2017

Energy Storage Strategies for the University of New Hampshire

A Feasibility Analysis of Energy Storage Opportunities on the Durham Campus

Jaclyn Kinson

UNHSI Sustainability Fellow

UNH Energy Office

8/11/2017

Table of Contents

List of Figures

List of Tables

Executive Summary

This report details the work of the summer 2017 University of New Hampshire Sustainability Institute UNH Energy Strategies Fellow, an undergraduate chemical engineering student at the University of New Hampshire (UNH). The fellow was tasked with conducting a feasibility analysis of energy storage opportunities at either the cogeneration plant or the Philbrook chilled water plant on the UNH Durham campus. Installing energy storage will contribute to future campus climate and energy resilience plans to be embedded into WildCAP, which targets a goal of a 50% reduction in campus greenhouse gas emissions by 2020. An energy storage project will also contribute to electricity consumption and demand charge reductions from the local utility by flattening the demand curve and increase production of cheaper and cleaner power from the cogeneration plant.

This report analyzes two energy storage projects: a chilled water thermal energy storage tank at the Philbrook chilled water plant and an electrochemical battery at the cogeneration plant. Only a partial feasibility analysis was completed due to the complexity of the electricity savings at the Philbrook chilled water plant and the lack of pricing information available for batteries (Table 1). Based off of the initial analysis, a chilled water TES tank would cost about \$2M to \$2.5M to construct, produce about \$80,000 of savings each year, and reduce about 163 metric tons of CO_2 per year. A TES tank would make use of the excess steam load from the cogeneration plant during the summer, increase campus climate resiliency, allow for future installations of renewable energy, and increase the chilled water capacity. The total cost of the battery could not be accurately estimated but it would produce \$380,000 of savings each year, and reduce 547 metric tons of CO_2 per year. The battery would bring UNH one step closer to being a micro-grid, increase campus resiliency, allow for future installations of renewable energy, and increase the steam capacity of the cogeneration plant.

Table 1. Cost Comparison of TES vs. a Battery

	Chilled Water Thermal Energy Storage Tank	Battery Storage
Capital Cost	\$1,498,037	\$832,000
Other Costs	\$502,000- \$752,000	\$277,511
Total Cost	**\$2,000,037 - \$2,250,037**	**?**
Electricity Savings	\$49,095.92	\$117,888.25
Demand Charge Reduction	\$34,641.01	\$279,254.19
Emission Reduction	163 metric tons CO_2 / yr	547 metric tons CO_2 / yr
Benefits	Harness Excess Steam Load Climate Resiliency Future Renewable Energy Increase Chilled Water Capacity	Microgrid & Resiliency Future Renewable Energy Increase Steam Capacity

The costs of a chilled water tank were accurately calculated with assistance from DN Tanks and RMF Engineering. The electricity savings were estimated based on fragmented historical data from the chilled water plant. Further analysis should be completed to determine the electricity savings of a chilled water thermal energy storage tank. In contrast, the costs of a battery storage project were estimated and a total cost could not be estimated accurately. The predicted total cost of a battery project is missing crucial measures such as operation and maintenance costs, installation costs, and disposal costs. Instead of recommending a highly inaccurate figure, the total cost remains unknown. Further investigation should be completed to determine the total cost of a battery. The electricity savings were confidently calculated using the historic data for the electricity load. However, an analytics team at Lockheed Martin was unsure of the success of an energy storage device based on UNH's rate structure. Moving forward, UNH should further analyze each project in more detail, but with emphasis on a chilled water thermal energy storage tank project.

An energy efficiency project involving the installation of individual hot water heater controllers was also investigated. Individual hot water heater controllers have the ability to control the operation of electric water heaters throughout campus. They can reduce standby losses and excess heating by controlling the time of operation and the maximum temperature of the hot water. The University of New Hampshire should conduct a trial with Aquanta's controller systems. Five to six controllers should be installed throughout campus to test the potential energy savings available. During this trial, UNH will receive the fleet dashboard software at no additional cost. The software includes tools such as metering data, and operation controls to maximize the efficiency of the electric heaters. After the trial, if the controllers and software prove to increase energy savings, these controllers should be installed on all of the electric water heaters throughout campus.

Introduction

Motivation of the Study

The University of New Hampshire's (UNH) climate action plan, WildCAP, adopted in 2009, targets a goal of a 50% reduction in its total greenhouse gas emissions by 2020. The University expects to meet its reduction goal before the deadline and is now looking ahead to the need to develop a campus climate and energy resilience plan to be embedded into WildCAP. The UNH Energy Task Force sought a Sustainability Fellow to work with the UNH Energy Office to identify and scope existing and emerging options for energy storage on campus including thermal and electrochemical storage systems. [1] Energy storage will ensure a comfortable living, learning, and research environment for students and faculty and increase campus sustainability and resiliency.

Campus Energy Background

An analysis of the historic energy data at the combined heating and power (CHP) plant and Philbrook chilled water plant was conducted to determine potential opportunities for energy storage technologies. About 85% of the campus electrical and thermal needs are provided by the cogeneration plant. Processed landfill gas from the landfill in Rochester, NH is blended with natural gas to power a 7.8 MW Siemens gas turbine to generate electricity and steam. Most of the steam is condensed into hot water and primarily used in the district heating system to provide heating and hot water for most buildings. Some of the remaining steam is used to chill water in a 685 ton steam absorption chiller at the Philbrook chilled water plant in addition to the absorption chillers at the CHP plant, Paul College, and Rudman Hall. At the Philbrook chilled water plant, the absorption chiller, along with two 600 ton York centrifugal electric chillers and a free cooling heat exchanger provides district cooling for the adjacent buildings, Kingsbury, Philbrook, Morse, SERCS, and Parsons. The remaining buildings are cooled by onsite chillers or chillers at the cogeneration plant.

The remaining 15% of campus electrical needs are purchased from the local utility, Eversource. The electricity is purchased under the large general rate (Rate LG) and the backup rate (Rate B), because UNH self-generates energy from the cogeneration plant. The demand charge is calculated by the maximum purchase of electricity in half an hour, over a 12 month period. For billing purposes, the demand in kVa is the greatest of either the on-peak kVa demand or the off-peak kVa demand of the current service month, or the previous 11 month high. If the previous 11 month high is the greatest of the three, a ratchet rate of 80% of the previous 11 month high is used to bill the demand charge. Under the Rate LG, the University pays a hefty demand charge, at $13 per kilowatt, in addition to kWh delivery and supplier services. Unlike other universities, the University cannot take advantage of time of use rates from third party energy suppliers. UNH purchases its electricity to supplement the cogeneration plant during peak hours, when electricity is most expensive. For this reason, it is cheaper for the university to buy additional power from a fixed rate, Rate LG, from Eversource.

Goal of the Project

Energy storage systems manage the power supply in order to create a more resilient energy structure, incorporate cleaner energy sources, and to bring cost savings to utilities and consumers. [2] At the University, energy storage technologies would reduce the amount of electricity purchased from the utility. As a result, the University would experience a decrease in energy costs, an increase in campus resiliency, and the reduction of Scope 2 emissions, emissions associated with the University through the purchase of electricity from the grid. The goal of the 10-week project is to deliver a report that inventories different energy storage opportunities, estimated life-cycle costs, estimated greenhouse gas reductions, implementation considerations, possible co-benefits, outstanding questions, and next steps. [1] This report recommends two energy storage projects, a chilled water thermal energy storage tank and an electrochemical battery, and an energy efficiency project, individual hot water heater controllers to flatten the electricity demand curve, induce energy savings, and increase campus sustainability and resiliency.

Chilled Water Thermal Energy Storage

Chilled water thermal energy storage (TES) is one of the many forms of thermal energy storage including hot water TES and ice storage. Chilled water thermal energy storage is abundantly installed throughout the nation in various settings such as government buildings, commercial companies and college campuses. In each situation they all serve the same purpose; to flatten cooling and electric profiles more efficiently and cost effectively. [3] The following section outlines a feasibility analysis of a chilled water thermal energy storage tank at the University of New Hampshire.

How it Works

Thermal energy storage systems stores thermal energy, such as chilled water, in concrete or steel tanks for a later use. [4] The volume of the water inside the tank never changes, but alters between cold and warm water depending on if the tank is charging or discharging. A stratified layer always exists between the cold, more dense water, and the warm, less dense water. This 5 foot layer of water is considered as a waste layer in the tank. However, the tank is designed to minimize the ratio between the stratified layer and the height of the tank.

To charge the tank, chilled water is produced by a combination of free cooling, absorption chillers and electric chillers and then stored in the tank (Figure 1). As the chilled water circulates throughout campus to cool buildings, the warm return water is deposited back into the tank, maintaining the volume of water in the tank. When the entire supply of chilled water has been discharged and replaced with warm water, the warm water in the tank cycles through the chillers to re-chill the water and recharge the tank. [4]

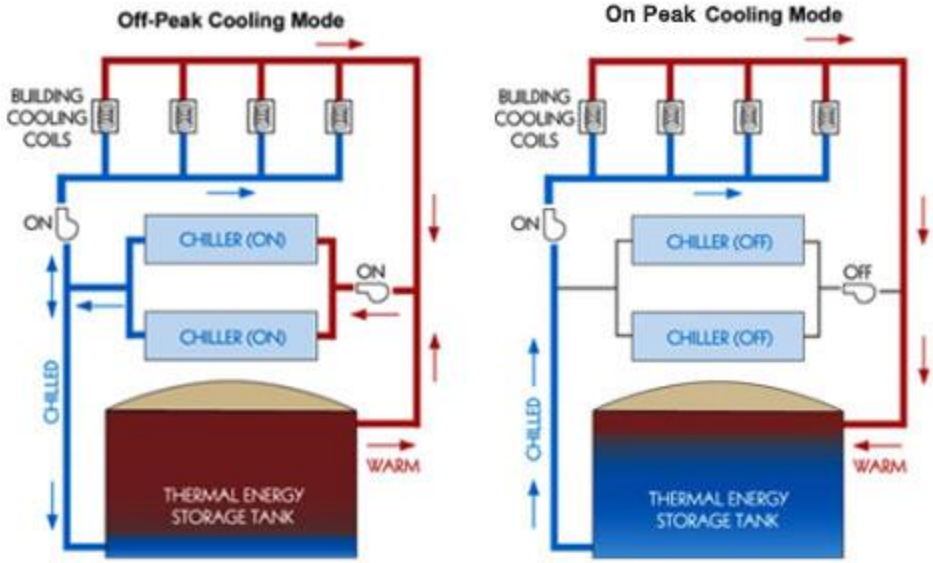


Figure 1. The Operation of the Chilled Water TES tank. A combination of free cooling, absorption chillers, and electric chillers charges the tank during the off-peak hours of the day when the cooling load demand curve descends. The tank discharges and distributes cold water to buildings during on-peak times when the demand for cooling is high and electricity prices are more expensive. The warm water from the buildings returns to the tank to maintain the volume of water. Once fully discharged, the warm water is cooled by the chillers and the process repeats itself. [4]

The tank is charged when the cooling load is normally low, such as overnight and early in the morning. During peak cooling loads throughout the day, the tank is discharged, distributing most or all of the cooling load from the tank rather than relying on the chillers. Therefore, the demand shifts from the chillers to the TES tank during these peak times. Operational equipment associated with the chillers such as pumps and cooling towers also require electricity. By utilizing these technologies during the off-peak times instead of during on-peak hours, the cost of operation decreases. By increasing the chiller usage during the minor cooling load and decreasing the chiller usage during the high cooling load periods, the load profile flattens. By flattening the load, cheaper off-peak electricity prices can be utilized and more expensive on-peak electricity prices can be avoided.

UNH Thermal Energy Loads

The University of New Hampshire caters to the needs of over 15,000 students and numerous faculty and staff each year. With over 45 residential buildings, 30 academic buildings, and 20 campus buildings throughout the Durham campus that require heating and cooling, thermal energy loads are a large portion of energy usage on campus. Each of these buildings require cooling and heating when students and faculty occupy the buildings. Residential halls require constant thermal energy whereas most academic buildings only need thermal energy for the hours when the building is occupied. Some academic buildings that contain laboratories, such as Rudman and Kingsbury, require both cooling and heating 24 hours a day, all year long.

The campus' heating load is efficiently provided by the recovered steam from the cogeneration plant. The cooling load is partially provided by any excess steam from this process, but heavily relies on two electric chillers and a free cooling heat exchanger at the chilled water plant. Most of the electricity used by these chillers at the chilled water plant is provided by the cogeneration plant. However, when the cooling load peaks on hot days, the cogeneration plant cannot provide enough electricity to power both the normal electrical needs of campus and the electricity to produce the entire chilled water load. Therefore, the University is forced to purchase a significant amount of electricity during the peak hours of cooling throughout the hottest periods of the day.

A chilled water thermal energy storage tank at UNH could significantly reduce peak cooling loads and electricity purchases from the utility. During the night and early morning, when the cogeneration plant has the capacity to provide electricity for chilled water loads, the tank could be charged. During peaks in cooling, when the cogeneration plant cannot provide the electricity for the entire chilled water load, the TES tank could be discharged. According to the 2016 historical data of the chilled water plant (CWP), the maximum load during one day was 25,443 ton-hours of chilled water (Figure 2). This daily load could be reduced by 32% with the addition of an 8,180 ton-hour capacity TES tank. The TES tank would provide most of the chilled water load during the peak hours, eliminating the need to purchase more expensive electricity to power the electric chillers. The absorption chiller would provide the remainder of the peak load, and the electric chillers would be used primarily to help charge the tank during the off-peak hours.

