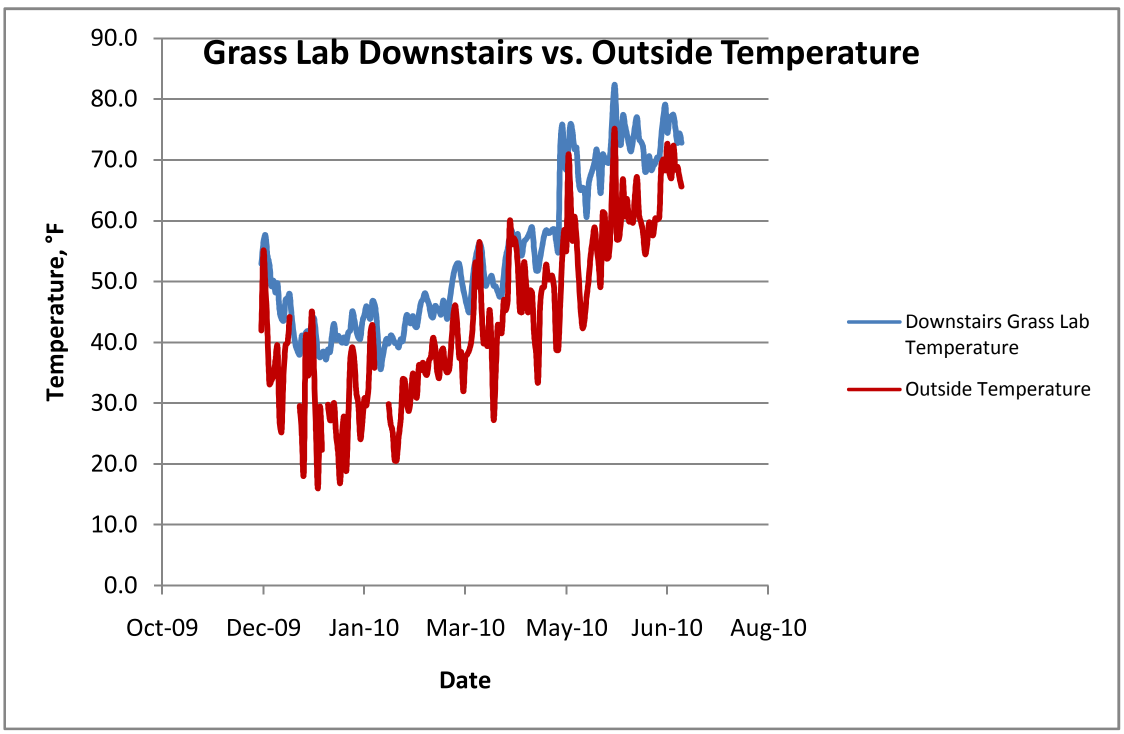

Figure 33: Downstairs Grass Lab Temperatures versus Outside Temperatures

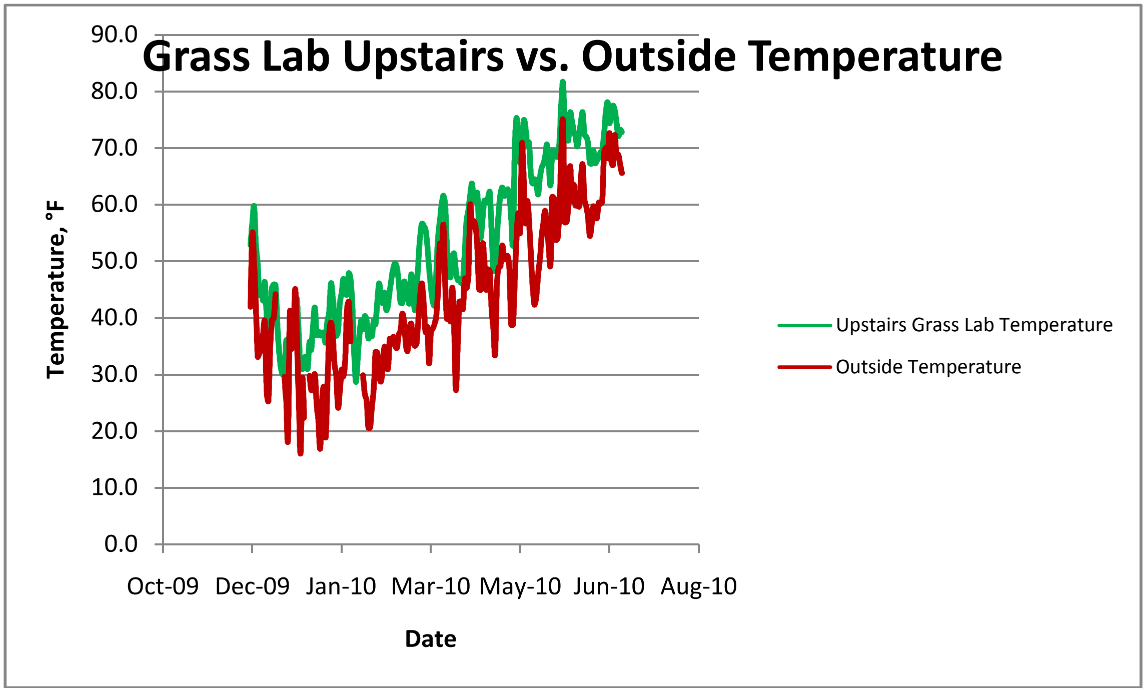

Figure 34: Upstairs Grass Lab Temperatures versus Outside Temperatures

Analysis

As seen in Table 50, the two largest reducers in daily propane required to heat Kingsbury House to 65°F are spraying closed-cell foam on the floor, i.e. the ceiling of the basement, and spraying closed-cell foam on the basement floor and walls. Spraying the walls and floor of the basement would provide slightly less benefit than spraying the basement ceiling and would accordingly cost slightly less. Spraying just the walls of the basement would provide about a third less benefit than spraying the basement ceiling, but it would cost less than half the amount. It is worth noting that the costs of these do not include the cost of transporting the contractor's equipment out to the island. It is evident that some of the options provided do not create nearly enough of a difference to even bother with, such as adding thermal blinds and rigid foam board to the upstairs ceiling. Perhaps the most cost-efficient per change in heat loss is the option to add rigid foam board on the basement walls. This would provide about two-thirds of the benefit of spraying the basement ceiling, and it would cost 84% less.