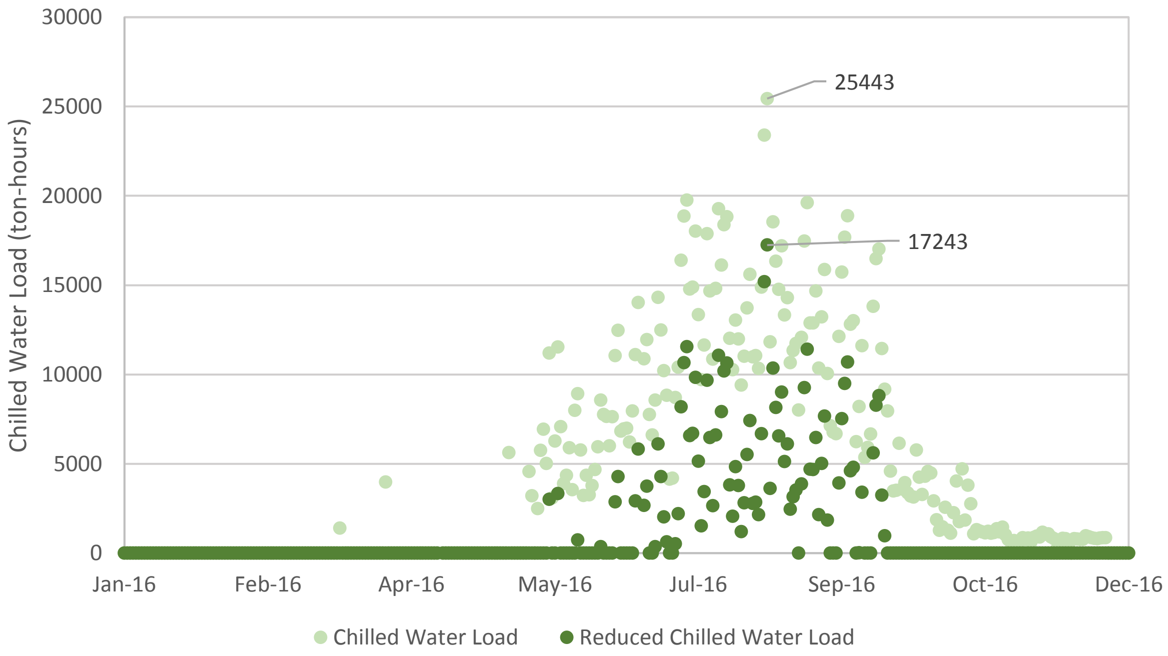


Figure 2. The Annual Cooling Load with and without Energy Storage. Without a TES tank, the peak load during one day is 25,443 ton-hours of chilled water. With the addition of an 8,180 ton-hour capacity TES tank, the peak load reduces to 17,243 ton-hours of chilled water, a 32% decrease. During the shoulder seasons, the load is reduced completely since the TES tank could provide the entire load for months with low cooling needs.

During the cooling season, a TES tank creates a dramatic decrease in the chilled water load. About 32% of the daily load can be distributed by the TES tank, leaving the chillers with a smaller load to provide. In the heating seasons, the drop is not as dramatic but equally significant. Since cooling loads are small, the TES tank could provide the entire daily cooling load each day. During the winter, when cooling loads reach their minimum, one cycle of the TES tank could provide the entire monthly load. Therefore, instead of running the chillers each day at a very low and inefficient partial load, the chillers could be operated more efficiently at full load only once or twice a month to charge the tank. The TES tank will not only flatten the cooling load profile in the cooling season, but could completely eliminate the cooling load in the heating season.

Cooling Season

In Durham, New Hampshire, the cooling season consists of half of the year, from May 1st to October 31st. During this time UNH experiences large demands for cooling due to the hot and humid weather conditions experienced during these months. The most demanding months are July, August, and September, when temperatures are at their highest (Figure 3). In 2016, August experienced the highest cooling needs. The combination of students returning to campus at the end of the month and high temperatures most likely cause this increase in cooling load. Similarly, the beginning of September requires a large cooling load because temperatures are still relatively high and all campus buildings begin to operate fully.

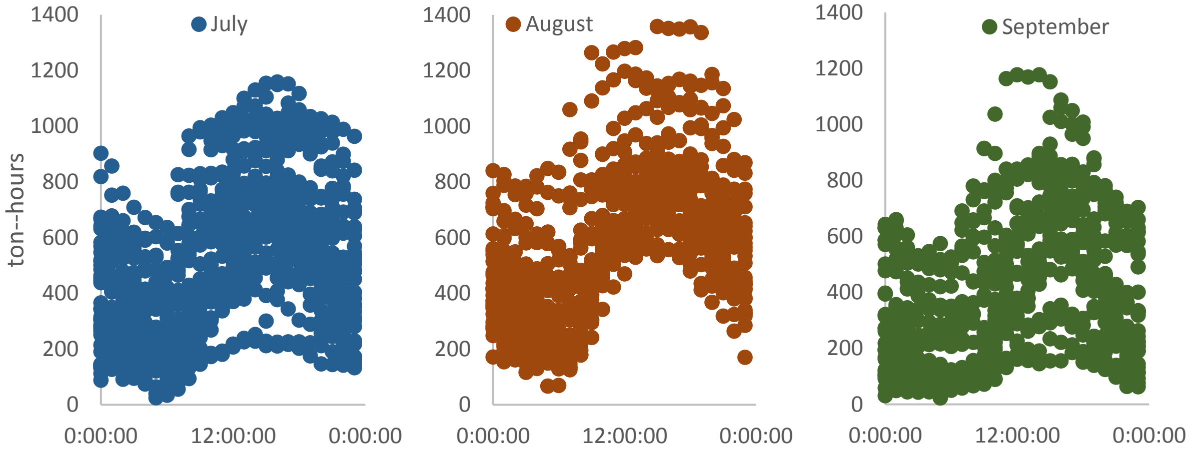


Figure 3. The Cooling Load of July, August, and September. Due to high summer temperatures, these three months have the maximum cooling needs throughout the year. In 2016, August had the highest cooling needs and July and September fell closely behind. By discharging a TES tank during the peak hours, around 12:00 PM to 7 PM, the load could be dramatically decreased. During the dips in the demand, after 8 PM and before 8 AM, the TES tank could be charged.

During the cooling season, the campus cooling load reaches its hourly peaks of about 1200 to 1400 ton-hours in July, August and September. These peaks occur during the hottest hours of the day, about 12 PM to 7 PM when students and faculty occupy both academic and residential buildings. During the peak hours, the TES tank would discharge to reduce the load and relieve the electric chillers. The TES tank would be charged during the night and early morning, after 8 PM and before 8 AM, when the cooling demand is significantly lower.

The heating requirements for the campus are very low during the cooling season. Besides hot water usage in select buildings, there is no need for the generated steam from the cogeneration plant. Since the cogeneration plant continues to produce electricity and the need for the recovered steam decreases, a majority of it is condensed and dispersed into the atmosphere. A chilled water TES tank could harness this excess steam by using the absorption chiller to charge the tank during off-peak periods. Also, the absorption chiller could be base loaded to provide the excess load the TES tank cannot provide, using the excess steam.

Heating Season

The heating season occurs from, January 1st through March 31st and November 1st through December 31st. During this time UNH experiences minute cooling demands and large heating demands due to colder winter and fall temperatures. The lowest cooling demand occurs in January and December (Figure 4). The maximum hourly cooling load is 304 ton-hours over the span of these two months. However, it seems to be significantly different than the other data points. For better comparison, the maximum hourly load should be considered as the peak in January, 142 ton-hours in one hour. These two months have particularly low and flat cooling loads because of winter break. Around Christmas and New Year's, the entire campus closes for the holiday break. During the remainder of the winter break, very few students and faculty remain on campus, eliminating most of the cooling load.

When students return from winter break, the cooling loads increase but remain far less than the cooling loads seen in the cooling season. The maximum hourly cooling load profile occurs in April, and requires only 285 ton-hours of chilled water. Throughout February, March, April and November, the loads are relatively flat, but there are some dull peaks from 12 PM to 8 PM (Appendix A: Chilled Water Hourly Load Profile of UNH).

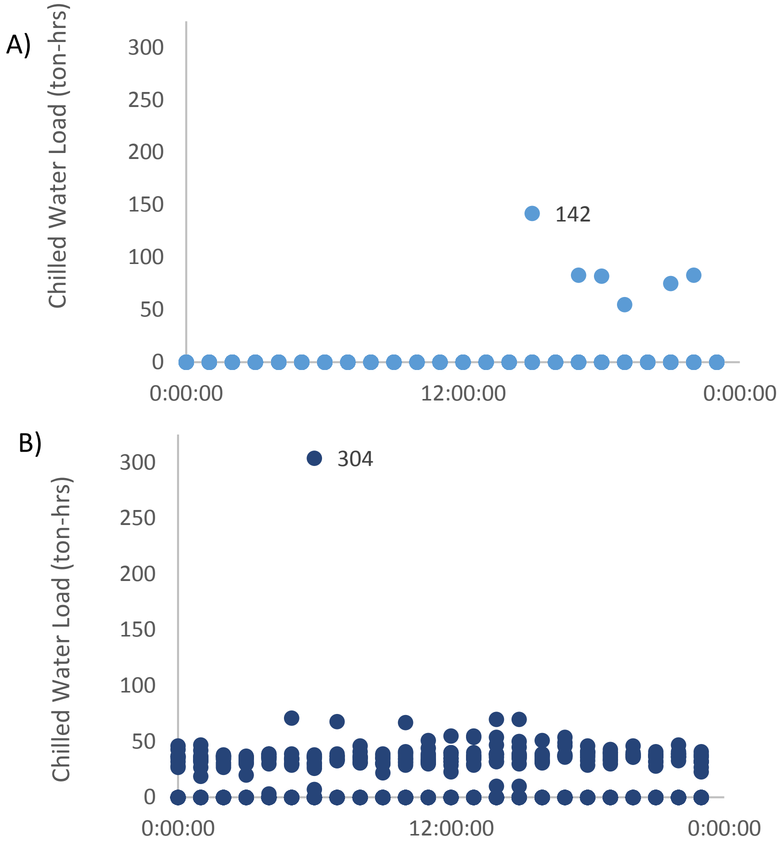


Figure 4. The Cooling Loads for A) January and B) December 2016. The maximum hourly cooling load is 304 ton-hours over the span of these two months. However, this seems to be an outlier in the data, so the maximum hourly load should occur in January, which required 142 ton-hours of chilled water. Loads are incredibly small during these months because of the cold winter temperatures and the lack of students on campus due to winter break and the holidays.

A chilled water thermal energy tank could provide the entire load during the heating season since there are no sharp peaks and the chiller load is insignificant. Instead of discharging only during the peak hours, the TES tank could discharge until it needs to be recharged, supplying most if not all of the monthly load. The tank would be charged either once a month or once a week, depending on the cooling needs of each month in the heating season.

Design of the Tank

An analysis of the historic data for the chilled water plant determined the size of a future TES tank for the University of New Hampshire. In addition, DN Tanks offered their own analysis of a future TES tank.

Tank Dimensions

Using historical data from the CWP, the load profiles were analyzed daily and hourly to determine the size of the TES tank. On average, the chiller must provide 8,180 ton-hours of chilled water per day and 340.8 tons per hour. Using these averages, three scenarios were considered: a tank sized for the average daily load, a tank sized for 13 peak hours from 7 AM to 8 PM (as determined by Eversource), and a tank sized for the 8 peak hours campus experiences, from 12 PM to 7 PM. [5] Each tank scenario was sized following a procedure outlined by HPAC Engineering. [6] However, after speaking with James Knight, Director of Energy and Utilities at Bucknell University, and Cameron Wise at DN Tanks, the scenarios for 13 and 8 peak hours were discarded. The overall consensus was bigger was better. After experiencing the benefits, several customers regretted not installing a larger TES tank at the time of purchase. Not only would an oversized TES tank shave larger peaks and increase chilled water capacity, but the price per gallon of a TES tank decreases as the tank size increases.

Calculations

The capacity of the tank in ton-hours was assumed to be the average daily chilled water load, 8,180 ton-hours. Five parameters, specific gravity (SG), heat capacity (c_p), density (ρ), the difference between the inlet and outlet temperatures of the chilled water (ΔT), and the storage efficiency (η) were assumed to find the storage volume (Equation 1).

$$storage\ volume\ (ft^3) = \frac{tank\ capacity\ (ton\ hours) \times \frac{12{,}000\ BTU}{ton\ hours}}{C_p\left(\frac{BTU}{lb_m{}^{\circ}\mathrm{F}}\right) \times \Delta T({}^{\circ}\mathrm{F}) \times SG \times \rho\left(\frac{lb_m}{ft^3}\right) \times \eta} \qquad \textbf{Equation 1.}$$

The following properties of water were determined: standard specific gravity, 1.0, heat capacity, 1.0 BTU per pound of mass per degree Fahrenheit, and density, 62.4 pound of mass per cubic foot (Table 2). The temperature difference was assumed to be 10 °F based on historic operational data from the chilled water plant. The plant usually distributes 42 °F water and sees a return of around 50 to 52 °F. The storage efficiency of the tank was assumed to be 90% because the tank cannot be perfectly insulated or stratified.

Table 2. Assumed Parameters of Chilled Water

Specific Gravity (SG)	1.0
Heat Capacity (c_p)	1.0 Btu/$\mathrm{lb_{mass}}$ °F
Density (ρ)	62.4 $\mathrm{lb_{mass}}$ / $\mathrm{ft^3}$
Temperature Difference (ΔT)	10°F
Storage Efficiency (η)	0.9

Using the calculated volume of the tank and area and volume formulas of a cylinder, the dimensions of the tank were determined with a minute stratified layer (Table 3). Since the stratified layer must be at least 5 ft, the height of the tank was determined to be 89 ft tall. At this height, the stratified layer would only be 5.6% of the tank's height.

Table 3: Dimensions of a TES Tank	
Tank Capacity (ton-hours)	8,180
Volume (gallons)	1.3 Million
Diameter (ft)	50
Height (ft)	89.6
Radius (ft)	25
Stratified Layer %	5.6 %

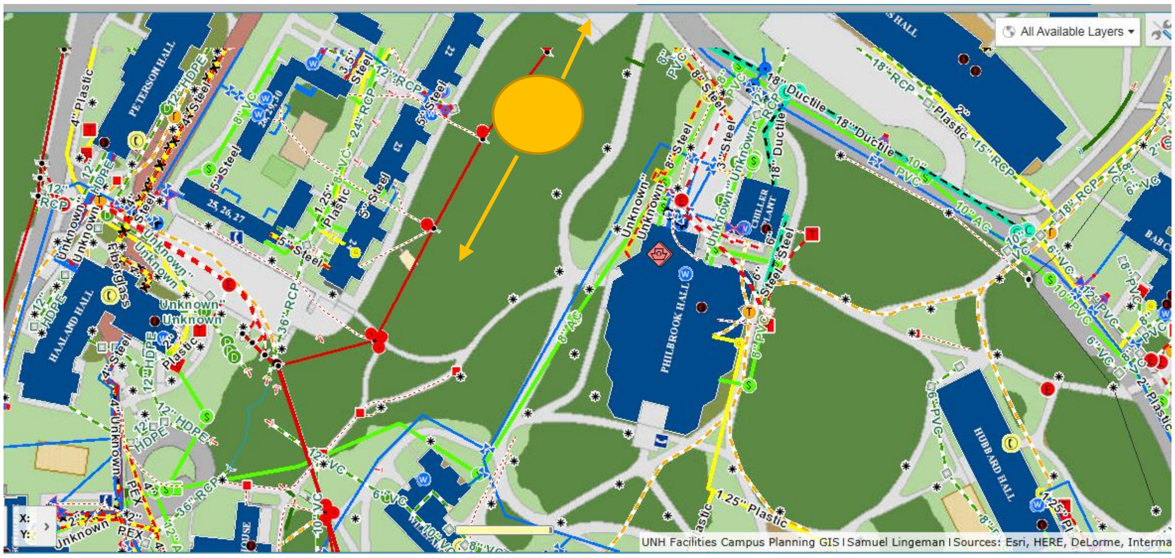
DN Tanks Design

Cameron Wise, regional manager of DN tanks for TES and biofuels, compiled a budgetary proposal for a TES tank at the University of New Hampshire. According to his work, UNH would install an 8,000 ton-hour TES tank with a total volume of 1.28 million gallons of water, similar to the proposed design above. However, DN Tanks does not like to build tanks that exceed a height of 50 ft due to expensive equipment, an increase in land space, and a longer construction period. Usually, tanks over 50 ft tall will be much more expensive due to these costs.

Location of the Tank

A thermal energy storage tank can either be located close to the chilled water plant or at a satellite location. However, the cost of the system increases as the distance between the chilled water plant and TES tank increases. More piping is required for TES tanks at satellite locations, increasing construction and equipment costs.

A potential sited close to the chilled water plant was located (Figure 5). In between the Philbrook Dining Hall and the Forest Park Apartment Complex, there is an empty area full of trees and a small parking lot. From UCAT, the University Campus Assets Tool, there seems to be minimal piping and utility obstacles in this area, which would avoid issues during construction. There are only low voltage subsurface electric lines and high voltage electric lines that could obstruct the construction process. A TES tank here would displace minimal activities. There is a trash bin located in the small parking lot next to the Forest Hill Apartment Complex that would need to be moved. However, the trash would most likely be relocated closer to their residence causing little to no opposing arguments. The parking lot contains only a few spaces dedicated to UNH service vehicles but there are several other parking lots and parking spaces on the road that could be utilized instead.



UNH Facilities Campus Planning GIS | Samuel Lingeman | Sources: Esri, HERE, DeLorme, Interma

Figure 5. A Possible Location for a TES Tank. A TES tank could be located in between the Philbrook Dining Hall and the Forest Park Apartment Complex. There are minimal obstacles in the way including a small parking lot, a trash bin, low voltage subsurface electric lines as depicted by the dashed white and red lines, and the high voltage electric lines as depicted by the dark red solid lines. A TES tank could be located closer to the road towards the parking lot and trash bin or further behind the road in the woods.

The TES tank could be located anywhere within this patch of land. It could be located closer to the road where there is currently a small parking lot and a trash bin, or further back from the road in the wooded area. This piece of land is made up entirely of ledge, which does not allow for further construction projects such as academic buildings or residential halls. Placing a TES tank here would be a great use of this space. If after further investigation this location is not suitable for a TES tank, the University should explore other locations such as underneath B lot, the wooded area between Philbrook and Hubbard Hall, and other empty spaces throughout campus.

Operation of the TES Tank

In order to maximize the economic benefits of the TES tank, the tank should be operated in the most cost effective manner. Overall, the TES tank and chilled water load should be base loaded with absorption chillers and free cooling, only using the electric chillers when absolutely needed. By minimizing the use of electric chillers, a large portion of electricity will be reduced, therefore reducing the strain on the cogeneration plant and the need to purchase as much electricity from the grid. UNH could save a significant amount on their electricity bill from reduction of electricity purchase along with a decrease in demand charge. Also, UNH will significantly reduce their scope 2 emissions.

Charging the Tank

Table 4. Chiller Combinations to Charge the Tank	
Combination of Chillers	**Time to Charge the Tank (hrs)**
Full Absorption & One Half Electric	8.32
Full Absorption	11.94
Full Absorption & One Full Electric	6.38
Full Absorption & Free Cooling	10.20
Free Cooling & One Full Electric	11.40
Free Cooling & One Full Electric & One Half Electric	8.10

An 8,180 ton-hour TES tank could be charged by several combinations of chillers. The method of charging the tank does not affect the operation of the TES tank nor its efficiency. However, choosing which chiller or chillers to charge the tank depends on several factors such as time of month, time of day, temperature, available steam load, and time required to charge the tank. Because each chiller has a different capacity, 685 ton absorption chiller, two 600 ton electric chillers, and a 115 ton free cooling exchanger, each chiller requires a different amount of time to charge the tank. Different combinations of chillers and varying full load and partial loads also alters the time to charge the tank. Table 4 portrays the most probable combinations of chillers to charge the TES tank.

Number of Charges per Day

Table 5. Monthly Charge Cycles		
Month	**Monthly Load (ton-hours)**	**# of Cycles**
January	520	0
February	1991	0
March	6241	1
April	17903	2
May	106640	13
June	211529	26
July	407791	31
August	440298	31
September	292244	30
October	78400	10
November	24488	3
December	8304	1

The cooling load profiles from 2016 were analyzed to determine the number of cycles required for each month. The average cooling load for each month was divided by the capacity of the tank, 8,180 ton-hours, to calculate the number of cycles the TES tank must complete each month (Table 5). At minimum, the TES tank would take 8 hours to charge and 8 hours to discharge. Depending on which chiller charges the tank, the charging time could reach twelve hours. Charging the tank during the off-peak hours and discharging it during the peak-hours only allows for the tank rotate through one cycle each day. Therefore, the maximum number of charges the TES tank can experience equals the number of days in each month.

The TES tank would need to charge frequently during the cooling season. During the hottest months, July, August, and September, the cooling load exceeds the maximum load the TES tank can provide. Ideally the tank would cycle about 50 times throughout the month but the number of cycles is limited to the number of days in the month. The TES tank would focus on shaving the loads of the most demanding eight hours instead of providing the entire load. In June, the tank would cycle 26 times, almost every day, to supply the cooling load. In May and October, the tank would be charged every other day to complete 13 and 10 cycles.

During the heating season, November requires the maximum number of cycles of the TES tank. Only needing three cycles, the TES tank would have to be charged about every week. Similarly in April, the cooling load requires two charge and discharge cycles. In April, the TES tank would charge every two weeks. In December and March, the cooling load only requires one cycle of the TES for each month. In January and February the cooling load does not even entail a full cycle of the TES tank to satisfy the cooling load. The tank could be charged once and then used over the two month period to supply both monthly cooling loads. Alternatively, the chillers could provide the entire loads if charging and discharging the tank was not as economical. The University should choose operate the chilled water plant depending on the cost to charge the tank versus the cost to provide these small cooling loads with an electric chiller or free cooling.

Chiller Operation in the Heating Season

During the heating season, most, if not all, of the steam generated from the Siemens turbine at the cogeneration plant heats the campus. Therefore, there steam is not available to chill water using the absorption chiller. However, during the heating season, the cold temperatures allow the free cooling heat exchanger to operate. When outside air temperatures are below 47 degrees Fahrenheit and the cooling load is under 200 tons, free cooling can provide the cooling load. Temperatures at night throughout these months are usually much colder than 47 degrees, providing colder chilled water and increasing the efficiency of the chilled water system. However, free cooling may not be able to charge the TES tank in April due to warmer temperatures. Free cooling should be utilized to charge the TES tank during the heating season.

If free cooling alone charged the entire TES tank, it would take 71 hours or about 3 days. Depending on the cooling load, it may be possible to charge the TES tank over this long period of time. Since the heating months have the lowest cooling demands, the electric chillers could provide the small cooling loads for three days while the TES tank charges. More analysis should be completed to determine the cost effectiveness of this operation.

If the University needs to charge the TES tank faster than three days or if this method proves to be cost ineffective, the TES tank could be charged in combination with free cooling and a full electric chiller in 11.4 hours or 8.1 hours with free cooling and one and a half electric chillers (one electric chiller at full load, 600 tons, and another electric chiller at partial load, 300 tons). Since there are no peak hours in the load profiles for the heating season, the tank could charge in 11 hours without disrupting the cooling demand. Electric chillers would increase the cost of charging the tank, but would reduce the overall electric chiller usage of that month. Instead of constantly running on partial load every day to provide the minute cooling needs, the electric chiller would run at its more efficient, full load each time the tank needed to be charged. The TES tank would provide the daily cooling loads reducing the overall need for electric chillers each day.

At Bucknell University, their TES tank is partially charged several times a month during the winter season. Unlike a battery, partially charging the TES tank would not affect its efficiency or health. UNH could operate the TES tank in this fashion worry free to minimize electrical chiller usage and solely harness free cooling to charge the tank. The average load in a winter day is about 3600 tons, about 40% of the capacity of the TES tank. Free cooling could be used on a daily basis to fill the tank to this capacity to satisfy the next day cooling needs. The operation of the TES tank in this manner would result in more charging and discharge cycles, but would reduce electric chiller operation even more.

There are several options to operate the TES tank in the heating season. Due to the low cooling demand, there is great flexibility in the operation of the tank. However, more research should be done to determine which operation of the tank will be the most economically beneficial for the entire system.

Chiller Operation in the Cooling Season

During the cooling season, high temperatures cause cooling demand to increase. Hot temperatures also eliminate the ability to utilize free cooling. Free cooling may be available during the cool nights in October and possible in early May, but most likely there will be little to no free cooling to assist the cooling needs. However, the heat of summer and spring reduces the heating loads on campus. In the cooling season the turbine at the cogeneration plant maintains operation to create electricity for the campus. Without the need to heat campus, most of the recovered steam is condensed and heat is dispersed into the atmosphere. Instead of wasting this excess steam, it could be harnessed to charge the TES tank with the steam absorption chiller.

Because the cooling loads are so large during the summer months, the TES tank will not be able to meet the entire daily cooling load. Instead, it will only be able to shave off about 1,000 tons for the eight greatest peak hours in the day. The remainder of the chilled water load must be provided by the combination of the electric chillers and the absorption chillers. However, since there is a large excess of steam during the cooling season, the absorption chiller should be base loaded to provide most of the residual chilled water demand.

In the summer, the tank would be primarily charged by the absorption chiller with help from the electric chiller. If the absorption chiller ran at full load, 685 tons, and one electrical chiller ran at partial load, 300 tons, the TES tank could be charged in about eight hours. If the TES tank was to be charged solely by the absorption chiller it would take about 12 hours to charge. This could be done overnight and in the early mornings when the cooling demand decreases, given that the steam load was available. This method would require little to no electricity costs and could provide a large portion of the cooling load without the use of expensive electric chillers.

The cost of the charging the tank and the overall benefits from a TES tank, heavily depends on the charging method. Electric chillers would obviously be more expensive, but would have to be used if there was no steam load available to use the absorption chiller or if temperatures were too warm to operate free cooling. The operation of the TES tank and these factors should be closely monitored to maximize the benefits of a chilled water thermal energy storage tank.

Economic Analysis

An economic cost benefit analysis was completed to determine the feasibility of constructing a TES tank on UNH Durham campus. The costs and benefits of the chilled water system with a TES were compared to the costs of the existing chilled water plant. Costs such as EMCOR operation and maintenance of the chilled water plant and the sewer and water costs were excluded because they will remain constant with or without a TES tank. Only the costs and benefits that changed due to the addition of a TES tank were analyzed.

Costs

Capital Costs

The capital cost of the TES tank was provided in the Utilities Master Plan Energy Utilities Progress Meeting No. 4, presented by RMF Engineering. The capital cost of an 8,100 ton-hour tank (1.2 gallons) was determined to be $1,458,000. [7] According to DN tanks, the installation of an 8,000 ton-hour tank (1.28 gallons) with appurtenances would be $1,280,374. With site preparation allowance totaling, $217,633, the total cost of DN Tank's services would be $1,498,037, slightly higher than RMF's prediction. These costs represent the cost to design and construct the tank.

Construction Costs

The construction of the TES tank consists of several factors. The tank itself, the pumps and ancillary piping, and the geotechnical work to prepare the construction site would be completed by three different companies. DN Tanks would construct the TES tank. These costs are included in the capital cost of the TES tank (Table 6). Local companies would need to be hired to complete the mechanical and geotechnical work required for the project. For example, RMF engineering could be hired to carry out the mechanical engineering responsibilities. The mechanical construction of the tank includes pumps and ancillary pumping. Other work would have to be performed by another company to clear trees and other geotechnical services. These costs are unknown, but Cameron Wise from DN Tanks predicted that the total cost of both a mechanical and geotechnical engineering firm would range from $500,000 to $750,000. Therefore the total cost of constructing the TES tank would be around $2,000,000 to $2,250,000.

Table 6. Total Cost of TES Project

Type of Cost	Cost ($)
TES Tank	1,498,037
Mechanical and Geotechnical	500,000 – 750,000
Total	**2,000,000 – 2,250,000**

Operational Costs

The operation costs of a TES tank are very low compared to operational costs of an entire chiller plant. There will be a slight increase in pumping energy due to the increase in the number of pumps at the chilled water plant. However, the overall energy consumption of the Philbrook chilled water plant would decrease. Other campuses did not keep track of the TES operation costs separately, but confirmed they were low. As an estimate, the operational costs were assumed to be 10% of the current monthly operation and maintenance costs at the chilled water plant provided by EMCOR.

Further Cost Analysis

These costs should be further investigated in the future when a TES project is seriously considered. The operational cost was an estimate based on other campus applications, but a concrete figure should be determined for a more accurate economic analysis. Other costs that should be considered during a TES construction process are equipment costs, pumping installation costs, and any costs associated with the land that the TES tank will occupy. These mechanical and geotechnical services were estimated but should be further investigated. The length of piping, number of trees to be cleared, possible utility barriers underground, and blasting of the land should be considered during a future study. These variables would most likely cause cost of the project to increase.

Benefits

Electricity Reduction

The electricity usage of the chiller plant is very complex. By considering the magnitude of the chilled water load, the number of charges each month, the price of each chiller per ton-hour, and the availability of each chiller, a theoretical operation of the TES tank was determined to calculate the possible electricity savings gained from an installation of a chilled water thermal energy storage tank. The savings were calculated by comparing the cost of electricity consumption based off of the chilled water plant data from 2016 and the theoretical operation of the chilled water plant with the TES tank (Appendix B: Chilled Water TES Electricity Savings). By installing a thermal energy storage tank, the amount of electricity consumed by the chillers could be reduced drastically.

Charging the TES tank with an absorption chiller and the excess steam from the cogeneration plant would be a cheaper form of charging the tank compared to an electric chiller. The cost of electricity exceeds the cost of natural gas and processed landfill gas used to generate steam. The price per ton-hour is cheaper to cool with steam than it is to cool with an electric chiller. Annually, the electric chiller costs about 57 cents more per ton-hour than an absorption chiller (Table 7). In addition, free cooling is a cheaper option than using the electric chillers. Free cooling requires some electricity because of the associated pumps and cooling towers, but since the heat exchanger itself requires little to no energy, it was assumed to be half of the price of the cost of an electric chiller.