If we consider labor and convenience in addition to financial cost, the problem becomes somewhat more complicated. If rigid foam is chosen for the basement, it must be cut into pieces and fit tightly into the spaces between the studs, and all leaks must be sealed. This is extremely time-consuming and since the job needs to be done with such care, it could not be easily accomplished by untrained volunteers. In the attic, the foam board could just be laid over the studs and fiberglass.

Table 50: Changes Relative to Current Insulation Conditions and Cost Comparison

Insulation Addition	Change in Total Daily Heat Loss, Btu/day	Reduction in Daily Amount of Propane Required to Heat Kingsbury House to 65°F, gal/day	Cost
Closed-Cell Foam Sprayed on Floor	1,528,664	18.7	$10,350
Closed-Cell Foam Sprayed on Basement Floor and Walls	1,493,992	18.3	$10,108
Closed-Cell Foam Sprayed on Basement Walls	1,106,657	13.5	$4,368
Rigid Foam Board On Basement Walls	1,075,541	13.1	$1,680
Thermal Blinds	128,423	1.57	$12,353
Closed-Cell Foam Sprayed on Upstairs Ceiling	102,643	1.26	$10,508
Rigid Foam Board On Upstairs Ceiling	84,904	1.04	$2,430

Recommendation

Energy consumption recommendation

For the short term, we recommend using the five-kilowatt Honda generator to power the Kingsbury House or purchasing a slightly larger one. If it is feasible, we recommend installing a photovoltaic array for the Kingsbury House.

Insulation recommendation

It is widely agreed that sprayed closed-cell foam is the most effective type of insulation. If it is feasible financially and practically, five inches of sprayed foam on the floor (the basement ceiling) is our top recommendation. This would reduce the propane usage by 14.79 gallons per day. The second choice is four inches of rigid foam board on the walls of the basement. In this case, the propane usage would go down by 10.40 gallons per day. It does not make sense to state a percent change because we were not able to take infiltration and ventilation into account, so the baseline numbers are off. The changes in heat loss and propane usage are conservative estimates if anything because the infiltration losses should improve with additional insulation. We strongly recommend a blower-door test before any insulation is purchased.

If neither of the above insulation options is feasible, we recommend using the Grass Lab as in past years and moving more beds into the room downstairs if more than four people want to stay there.

Water consumption recommendation

To have enough water for 10 people staying in the Kingsbury House for two weeks, we recommend a 1,000-gallon tank stored in the basement. If the basement walls and floor are insulated, the tank will not require any additional insulation. If the basement ceiling is insulated instead, the tank would have to be enclosed in a super-insulated room along with the larger comp

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Kevan Carpenter	Willy Bemis
Al Russell	Doug Colby
Nick Dika	SML Staff

Future Project Suggestions

Alternative Energy

There was not enough time this season to fully investigate the battery voltage data. Future interns should track how often the batteries are full and if green energy is being wasted by turning off the water heaters and programming the solar panels to produce less energy when the batteries are full. It should be determined if the wasted potential green energy can power an additional building, such as Palmer-Kinne. Also, once a meter is purchased and installed enabling the wind turbine power output data to be recorded, it should be collected and analyzed.

Gray Water Solutions

A different method should be used to find where the leachate in the Bartels leach field comes out. A lysimeter can be used to more accurately do this. Angled tubes can be stuck in the ground where the leach lines end and the lysimeter can be used to suction the leachate from under the leach lines for testing.

Septic Level Testing

The level of solids in the septic tanks should be measured with the sludge judge and drying test and compared to the results from these tests conducted by the 2010 interns to determine the effect the new composting toilets installed in Kiggins Commons has had one the buildup of solids in the septic tanks.

Fresh Water Supply to Well

The water level of Crystal Lake and the water level of the well should be consistently monitored as water is drained from Crystal Lake to the area around the well to increase the fresh water supply to the well to make sure the water level does not decrease more than six inches per the draining permit. The amount of water drained and entering the well should also be closely monitored to determine how much water siphoned from Crystal Lake to the well area actually makes it into the well. The well height and height of Crystal Lake should also be correlated to rainfall data to determine how much water the well and Crystal Lake collect from rainfall. A ultrasonic water level height monitoring device should be purchased and installed in both the well and Crystal Lake.

Kiggins Commons Acoustics

Install homemade sound panels suggested by 2010 interns and re-test the acoustics of the room with the same tests conducted by the 2010 interns to quantify the improvement these sound panels provide.

Fire Suppression System

Investigate what is necessary for an adequate fire fighting system for the island in terms of flow rate, water pressure, and pumps. The current fire hoses have very little pressure or flow and would not be able to put out a building fire. The feasibility of using a water truck that can be driven to the location of the fire should also be investigated.

Standardizing Wastewater Sampling Procedure

The sampling procedure for the various wastewater tests should be standardized per the laboratory standard in order to accurately compare test results from various years.

Energy Conservation

The use and energy consumption of the ice machine should be investigated. The actual fuel consumption of the Kingsbury, Heiser, and Miss Christine per round trip should be measured using data collected from the fuel tank.