Table 7: Cost to Charge the TES Tank: Absorption, Electric, and Free Cooling

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Absorp. Cost of Steam ($/ton-hr)	$0.0358	$0.0328	$0.0343	$0.0187	$0.0155	$0.0131	$0.0122	$0.0127	$0.0119	$0.0129	$0.0162	$0.0446	**$0.26**
Elec. Cost of Electricity ($/ton-hr)	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	$0.0691	**$0.83**
Free Cool. Cost of Electricity ($/ton-hr)	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	$0.0346	**$0.41**

Each month varied in chilled water load distributions, number of days charged, and hours to charge the tank based on the method to charge the tank. In January, February, and March, when chilled water loads were low and there was no steam available, the TES tank would be charged for 11.4 hours with 600 tons per hour of electric chiller and 115 tons per hour of free cooling. In April and May, as cooling needs began to rise, the TES tank would be charged for 8.06 hours each charging cycle with 900 tons per hour of electric chiller and 115 tons per hour of free cooling. In June, July, August, and September, when cooling loads maximized and absorption chilling became accessible, the TES tank would be charged for 8.32 hours each charging cycle with 685 tons per hour of absorption chiller and 300 tons per hour of electric chiller. In October, November, and December, the 2016 CWP data suggests there is still absorption cooling available. Therefore, the TES tank would be charged for 10.2 hours with 685 tons per hour from the absorption chiller and 115 tons per hour from the free cooling. The charging methods were determined based on the historical availability of each chiller. Further research should be conducted to determine if these methods are also the most economically beneficial, or if more efficient and cost effective charging methods exist.

Using these assumptions, the total cooling load the TES tank could provide in a month was calculated and was compared to the monthly cooling load from 2016 (Appendix B: Chilled Water TES Electricity Savings). It was assumed that an 8,180 ton-hour TES tank could discharge in 8 hours, distributing 1022.5 tons of chilled water per hour. If the TES tank could provide the entire monthly load, only the price of charging the TES tank was included in the total cost for the month. If the TES tank could not provide the entire monthly load, the price to charge the TES tank was added to the cost of supplying the remaining chilled water load. The cost of the remaining load was determined by using the prices per ton for the absorption chiller, electric chiller, and free cooling (Table 7). Using historic data from 2016 at the CWP, the contribution of each chiller to the entire load was determined, and transformed into a percentage. The remaining load, not provided by the TES tank, was multiplied by the percentage of each type of chiller and then the price of each chiller per ton to determine the cost to provide the remaining load for each chiller. The sum of the cost for the absorption chiller, electric chillers, and free cooling determined the total cost to provide the remaining loads. Using this method, the cost of the chilled water plant with a TES tank was determined.

The cost of a chilled water plant with a TES tank was compared to the cost of the chilled water plant without a TES tank. The cost of normal operation at the chilled water plant was determined with the similar method. Instead of dedicating part of the load to the TES tank, the entire load was provided by a combination of the absorption chiller, electric chillers, and the free cooling heat exchanger. From historical data, percentages of each chiller's contribution to the chilled water load were determined during 2016 (Table 8). In January, February, March and April, the electric chiller provided 75% of the cooling load while the free cooling heat exchanger provided the remaining 25%. In May and June, the electric chiller provided 100% of the chilled water load. In July 21% of the cooling load was provided by the absorption chiller and 79% by the electric chillers. In August 55% was provided by the absorption chiller and 45% by the electric chiller. In September, 61% of the cooling load was provided by the absorption chiller and 39% from the electric chiller. In October the cooling load was 98% absorption and 2% electric. In November, the cooling load was supplied by 100% absorption. In December, the absorption chiller provided 88%, the electric chiller provided 7% and free cooling provided the remaining 5%. Using these percentages, the total cost of each chiller was determined based on the total chiller load of the month and the price per ton of each chiller.

Table 8. Chiller Load Distribution

Month	Free Cooling	Electric Chiller	Absorption Chiller
January	25%	75%	0%
February	25%	75%	0%
March	25%	75%	0%
April	25%	75%	0%
May	0%	100%	0%
June	0%	100%	0%
July	0%	79%	21%
August	0%	45%	55%
September	0%	39%	61%
October	0%	2%	98%
November	0%	0%	100%
December	5%	7%	88%

Overall, adding a TES tank to the chilled water plant would save about $27,000 in electricity costs each year. However, it is interesting that the operation of the TES tank in this manner does not provide consistent monthly savings (Appendix B: Chilled Water TES Electricity Savings). Further research should be conducted to determine an optimal operation of the TES tank during these months to further increase the savings.

This analysis only compares the savings of the supplier charge from the utility and does not include the cost reductions from delivery charges such as the kWh distribution charge, and the kWh stranded cost recovery charge. Because of the minute difference in on and off-peak delivery electricity prices offered by Eversource, the delivery price would not change significantly by altering the time of use of the chillers. However, because there are reductions in kWh hours purchased from the utility, these charges would decrease but was not calculated. The exact kWh reductions a TES tank can implement should be determined to calculate the delivery charge cost reductions available.

Since the University does not utilize time of use rates, it will not experience as dramatic energy savings as other campuses. The supplier charge is fixed for the entire day, whereas other campus see ten cents difference between on- and off-peak electricity supplier prices. In addition, the delivery charges have minute differences between the on- and off-peak rates and would not change the price of delivery drastically if chillers were operated during the night rather than during the day. Instead of focusing on the electricity savings in terms of load shifting, they were analyzed by reduction of kWh purchased from the utility. Some savings may have been lost because of the assumptions made within this analysis. The electricity savings should be further analyzed with specific data regarding kWh consumption for each chiller to find the most cost effective operation of the TES tank.

Demand Charge Reduction

The UNH demand charge is determined by the peak half hour of electricity use in a 12 month period. A large cooling load, typically in the summer months, requires a significant amount of energy in addition to the other activities on campus and increases electricity usage. The cogeneration can only provide 85% of campus needs. An increase in electricity demand from the chillers also increases the amount of electricity that must be purchased from the utility. Although this only occurs in the summer, the demand rate structure depends on the highest purchase of electricity for the entire year. Therefore, it is most important to reduce these large demand charges, particularly in the summer time. By discharging the TES tank during the peak hours of the day in the summer, the demand charge will decrease since the chillers will not be using electricity during the peak hours to provide the chiller load.

Table 9: Demand Charge Reduction

Demand Charge Normal (kW)	8316
Demand Charge with TES (kW)	7912
kW Saved	403.74
Annual Demand Charge Reduction ($/year)	**34,641**

The demand charge was assumed to reduce by the amount of energy that an electric chiller would use to deploy the same peak load the TES tank could deploy. In the summer, the TES tank could discharge 8,180 tons in eight hours to provide the maximum cooling load during the eight most peak hours, typically 12 PM to 7 PM. In one hour, the TES tank could discharge 1,023 tons of chilled water. The Non-Standard Part Load Value (NPLV) rating for the York 600 ton chiller, 0.691 kW/ton, was used to determine the required energy (kW) to provide the hourly load. The energy requirement of the hourly load was halved to determine the half hour demand, 7912 kW. According to the Eversource bill from April 1st to May 1st, 2017, the demand charge was based off 4574 kVa, or 8316 kW. A TES tank could save 403 kW of energy by discharging it during the peak periods (Table 9). Currently, the demand charge is $13/kVa within the Rate LG, the large general delivery service rate. By reducing the maximum energy purchased from the utility with a chilled water TES tank in the summer months, the total annual demand charge would reduce by $34,641 per year.

Steam Load

During the cooling season, the turbine still produces 85% of the campus' energy. However, the demand to provide heating for the buildings decreases immensely and is replaced by cooling needs. Some steam provides hot water in showers and bathrooms, but most of the steam load diminishes (Figure 6). As a result, the extra steam collected from the waste heat from the turbine is condensed and dispersed into the atmosphere. Instead of condensing and wasting most of the steam, it could be used to chill the TES tank. By using the absorption chiller to charge the tank, the steam load could be harnessed and make the cogeneration plant more efficient.

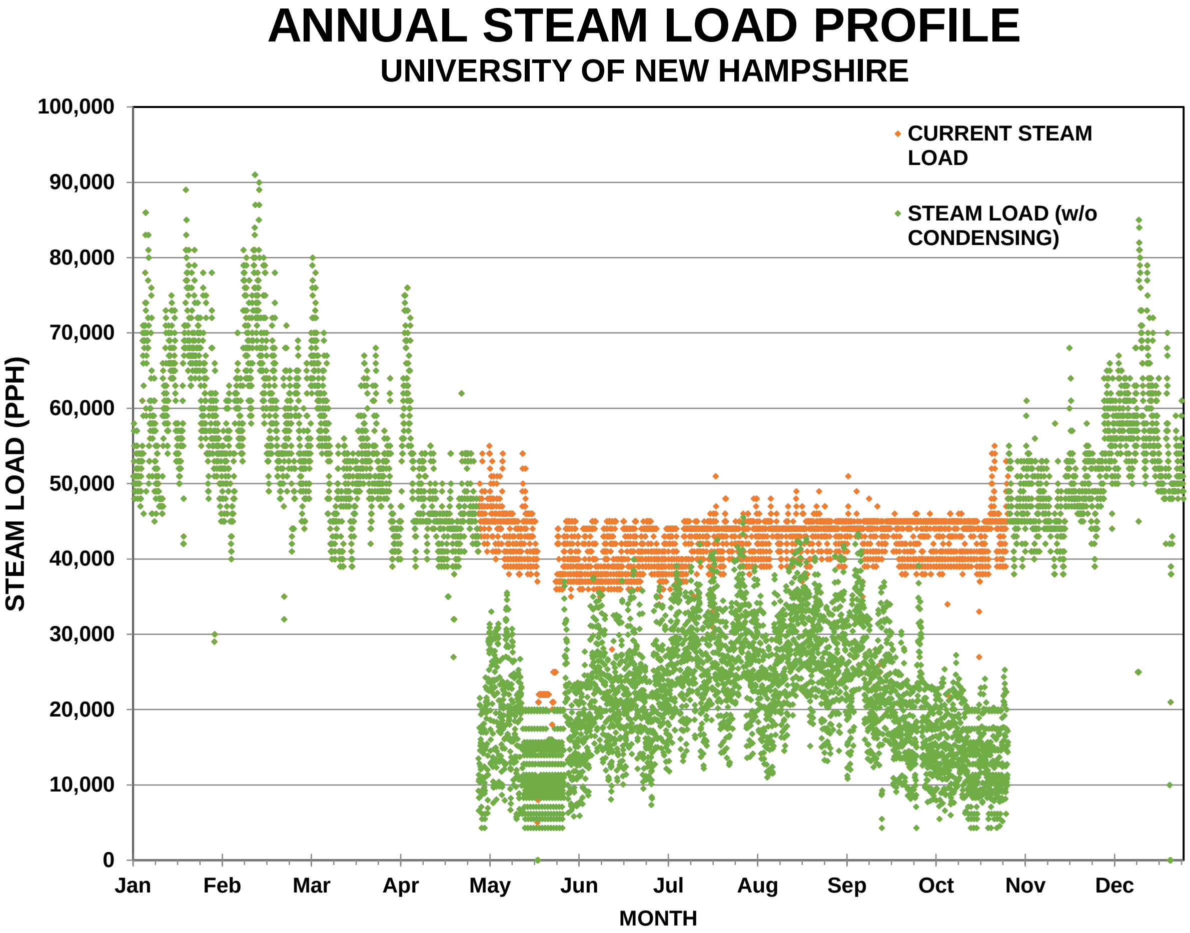


Figure 6. The Annual Steam Load Profile for the University of New Hampshire created by RMF Engineering. The steam load without condensing represents the steam actually used on campus annually. The steam load with condensing represents how much steam is produced from the turbine during the heat recovery steam generation (HRSG) process. During the cooling season a significant amount of steam is condensed and wasted. [8]

The steam is a byproduct of the electricity generation that occurs with or without the need for steam across campus. Using steam to charge a TES tank with an absorption chiller gives the wasted steam a purpose. Therefore, the cost to create this steam was considered a "saving" in the economic analysis. The total amount of steam (MMBTU) to charge the tank each month was calculated based on the number of charges of the TES tank each month, the thermodynamic properties of the steam, the heat rate of the turbine, and the amount of steam in pounds to chill one ton of chilled water using the absorption chiller. Then, the total cost to generate this amount of steam each month was calculated based off of the price of natural gas and processed landfill gas (PLG) from 2016 and the blending ratio of natural gas and PLG (

Appendix C: Cost of Steam to Charge the TES Tank). Each year, the TES tank would be able to harness $21,938 worth of steam to charge the TES tank. Instead of wasting the steam, and the money required to create it, the TES tank can utilize this steam and satisfy the campus' cooling needs more efficiently.

Microgrid and Resiliency

The addition of a TES tank would bring UNH one step closer to being a micro-grid. A microgrid is a local electrical system that combines thermal and electrical loads along with thermal and electrical storage to provide energy needs in parallel or in isolation from the grid. Microgrids provide the choice to produce cleaner energy, enhances local resiliency and responsiveness, and improves the operation and stability of the larger electrical grid. [9] Adding energy storage allows the campus to store more of the energy it already produces, relying less on the utility and focusing more on the efficient, inexpensive energy that is produced on the UNH campus.

Cost reduction aside, the TES contributes one of the most important aspect of the microgrid, the increase in resiliency. For example, if the grid was overwhelmed in the peak of the summer and resulted in a power outage on campus, there would be no electricity to power the chilled water plant and meet the cooling loads. Campus would be uncomfortably hot, daily operation would be effected, and the University would not be operating at maximum efficiency. However, with the addition of a TES tank, a power outage would minimally affect the ability to distribute chilled water on campus. Stored chilled water, already cooled and ready to go, would require little energy to pump the chilled water into the buildings and satisfy the cooling needs. This small amount of energy could easily be provided by the cogeneration plant, which would be unaffected by the power outage. Without the TES tank, there would not be enough energy at the cogeneration plant to supply all electrical and thermal needs to operate campus. With a TES tank, in the event of an outage at the grid level, daily operation would not stop, and campus would not be effected by the outage.

This increase in resiliency and responsiveness could occur during more serious events such as storms or other disasters which could affect our cogeneration plant directly. If such an event occurred, the TES tank would still be able to discharge and provide some cooling loads that were still needed. In addition, the TES tank could act as a large fire hydrant for any fires on campus. A firefighting feature could even bring UNH insurance savings.

Emission Reduction

There are 3 scopes of emissions, Scope 1, Scope 2, and Scope 3. Scope 1 emissions are emissions generated directly from the University such as stationary combustion of natural gas and processed landfill gas, mobile combustion of fossil fuels from transportation services, and fugitive emissions from natural gas distribution and refrigerant systems. Scope 2 emissions are indirect emissions from the consumption of electricity, steam and other sources of energy such as chilled water. [10] In this analysis, the scope 2 emissions from electricity consumption were analyzed. The contribution of steam and chilled water emissions should be investigated further. Scope 3 emissions are other indirect sources of greenhouse gas emissions that result from the operations of the University by are not directly owned or controlled by the University. For example, commuting, business travel, and other sources contribute to the Scope 3 emissions. [10]

The addition of a TES tank could reduce scope 2 emissions associated with the University. Since the TES tank would be charged primarily by the absorption chillers and free cooling and then discharged at peak periods, less electricity would be purchased to chill water. Decreasing the total purchase of electricity from the utility will also decrease the Scope 2 emissions the University produces.

According to the campus calculator version 9, created by the UNH Sustainability Institute, the reduction of electricity could save about 163 metric tons of CO2 each year and a total of 6,520 metric tons of CO2 over the lifespan of the project. [11] However, this reduction only includes the reduction of kWh from the demand charge, and does not include the entire electricity reduction with a TES tank. Further research should be conducted to determine the exact emission reductions from the decrease in electricity purchased.

Not only does the reduction of electricity purchases reduce emissions, but the time of day that electrical chillers are run also reduces the emissions. During off-peak hours when grid demand is low, the utility only allows a few generators to run and produce electricity. These generators are called "base-load" plants and normally consist of hydro, wind, and nuclear sources of energy. None of these generators are combustion based, therefore providing almost CO_2 free energy. Then, when demand rises during on-peak times, more polluting generators begin to run and produce electricity such as coal and gas-fired plants. At the highest demand, "peaking" plants, such as diesel generators and simple-cycle gas turbines, begin to operate and provide the demand. These plants are the least efficient users of fuel energy and tend to be the most polluting plants. [12] By running the electric chillers at night to charge the tanks (in the winter months when absorption chillers may not be available), the emissions are reduced because the grid is being power by low emitting resources. In normal operation, when the chiller plants are running during the peak hours to meet campus demand, "peaking" plants are powering the grid. Therefore the electric chillers create more emissions during the day than when operated at night.

Overall, a rough estimate of emission reductions was calculated through this analysis and should be investigated much more thoroughly. However, as described above, a TES tank introduces several opportunities to reduce Scope 2 emissions for the University of New Hampshire. A TES tank would help the campus reach the WildCAP goal, of 50% reduction of total greenhouse gas emissions by 2020.

Other Benefits

TES tanks have been around for several decades. Because TES tanks are a very mature technology, UNH can have confidence that this system will work correctly with little to no issues. There are several case studies of operating TES tanks at other campuses such as Princeton University and Bucknell University, which demonstrate the benefits a TES tank could bring to the University of New Hampshire. When speaking with experts in the field, many said that the only thing they regret about buying a TES tank is they should have invested in a larger tank. The University of New Hampshire can confidently follow in the successful footsteps of others and construct a TES tank on Durham campus.

Because the TES is a thermal version of an electrochemical battery, a TES tank brings renewable energy options to UNH. With the ability to store variable energy techniques, renewable energy such as wind or solar could be used to power the electric chillers. For example, wind energy could be harnessed during the night when it is abundant and used to charge the TES tank with the electric chillers. A TES tank not only saves the University money now, but introduces opportunities to save more money and be more sustainable in the future with renewable energy technology.

Payback Period

Although an exact payback period was not able to be calculated because of the complexity of the electricity savings at the Philbrook CWP, other TES projects such as Princeton University and Bucknell University have found payback periods of 3-5 years. This is due to immense electricity savings from the difference between off-peak and on-peak prices to charge and discharge the tank. Although UNH does not reap such benefits from Eversource, the demand charge reduction combined with electricity reduction could experience similar benefits and allow a similar payback period. Also, a TES tank lifespan ranges from 20-40+ years. The payback period of the project would only be a fraction of the lifetime savings, securing great benefits for an extended amount of time.

Future Projections

Climate Change Mitigation

Humanity's inefficient use of resources and fossil fuels has left our planet with a warming trend which will affect the climate of New Hampshire in the near future. As temperatures continue to climb, Durham will experience hotter seasons. The number of days above 95 will continue to increase. With high emissions, there will be an entire month's of above 95 degree days compared to two days over 95 degrees that the seacoast area experiences now (Table 10). With high emissions, in the long term there will eventually be no days below zero degrees and a 48 day decrease in days where temperatures reach below 32 degrees. Currently, the chiller plant reaches its capacity during 95 degree days. If more of these days occur, there will be a large increase in cooling loads and the existing chillers may not be able to provide the entire load

In the immediate future, the short term data suggests UNH will experience hotter temperatures. There will be one more day where temperatures exceed 95 degrees and the number of days over 90 degrees will increase by about a week. This rise in temperatures may not seem large, but will have a great effect on the cooling demand of the academic and residential buildings at UNH, requiring more cooling and more electricity.

Table 10. Annual Future Number of Days of Extreme Temperatures with Low and High Emissions [9]

Temperature	Historical	Short Term (2010-2039)		Medium Term (2040-2069)		Long Term (2070-2099)	
		Low Emissions	High Emissions	Low Emissions	High Emissions	Low Emissions	High Emissions
<32 °F	154	143	143	136	126	132	106
<0 °F	10	7	6	4	3	4	0
>90 °F	10	16	17	25	38	31	67
>95 °F	2	3	3	6	13	10	34

As the climate changes and temperatures rise, UNH will experience a much greater need for cooling. This need for cooling will surpass the capacity currently available on campus and require the purchase of more chillers. With the construction of a TES tank now, we can access the economic benefits now and prepare for future temperature changes in the future. The TES tank will create even more savings with an increase in cooling capacity. Without the TES tank, the more expensive and energy intensive cooling season will be extended, increasing the electricity bill. A thermal energy storage tank would help UNH prepare for the increased cooling that climate change will inevitably create.

Operation of Campus

Since UNH Durham campus has limited land, there is little room to expand and construct more academic buildings. Therefore, UNH has future plans to optimize the space they already have by offering more night classes and summer classes. [14] More summer classes could potentially increase the cooling load during the summer and somewhat increase the demand charge. With the addition of night classes to the normal class schedule, the occupation of buildings elongates, creating a much larger cooling and heating load. The cooling systems almost reach capacity. With an increase in building occupation, the capacity may surpass its limit. Therefore, the addition of a TES tank would help the chiller plant meet its own future cooling loads.

Natural Gas and Electricity Prices

Based off of historical trends, energy prices continue to rise. Natural gas prices recently dipped in price but the market continuously changes. It cannot be confidently predicted if natural gas prices will remain this low or increase. The price of natural gas also varies with the seasons (Figure 7). In the summer months, prices are low and close to $3 per MMBTU, whereas in the winter months prices can reach $11 per MMBTU. In the summer, when cooling demand is high and heating demands are low, the low natural gas prices could be taken advantage of to charge the TES tank with absorption chillers.

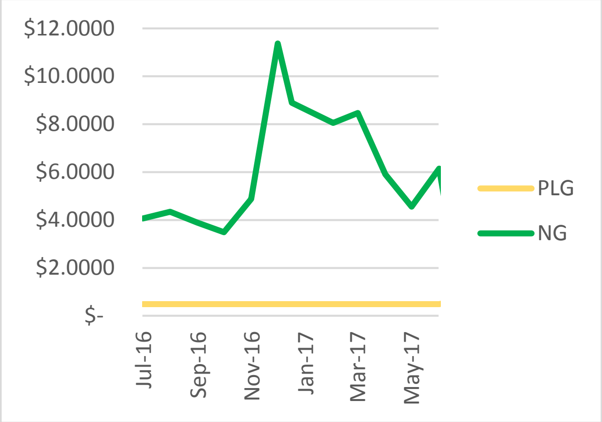


Figure 7. The Price of Fuel for Fiscal Year 2017. The price of natural gas continuously dips and peaks depending on the time of year. In winter Natural Gas prices skyrocket. The processed landfill gas remains constant throughout the year but is projected to increase this fiscal year.

Also, the processed landfill gas prices continue to increase. Last fiscal year UNH paid $0.4896 per MMBTU of processed landfill gas, but starting July 1st 2017, the price of processed landfill gas increased to $0.68. This increasing trend will most likely continue over the years especially as the methane content of the landfill continues to decrease, causing the quality of the gas to decrease. By constructing a TES tank, the cogeneration plant will become more efficient by using the excess steam to chill water and charge the tank.

In addition, the price of electricity is continuously increasing. According to the U.S. Energy Information Administration, the price of electricity continues to increase by 2% each year. [15] If UNH continues operation as is, the cost of electricity bills will increase as electricity prices increase as well. However, with the addition of a TES tank, electricity costs could be reduced and the increasing price of electricity would have little effect on the UNH electricity bill.

Concluding Remarks

A chilled water thermal energy storage tank should be installed at the Philbrook chilled water plant at the University of New Hampshire. Increasing the chilled water capacity with the addition of a TES tank will maintain a comfortable living, learning, and research environment in the event of rising temperatures due to climate change. In addition, a TES tank will bring immediate economic benefits to the University. By reducing the demand charge and the overall amount of electricity purchased from the local utility, the TES will reduce energy costs significantly. A chilled water thermal energy storage tank will also help our campus become more sustainable by reducing scope 2 emissions, introducing future renewable energy sources and increasing campus resiliency. Moving forward, the University of New Hampshire should seriously consider the installation of chilled water thermal energy storage tank.

Individual Hot Water Controllers

When considering thermal energy storage, it was determined that hot water thermal energy storage would not be ideal for the UNH campus because it would not match campus needs. Instead of expanding the hot water district energy system, UNH plans to reduce some piping due to lack of efficiency, old age, and cost. Therefore, hot water thermal energy storage is not the right choice for UNH. However, since there is an abundance of electric hot water heaters installed throughout campus buildings, individual hot water controllers could be installed to make the electric hot water heaters more efficient and reduce energy costs.

What are Individual Hot Water Controllers?

Individual hot water controllers are junction boxes connected to an electric hot water heater's power source and used to manage the energy usage of the electric water heater. [16] The controllers relate to the idea of grid integrated water heating which allows system flexibility and other benefits at a fraction of a cost of a battery. With controllers, the electric water heaters could act as a battery and provide services such as load shifting, peak shaving and integration of renewables.

In a residential perspective, customers mostly use hot water during the morning and evenings. Instead of running the electric heater all day to provide for these two load periods, the controller could adjust the energy usage of the electric water heater so the water would be warmed during off peak periods and then stored until it is needed. This could shift 40-60% of demand used for hot water heating to create customer savings and grid services such as avoided generation capacity and avoided transmission and distribution capacity. [17] In addition, wind and solar energy could be utilized to provide the power to heat the water. Wind energy, which is most abundant at night, would provide electricity to heat the water before the morning load. Solar energy could be harnessed midday when it is most abundant to provide the heating for the evening load. The controller would allow the user to control the operation of the water heater to take advantage of these opportunities.

Operation at UNH

These benefits could be translated to the University of New Hampshire. The University does not experience the standard morning and evening hot water loads experienced by residential customers. Instead, there is a constant demand for hot water throughout the day to provide hot water for students. However, the University experiences standby losses and overheating to excess temperatures which wastes a lot of energy. The installation of individual hot water controllers at UNH could make the electric heaters more energy efficient. The controller would be able to turn the heater on during the night to heat the water, then turn it off during the day so the heater does not produce excess heating standby losses. During the day the hot water would be distributed to campus and the process would repeat. In addition, maximum temperature controls could be programmed so the tank does not waste energy heating the tank to excessive temperatures. When the tank reaches the predetermined temperature the controller will shut off the tank. Electric heaters are one of the most expensive methods to heat water. By installing controllers the University will use their energy more efficiently and save money.

Electric Hot Water Heaters on Campus

UNH has approximately 80 electric hot water heaters ranging from 12 to 120 gallons that could be retrofitted with individual hot water controllers. Although an exact figure is unknown, a significant amount of energy could be reduced from the installation of controllers. Generally, a 40 gallon water heater uses 2500 kWh/year. If all 80 tanks on UNH campus were assumed to be 40 gallon tanks, the annual electricity usage would be about 200,000 kWh/year, approximately 0.3% of the annual total electricity usage of campus. In residential applications, the installation of a controller could reduce the entire household bill by 10-30%. Although this percentage of savings would never happen at UNH, since the bill for the University has many other factors than one residential home, this comparison demonstrates the magnitude of electricity that could be saved from the controllers. The savings, although a very small percentage of our bill, could decrease demand charges and reduce electricity costs.

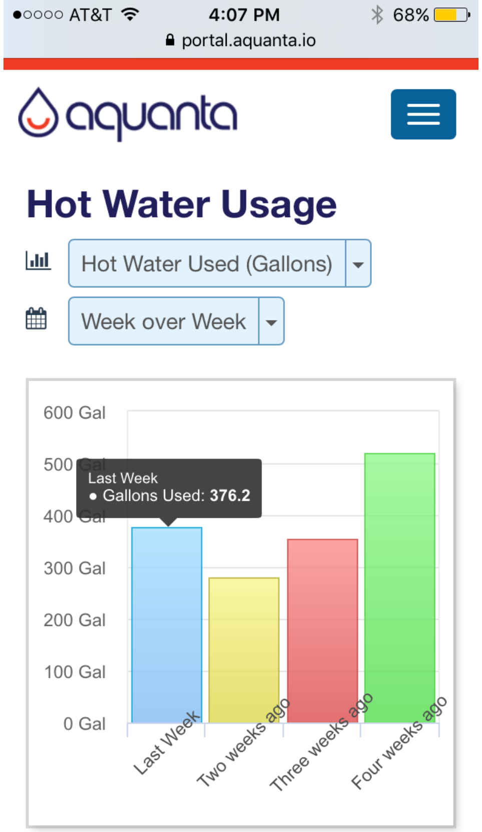
Aquanta Controllers

Aquanta sells individual hot water controllers for electric water heaters that are less than fifteen years old, contain a T&P outlet, and are 120 gallons or less. Controllers are $150 per controller with an additional $25 per controller for a leak protection service (Table 11. Cost of Aquanta ControllersTable 11). Controllers could be bought in bulk, but to receive a discounted price the order would need to be a minimum of 500 units. A general contractor would be hired to install the controllers. Each installation would take roughly 45 minutes and cost $100-$200 per controller. The controllers could easily be installed by Facilities employees, but there was concern about employees not having enough time to complete their normal tasks in addition to installing the controllers.

Table 11. Cost of Aquanta Controllers

Cost Description	$ / controller
Controller	150
Leak Protection	25
Installation	100-200
Total	**275-375**

Aquanta controllers come with a customer dashboard which displays an array of data including tracking information for the change in energy in a water heater, standby losses, hot water out, electricity metering, temperature of the water at the top of the tank and other useful data points (Figure 8). A profile for each individual hot water tank and controller would be available with this software. The customer dashboard can be viewed from an application on a mobile device or on a computer. This mobility could be useful for Facilities employees when conducting maintenance or checkups on hot water heaters. Instead of checking a computer and then going to the site. The customer dashboard and data will be with them at the time of the maintenance.



Hot Water Usage

Hot Water Used (Gallons)

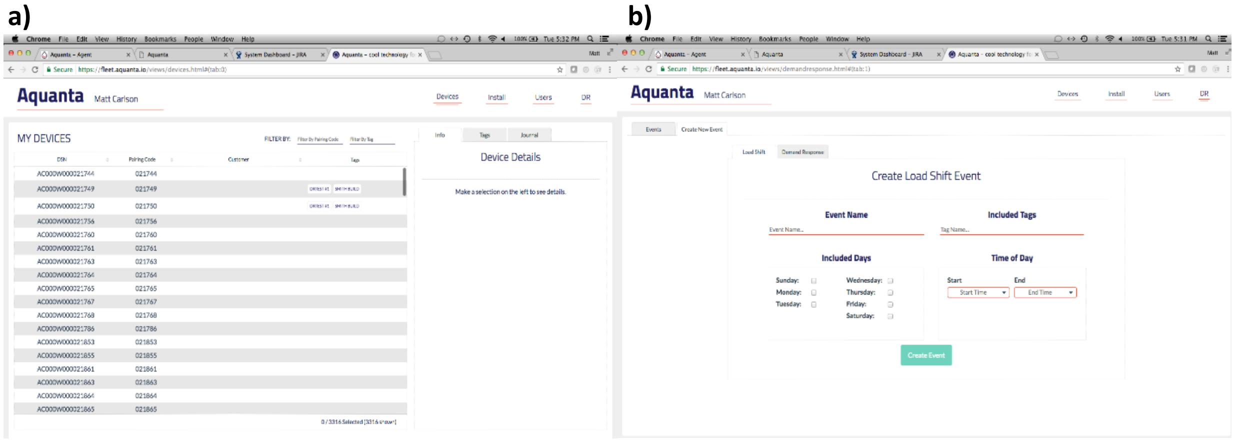
Week over Week

Figure 8. Customer Level Metering. Within the customer dashboard of Aquanta controllers, metering of the individual heaters is available. Specifically shown is the hot water usage of the past four weeks of a residential system.

Fleet Dashboard

Although the customer dashboard includes useful information, the fleet analytics would provide much more detailed information to better understand the savings and operation of the controllers. Additionally, since multiple controllers are being bought, a fleet control system would be able to control each controller under one account versus potentially having to control each hot water heater under 80 different accounts with the customer controls.

This data set could manage fleets of water heaters, such as the 80 electric water heaters on UNH campus. Within this program, all of the controllers could be organized and controlled in one dashboard (Figure 9). Tags could be added to the controllers to organize water heaters by which building they are located in and by size, make, and model. The current documentation of electric water heaters is not detailed or very organized. The fleet dashboard could provide a user-friendly interface to store this information in a more organized fashion. The fleet dashboard also offers load shift and demand response events in addition to a time of use scheduler which prioritizes heating during a specific time of day. An event for each controller can be made for load shifting or demand response. The events specify which days of the week and at what times of the day the controller should operate and at what day, time, or temperature it should shut off. For example, an electric water heater in an academic building would only need to operate Monday through Friday during the times of building occupation. These settings could be determined in the fleet dashboard by creating events. If additional heating was needed, the operator could press the “boost” button and immediately provide extra heating despite what the event outlines. Using the event planning tool in the fleet control dashboard could reduce standby losses, provide extra heating, and reduce electricity use.



DSN	Pairing Code	Customer	Tags
AC000W000021744	021744		
AC000W000021749	021749		DRTEST #1 SMITH BUILD
AC000W000021750	021750		DRTEST #1 SMITH BUILD
AC000W000021756	021756		
AC000W000021760	021760		
AC000W000021761	021761		
AC000W000021763	021763		
AC000W000021764	021764		
AC000W000021765	021765		
AC000W000021767	021767		
AC000W000021768	021768		
AC000W000021786	021786		
AC000W000021853	021853		
AC000W000021855	021855		
AC000W000021861	021861		
AC000W000021863	021863		
AC000W000021864	021864		
AC000W000021865	021865		

0 / 3316 Selected [3316 shown]

Figure 9. a) Fleet Dashboard and Tags. All of the controllers and water heaters are organized in the "My Devices" tab. The tags further organize the list of heaters and can be organized by size, make, model, and building location. b) Creating an Event. Within the fleet dashboard, events can be made for each hot water heater. There are two types of events, load shit events and demand response events. The operator can determine which days, times, and tags, are included in the settings. Events can be overridden, deleted, and recalled at any time.

At an additional cost, the fleet dashboard could be purchased for $1000/year. This will include fleet access and control, the operational dashboard, and Tier 2 support. Aquanta's CEO, Matt Carlson, has agreed to initially include this service for free, as it will be a learning opportunity for both parties. Although Aquanta has worked with large fleets of controllers in utility settings, they have not worked with a college campus yet.

Further questions about the Aquanta systems should be directed to Matt Carlson, CEO of Aquanta.

Future Plans

Initially five or more controllers should be installed throughout campus as part of a feasibility test to determine the benefits of Aquanta's controllers. In the following year, an assessment should be completed to determine if more controllers should be purchased. The benefits such as standby losses, electricity reduction, ability to provide hot water, and data accessibility should be compared to the costs of the controller, installation, and fleet dashboard, along with any other consequences attributed to the controllers. Special attention should be noted to whether or not the controllers interrupt the hot water load and cause complaints from students or faculty. Because the energy used by the electric water heaters is not individually metered, the test controllers will be very important not only to realize how much energy savings are available, but to get a better idea on what percentage of UNH electricity use attributes to electric hot water heaters.

Battery Storage

Another popular energy storage option is electrochemical storage through batteries. There are several chemistries available such as lead acid, sodium ion, nickel cadmium, lithium ion and flow batteries. Lithium ion are the most mature and powerful batteries available. Lead acid batteries are also mature technologies but lack the power and capacity of lithium ion batteries. Other electrolyte solutions and flow batteries are less mature but can be just as powerful as lithium ion. When considering a battery project, the safety, maturity, and expense of the materials should be considered. However, this feasibility analysis will only focus on the EOS Aurora battery. Other battery technologies are very popular and could deliver better cost savings, but the costs of these batteries were not publically available. If UNH seriously considers a battery energy storage project, they will most likely have to pay for a feasibility analysis of the project. Some companies have already expressed interest in this project but couldn't provide further information including Lockheed Martin and UniEnergy Technologies.

How it Works

The Chemistry

Batteries store and release energy through chemical reactions. Batteries contain two electrodes, an anode and a cathode, and an electrolyte in between the two electrodes. An oxidation reaction, which loses electrons, always occurs at the anode. A reduction reaction, which gains electrons, always occurs at the cathode. These terms are used only to describe the type of reaction that occurs at each electrode and the positive or negative charge of the electrode. [18] In rechargeable energy storage batteries, the electrodes comprise of two different reversible reactions. The reactions must be reversible to allow for charging and discharging. For example, in a simple cell, the following reversible reactions would occur at each electrode:

$$Zn \leftrightarrow Zn^{2+} + 2e^-$$
$$Cu^{2+} + 2e^- \leftrightarrow Cu$$

The direction of the chemical reactions switch depending on whether or not the battery is being charged or discharged. To charge the battery, the cell acts as an electrolytic cell. The reactions within the electrolytic cells are not spontaneous, meaning they will not occur on their own. Therefore, a power source is required to ignite these reactions. Excess electricity to be stored is used as the power source. The electricity spurs the anode to react and lose electrons. The electrons travel through the electrolyte and react with the cathode (Figure 10). The battery becomes fully stored when the electrodes have completely reacted. Now, the excess electricity is stored as chemical energy.

When electricity is needed to provide the load, the battery is discharged. Now, the cell acts as a galvanic cell. The reactions within the galvanic cell are spontaneous and require no electricity to start the reaction. The electrodes begin to react and gain or lose electrons but instead of flowing through the electrolyte, the electrons travel through the wire connecting the positive and negative electrodes, creating electricity. Therefore, as the electrodes react spontaneously, the chemical energy is converted into electrical energy and heat. [19]

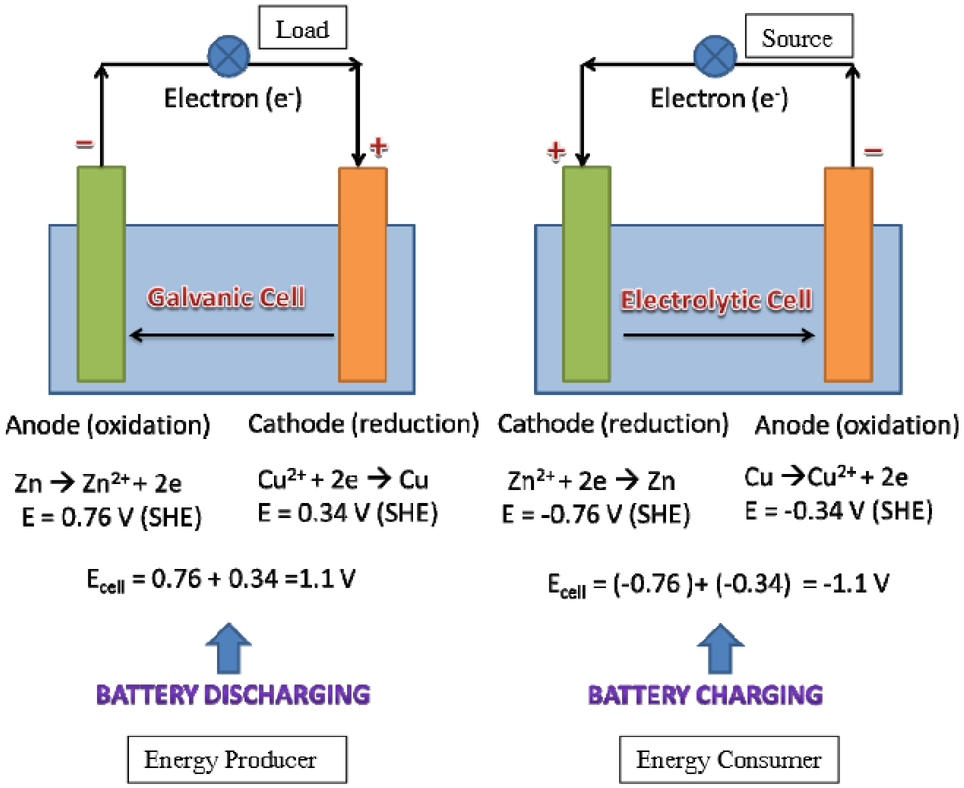


Figure 10. The Chemical Reactions to Charge and Discharge A Simple Cell. The battery acts as an electrolytic cell to charge the battery. A power source supplies electricity, allowing the non-spontaneous reactions to react and store the electrical energy as chemical energy. When the battery is discharged, the cell acts as a galvanic cell. The reactions react spontaneously without a power source. Electrons from the reactions travel through a wire connecting the two electrodes, converting the chemical energy into electrical energy to provide the load. [19]

In more complex energy storage devices, such as lithium ion, lead acid, and nickel hydride batteries, the same basic concepts occur but with different reversible reactions. For example, in a lithium ion battery the electrodes comprise of carbon or silicon, and a lithium-metal oxide. The following reactions are one example of a lithium ion battery with electrodes made of carbon and a lithium-doped cobalt oxide:

$$CoO_2 + Li^+ + e^- \leftrightarrow LiCoO_2$$
$$LiC_6 \leftrightarrow C_6 + Li^+ + e^-$$

The material of the electrodes and electrolyte changes the characteristics of each battery such as depth of discharge, safety rating, cycle life, energy density, efficiency, and most importantly price. Different types of batteries should be evaluated based on these characteristics to determine the most suitable battery for UNH.

What do they look like?

Most energy storage batteries are stored in large shipping containers. The individual battery cells are assembled into a module which is surrounded by a protective circuit and a management system that monitors the status of the batteries. [20] Several modules are packed into the shipping container to form the entire battery. Control systems are also located in the container to manage cooling and other safety features. These containers are designed to withstand the elements in all outdoor climates. [21]

Most batteries are installed outdoors adjacent to the energy source, e.g. a solar array, wind turbine, or a cogeneration facility.

What Services Can Batteries Provide?

The Rocky Mountain Institute determined that batteries can provide thirteen fundamental services to three major stakeholder groups when deployed behind the meter. Each service generally provides services and benefits to one of the three stakeholders: customers, utilities, or independent system operators/regional transmission organizations (ISO/RTOs). Customers could experience services such as time-of-use bill management, increased PV self-consumption, demand charge reduction and backup power. Utilities receive services such as resource adequacy, distribution deferral, transmission congestion relief, and transmission deferral. Lastly, ISO and RTO's receive services such as energy arbitrage, frequency regulation, spin/non-spin reserves, voltage support, and black start from battery energy storage. [22] The ability to provide multiple of these services increases the value and benefits of a battery storage project.

The University of New Hampshire's unique energy system can be described by a combination of the characteristics of these three stakeholder groups. The University purchases electricity from the utility, making it a customer, but also provides electricity to the campus using the cogeneration plant, which is a characteristic of an independent system operator (ISO) and utility. Therefore, the University would be able to harness several of these services, to increase the value of an energy storage battery on campus.

Customer Services

In particular, the customer services such as demand charge reduction, increased PV self-consumption, and backup power would be useful for the University. Currently, the demand charge reduction would be the most important service for the University. The demand charge is a large portion of the electricity bill throughout the entire year. Even during the winter months when electricity consumption is low, the demand charge is based upon the highest consumption periods during the summer. By reducing the demand charge in the summer, the electricity bill will decrease all year long.

Backup power services provided by a battery would be beneficial to UNH. Throughout the year, there are power outages throughout campus. In the event of a cogeneration plant failure or a grid failure, the battery could provide backup power for academic buildings and residence halls until power was restored. [22]

In the future, a battery could increase PV self-consumption. Currently, there is very little solar energy on campus. Adding an energy storage battery device could maximize the financial benefit of solar PV. With the ability to store variable energy sources, such as solar energy, an important obstacle of solar installations could be overcome.

A battery at UNH would not provide the time-of-use (TOU) bill management service. The University buys most of its power during the peak periods of the day when the cogeneration plant cannot produce the entire electrical load. Therefore, it would be more expensive for the University to follow TOU rates because electricity prices are highest at the peak periods of the day. A battery could potentially allow the University to convert to TOU rates, but the savings would still be minimal. The inability to harness this service is detrimental to the project, because this service is one of the most valuable and cost effective benefits for energy storage projects.

Utility Services

Out of the four services energy storage can provide a utility stakeholder, resource adequacy is the only service applicable to UNH. Instead of investing in new natural gas combustion turbines at the cogeneration plant to increase generation requirements during peak electricity-consumption hours, energy storage could be purchased to provide the generation capacity. [22] An energy storage device could minimize the risk of overinvesting in natural gas and processed landfill gas. If natural gas prices skyrocket or if the processed landfill gas becomes tainted, the cogeneration plant could become very expensive or inactive. However, an energy storage device would still function in these events and could be utilized to provide the electrical load in a different manner.

The other utility services, distribution deferral, transmission congestion relief, and transmission deferral, only apply to larger scale utilities unlike the University of New Hampshire.

ISO/RTO's Services

The operation of the cogeneration plant would benefit from the spin/non-spin reserve, voltage support, and black start services a battery could provide. The voltage support services would ensure the cogeneration plant was distributing energy most efficiently during normal operation. In the instance of an outage or cogeneration plant failure, the spin/non-spin reserve and black start services could improve the resiliency of the cogeneration plant.

Services at UNH

Energy storage generates the most value when multiple services are provided by the energy storage device. [22] At the University of New Hampshire, electrochemical storage could be installed in collaboration with the existing cogeneration plant to harness services from all three stakeholder groups. Overall, a battery on campus will provide demand charge reduction, electricity consumption reduction, a future increase in PV self-consumption, backup power, resource adequacy, spin/non-spin reserve, voltage support and black start services. Specifically, the demand charge and electricity consumption reduction services will be analyzed in this feasibility report because they will yield the most monetary savings.

UNH Electricity Demand

The daily and hourly profiles of the electricity usage of the campus were analyzed to determine the electricity trends at UNH (Appendix D: UNH Electricity Load Profiles). Overall, the cogeneration produces 85% of the annual campus's electrical needs. The electricity that UNH produces onsite is much less expensive than the electricity that it purchases from the local utility, Eversource. Most days, the electricity demand exceeds the 7800 kW capacity of the cogeneration plant during the day, forcing the University to buy power. During the night, the cogeneration plant experiences spare capacity as electricity demands decrease. Therefore, electricity purchase trends were analyzed closely to determine how a battery could increase electricity savings by reducing more expensive purchases from the utility and generating more of UNH's electricity from the cogeneration plant.

Daily Load Profile

The campus experiences noticeable decreases in electricity requirements during weekends and even more significant dips during holidays and school breaks. During the weekday the university purchases on average about 11,000 kWh each day whereas the university purchases almost no electricity during the weekends (Figure 11). On weekends students are not in academic buildings and sometimes do not even stay on campus. Students at UNH tend to go on weekend excursions to the Seacoast area, the White Mountains, or back to their families at home. With less students on campus during the day, in both academic and residential buildings, there is a noticeable decrease in electricity usage.

Similarly, when the campus closes for holidays such as Thanksgiving, Christmas, and New Year's, the campus electricity usage decreases significantly. During these holidays the campus closes almost all of its buildings except one dining hall and a few dorm buildings. Most of the student and faculty population return home, leaving campus empty and with little need to purchase electricity. Even during holidays when campus does not officially close, such as Easter weekend, the campus experiences a similar dip in electricity needs. During school breaks such as spring break and winter break students are sent home and the campus requires limited operation, the electricity demand curve decreases significantly.

Ideally, electrochemical storage would be able to take advantage of these dips in electricity usage. The battery would operate weekly to store excess electricity during the weekends and then discharge the electricity throughout the weekdays. Currently, the cogeneration plant serves the campus demand and ramps up and down to match the campus electric load. For example, the cogeneration plant ramps down and experiences excess capacity on the weekends when the campus electricity demand decreases. A smaller electrical load allows the cogeneration plant to supply the entire campus load without purchasing electricity (Figure 11). With energy storage, the turbine at the cogeneration plant would be base loaded and batteries would be dispatched rather than importing electricity when needed. The turbine would always operate at maximum capacity instead of operating to match campus needs. On the weekends any excess electricity would be stored in the battery. During the week, the battery would discharge, minimizing the need to purchase electricity. During the holidays and school breaks, a similar processed could be carried out. Energy would be stored while students and faculty were away and then deployed when they returned to campus.

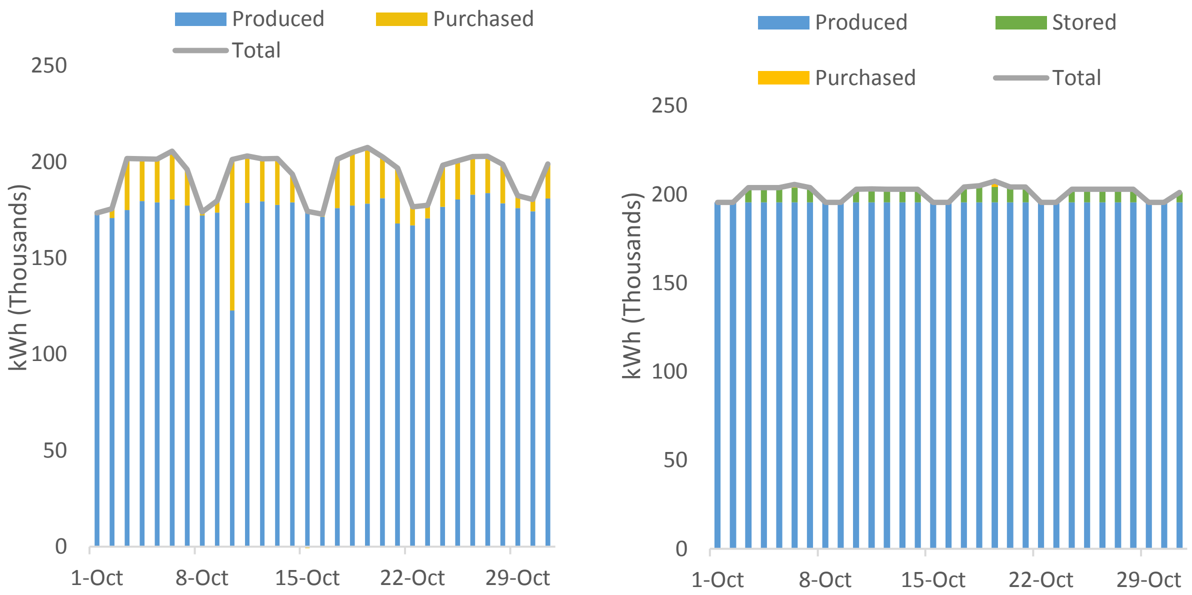


Figure 11. The Daily Electricity Load Profile of October 2016 with and without Battery Storage. Without battery storage there are obvious peaks and dips in the demand curve. During the weekdays, about 40,000 kWh of electricity is purchased each day to satisfy the entire electricity demand on campus. During the weekends, the cogeneration plant can provide the entire load. By base loading the cogeneration plant and storing electricity in the battery, the stored electricity could be discharged throughout the week, flattening the demand curve. This operation would minimize the amount of electricity purchased throughout the week.

However, the current state of battery technology does not allow for such long term and large scale operation as depicted above. When battery technology reaches this point, this operation would efficiently flatten the demand curve and take advantage of the decrease in electricity demand during weekends and holidays.

Hourly Load Profile

Overall, the campus is purchasing the most power during the school day when classes are in session and the operation of campus is in full swing. Campus is fully active from about 9 AM to 6 PM when students are in class, going to dining halls, studying in the library and faculty and staff are in their offices and laboratories. The daily peak cannot be shaved entirely because battery technology does not support a battery of this magnitude yet. Also, there is not enough spare capacity at the cogeneration plant to fully charge a battery of this size. Therefore, a closer look at the hourly load profile was required to determine what size of battery should be installed and how it should be operated.

The average load profile for the entire year suggests that the peak hours for campus are about 12 PM to 6 PM each month (Figure 12). There are large dips in power purchases late in the night and early in the morning. Once students and faculty arrive on campus at around 7:30 AM, the electricity demand begins to exceed the 7800 kW capacity of the cogeneration plant. Now the cogeneration plant cannot provide the entire campus load and must purchase electricity from the utility. When most faculty leave and most classes end around 5 PM, the electricity demand and therefore purchase of electricity begin to decline. When all buildings are closed, including the library and the Memorial Union Building (MUB) which are open until 2 AM and 12 AM on most week nights, the campus demand drops near or below 7800 kW. The cogeneration plant can supply this load without purchasing electricity from the utility.

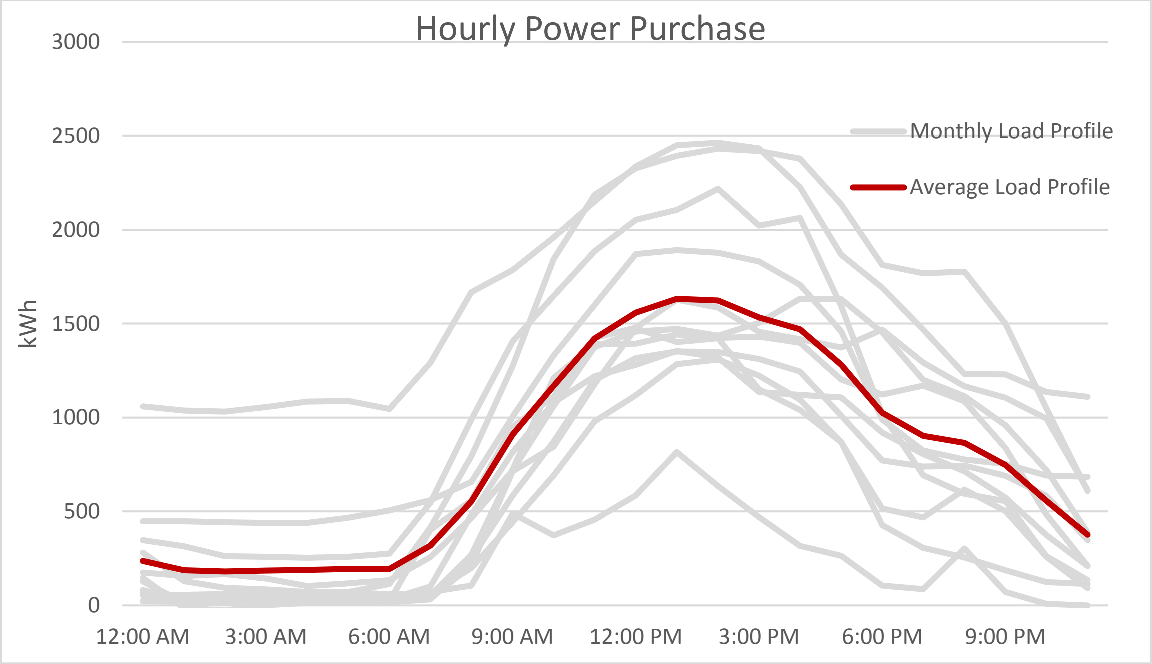


Figure 12. The Hourly Load Profile of the UNH Durham Campus. The average hourly load for the entire year peaks from the hours of 12 PM to 6 PM. Other months slightly extend this range and peak between 10 AM and 7 PM and 9 AM and 8 PM. These extended ranges typically occur in the summer months of July, August, and September. When campus demand exceeds the 7800 kW capacity of the turbine at the CHP the campus must purchase electricity from the utility.

The range of peak hours extends slightly during the hotter months. Because of the intense heat of the summer the buildings must be cooled creating larger demands for electricity over a longer period of time. In September, the peak hours range from about 11 AM to 8 PM. Similarly, in July and August the peak hours range from 10 AM to 7 PM.

Designing the Battery

The analysis of the electricity trends at UNH was compared to the services a battery could provide to determine the size and operation of the battery. The ideal material for the battery was not determined.

Sizing the Battery

Over the entire eight hour peak period, UNH purchases on average 11,685 kWh, about 12 MWh, per day. In order for a battery to discharge this amount of energy over the eight hour peak period, the power rating of the battery would need to be 1.5 MW. The ratio of energy capacity (kWh) to power rating (kW) determines the length of time the battery can discharge. Most batteries can discharge a limited amount of energy over the course of 30 minutes to eight hours. Current battery technology does not allow for a singular 12 MWh / 1.5 MW battery. Only an array of smaller batteries would be able to provide this capacity.

An array of batteries was considered during the analysis but the cogeneration plant would not have enough spare capacity in the off-peak loads to charge the entire array. The array would most likely have to be charged with a combination of the cogeneration plant and electricity from the utility. Since the University of New Hampshire does not experience time-of-use (TOU) rates, purchasing electricity to charge the battery would decrease the value of a battery project.

A singular, smaller battery was considered. The University of Massachusetts Amherst is currently considering a 4 MWh / 1 MW battery installation from Tesla. Out of all of the battery storage projects on college campuses nationwide, the UMass case study resembled UNH's electric load the closest. In addition, a battery of this size was available at several different energy storage companies such as Lockheed Martin, LG Chem, GE Electric, and EOS and could contribute information to aid the feasibility analysis of a battery. There was limited public information available for larger projects without purchasing a feasibility analysis from an energy storage company. Therefore, this size was used as basis for a battery energy storage project at the University of New Hampshire.

Discharge and Charge Cycles

A 4 MWh / 1 MW battery could discharge 800 kWh each hour in a 4 hour discharging period to deploy the electricity quickly. Due to an assumed efficiency of 80%, the battery could be charged 800 kWh each hour in a 5 hour charging period. Alternatively, the battery could charge and discharge less kWh over a longer period of time. There are countless options to operate the battery. Further analysis can be completed to determine the optimal charge and discharge cycles. This feasibility analysis examined the fastest charge and discharge cycles to reduce the peak four hours on the demand curve. Compared to the average hourly electricity load, these discharging and charging cycles could reduce a significant amount of electricity purchased.

The battery should be charged during the five consecutive lowest demand hours during the day. Historical data can be used to determine which hours require the most and least electricity for each month. During periods of low electricity demand, the cogeneration plant would have the flexibility and capacity to increase electricity production to charge the battery.

The battery should be discharged during the four peak hours of the day to minimize the amount of electricity purchased. Typically the peak hours of the day will be when campus demand exceeds the capacity of the cogeneration plant and requires the most electricity to be imported. Throughout the year, most months have peak periods during 12 PM to 4 PM. In September these hours change to 1 PM to 5 PM. The operation of the battery should be altered to serve each individual month's hourly peaks. During the four peak hours, the battery will discharge its electricity to satisfy the electricity load, reduce the amount of electricity purchased from the utility, and flatten the demand curve.

Economic Analysis

The economic analysis was conducted based on the EOS Aurora 1000 | 4000 Grid-Scale Energy Storage Device. This battery is a DC battery system designed to meet grid-scale needs in the energy storage market. It has 4 hours of discharge capability at 100% discharge and 75% efficiency. At this efficiency it will take about 5 hours to charge the battery. The Aurora is projected to withstand 5,000 cycles for a 15-year lifespan. It is advertised as a non-flammable aqueous electrolyte with no flashpoint, and is non-hazardous and non-corrosive when shipped. [21]

Figure 13. The EOS Aurora Battery. [21]

Costs

Capital Costs

According to the EOS Aurora Cost Calculator, a 4 MWh/1MW battery would cost $848,000 if shipped in the year 2017. This cost includes the DC System Price along with the Baseplate price. The price reflects the full DC system including the batteries mounted and wire, the Energy Stack enclosure, and a battery management system (BMS), but does not include other amenities such as aesthetic energy stack skins, the PCS, EPC, or shipping estimates. [23]

The price of the battery will decrease in the future. The EOS cost calculator predicts the price of the battery and amenities will be $760,000 in 2018, $712,000 in 2019, $672,000 in 2020, $632,000 in 2021, and $592,000 in 2022. [23] The University should consider waiting to purchase a battery since the capital cost of the battery is going to decrease in the near future.

Fuel Costs

If the battery was charged during the off-peak hours by the cogeneration plant, more fuel will be required to meet this increased load. Each day the battery would be charged to capacity, increasing the load by 800 kWh each hour, for five hours, each day of the year. Compared to normal operation of the cogeneration plant, the price of fuel to create electricity from the turbine would only increase by about $29,000 per year (Table 12).

Table 12. Fuel Costs With and Without a Battery

Operation	Cost / Year
Normal	$1,306,457.01
With Battery	$1,335,336.65
Cost Increase	**$28,879.64**

Other Costs

Throughout this project, it was very difficult to obtain exact prices of batteries and information about other associated costs. Companies had a tendency to give general statements of prices per kWh which did not include costs such as installation, maintenance, operation, disposal, and other costs that may be involved. Many companies keep these costs private and report them in a feasibility analysis of their own. Energy storage companies offer to conduct a feasibility analysis for customers at an unknown cost. Therefore, more research should be conducted on the true price of a battery If UNH decides to seriously considering a battery project on campus.

When further examining energy storage options, the operational and maintenance costs should be considered in particular. The University should determine what controls and man-power are required to safely operate the batteries in addition to any other maintenance costs. Seasonal maintenance such as snow removal, may require extra costs. During the winter, if snow builds up on the container snow could cover the cooling fans and potentially cause overheating and dangerous malfunctions of the battery. Frequent part replacements could also contribute to the cost of maintaining a battery. At the end of the battery's life it will need to be disposed of properly. Due to the hazardous materials in the electrodes and electrolytes, specific waste removal and recycling procedures will need to be carried out. These unknown operation costs could increase the cost of the battery significantly.

Benefits

Electricity Savings

The addition of a battery could create energy savings by reducing the amount of electricity purchased from the local utility. Annually, the cost of natural gas and processed landfill gas is about $0.02 per kWh whereas the cost of imported electricity is about $0.11 per kWh. Since the cost of natural gas and processed landfill gas is lower than the cost of electricity, it would be cheaper to charge the battery with the cogeneration plant than by purchasing electricity. By charging the battery with cheaper energy from the cogeneration plant and deploying it later in the day, UNH avoids purchasing more expensive energy from Eversource. Based off of electricity prices from 2017, the annual cost of electricity purchased in 2016 without a battery compared to installing a battery would reduce the electricity bill by $117,888.25 each year.

Although the cogeneration plant would consume more natural gas and processed landfill gas to charge the battery, the cost savings from electricity purchases would offset the cost of fuel (Table 13). If the cogeneration plant charged the battery 800 kW per hour, for five hours each day, the annual fuel load would only increase by 1,000,000 kWh and cost $28,879.64. Comparatively, by discharging this electricity over the four peak hours every day, the University would reduce its electricity purchase by 1,000,000 kWh each year and save $117,888.25. Including the cost of fuel, operating the battery in this manner would save the University about $90,000 each year in electricity savings.

Table 13. Fuel Load and Purchased Electricity Load with and without a Battery

	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Normal Load	Purchased Electricity (10^6 kWh)	0.2	0.6	0.5	0.5	1.4	0.4	0.7	0.6	1.0	0.5	0.5	0.4	**7.3**
	Fuel Load (10^6 kWh)	5.4	5.1	5.5	5.1	3.5	4.6	5.1	5.1	5.2	5.4	5.3	5.3	**61**
Battery Load	Purchased Electricity (10^6 kWh)	0.1	0.6	0.4	0.4	1.3	0.5	0.6	0.5	0.9	0.4	0.4	0.3	**6.3**
	Fuel Load (10^6 kWh)	5.6	5.3	5.6	4.4	4.3	4.6	5.2	5.4	5.4	5.5	5.3	5.4	**62**

Demand Charge Mitigation

The UNH demand charge is determined by the largest purchase of electricity in a half hour over a 12 month cycle. By discharging the battery during the peak hours of the day, the demand charge will decrease. Instead of purchasing power from the utility to satisfy the 15% of electricity needs the cogeneration plant cannot produce, the battery can provide the remaining load. The battery would discharge during the four peak hours of the day, shaving the electricity purchases. As a result, the maximum electricity purchased in one half hour will also reduce, and therefore reduce the demand charge. In 2016, the maximum electricity purchased in one half hour was 2515.7 kW (Table 14). With a battery discharging 800 kWh per hour (400 kWh per half hour) during the peak hours, the maximum electricity purchased from the utility during a half hour would only be 1531.2 kW. By reducing the demand by almost half, the University would save $279,254.19 every year in demand charge reductions.

Table 14. Demand Charge Savings

Highest Demand (2016)	2515.7 kW
Demand with Battery	1531.2 kW
Cost Savings	$279,254.19

Emission Reductions

There are 3 scopes of emissions, Scope 1, Scope 2, and Scope 3. Scope 1 emissions are emissions generated directly from the University such as stationary combustion of natural gas and processed landfill gas, mobile combustion of fossil fuels from transportation services, and fugitive emissions from natural gas distribution and refrigerant systems. Scope 2 emissions are indirect emissions from the consumption of electricity, steam and other sources of energy such as chilled water. [10] In this analysis, the scope 2 emissions from electricity consumption were analyzed. Scope 3 emissions are other indirect sources of greenhouse gas emissions that result from the operations of the University by are not directly owned or controlled by the University. For example, commuting, business travel, and other sources contribute to the Scope 3 emissions. [10]

Although charging the battery will require more fuel and therefore increase scope 1 emissions, the battery will reduce the consumption of electricity from the utility and reduce scope 2 emissions. Only the consumption of natural gas is considered a scope 1 emission. The consumption of the processed landfill gas does not contribute to the emissions from UNH because the emissions would have occurred whether or not they were burned at the cogeneration plant. Either way, the landfill would have emitted the methane into the atmosphere. Instead, UNH harnesses the methane as an energy source. The landfill is responsible for accounting these emissions from the methane gas in their carbon footprint because the landfill produces the methane. Therefore, the processed landfill gas is neither a scope 1 nor scope 3 greenhouse gas emission produced by UNH.

Using the Campus Carbon Calculator Version 9, created by the UNH Sustainability Institute, the emissions were calculated and compared. By determining the increase in MMBTU of natural gas and how many kWh of electricity was reduced, the total emission reduction was calculated. Since the processed landfill gas emissions are not considered as an emission produced by UNH, the scope 1 emissions only increase by about 3 metric tons of CO_2 per year due to the increase in natural gas to charge the battery. The reduction in electricity purchases decreases the scope 2 emissions by about 547.8 metric tons of CO_2 each year. [11] Therefore, installing a battery would reduce the annual net greenhouse gas emissions by about 545 metric tons of CO_2 and would help UNH reach its WildCAP goal of 50% reduction of total greenhouse gas emissions by 2020.

Microgrid & Resiliency

By adding a battery to the cogeneration plant, the campus would be one step closer to becoming a microgrid. A microgrid is a local electrical system that combines thermal and electrical loads along with thermal and electrical storage to provide energy needs in parallel or in isolation from the grid. Microgrids provide the choice to produce cleaner energy, enhances local resiliency and responsiveness, and improves the operation and stability of the larger electrical grid. [9] Adding energy storage allows the campus to store more of the energy it already produces, relying less on the utility and the grid and focusing on the efficient, low-cost energy that is produced on UNH campus. In the event of a grid outage or a severe storm, the cogeneration plant could continue to provide 85% of the campus' power. With a battery, the co-gen could provide most if not all of the power required during the outage and maintain campus' needs without a flicker. Becoming a micro-grid not only allows UNH to produce cleaner and cheaper power, but increases campus resiliency and decreases dependency on the grid.

Other Benefits

Renewable energy technologies could be installed more easily with a battery at the University of New Hampshire. With the ability to store variable energy techniques, renewable energy such as wind or solar could provide a portion of the electricity load. For example, wind energy could be harnessed during the night when it is abundant and stored in the battery for later use during the peak hours of the day. A battery not only saves the University money now, but introduces opportunities to save more money and be more sustainable in the future with renewable energy technology.

A battery could also increase the efficiency of the cogeneration plant. During the winter the heating load often exceeds the electricity load. As a result, the turbine produces an excess of electricity to generate enough steam to supply the campus heating load. If UNH generates too much electricity and sends it back to the utility, they could be charged a fine. To avoid this issue, the battery could be used to store the extra electricity and deploy it later.

Payback Period

Although a payback period was calculated, it should be referenced with caution since many of the costs of a battery are missing from the cost benefit analysis. These costs include operation and maintenance costs, installation costs, disposal costs and several others that could be associated with the purchase of a battery. According to the costs and benefits that were calculated, the payback period would occur at the beginning of year 3 (Figure 14).

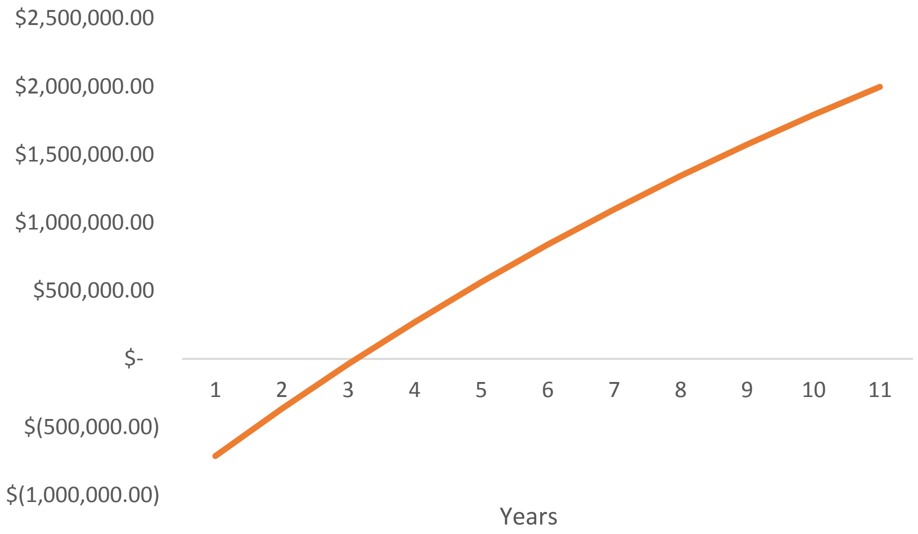


Figure 14. The Payback Period of a 4 MWh / 1 MW Battery Project. Considering the known costs and benefits, the project would pay back in year three. However, this projection should be referenced with caution as it does not include several costs such as operation and maintenance, installation, disposal, and other important costs.

Incentives

Eversource offers several incentives for energy efficiency projects. At first, these projects seemed ineligible for such rebates or incentives because they're main goal is to load shift electricity rather than reduce the overall amount of electricity used. However, after further review, both projects should be eligible because they reduce the amount of energy UNH requires from the utility. Under the Energy and Rewards Request for Proposal Program, offered by Eversource, a project must produce a minimum of 100,000 kWh per year and cost at least $150,000. [24] In order to reach the qualifications the project can be at different sites or be a combination of two separate projects occurring at the same time to reach to 100,000 kWh.

It is unclear whether the TES could provide such savings without a further feasibility study. A 4 MWh / 1 MW battery would be able to provide these savings. If the battery was operated as described, there would be a reduction of 974,050 kWh throughout the year. Since the project would be much more expensive than $150,000, the University of New Hampshire should apply for this program when considering a battery project (

Appendix E: Incentives from Eversource).

Eversource also offers a “New Equipment and Construction Program” which provides rebates for the purchase and installation of new energy efficiency technologies or custom projects where kWh reductions are available. [25] Both an electrochemical battery and the thermal energy storage would qualify for this incentive program because they reduce the amount of electricity purchased from the utility.

Although both of these projects technically qualify for these incentives, the utility may not consider them as true energy reduction technologies because they mostly shift the electricity usage to other sources of generation such as the UNH cogeneration plant. For example, a battery project would reduce the electricity purchased from the grid but the turbine at the cogeneration plant would produce the electricity to charge the battery instead. The amount of electricity would not decrease in the entire system. The electricity would be transferred from being purchased from the utility to being produced at the cogeneration plant. Although the qualifications may not match precisely, either project should apply for both programs because they reduce the amount of electricity purchased from the utility itself.

Recommendation

Energy Storage

After comparing several different types of energy storage technologies, the list was narrowed down to the installation of either a thermal energy storage tank or an electrochemical battery. Due to the complexity of the electricity savings at the Philbrook chilled water plant and the lack of information available about battery pricing, a partial economic analysis was completed (Table 15). Based off of the initial analysis, a chilled water TES tank would cost about \$2M to \$2.5M to construct, produce about \$80,000 of savings each year, and reduce about 163 metric tons of CO_2 per year. A TES tank would make use of the excess steam load from the cogeneration plant during the summer, increase campus climate resiliency, allow for future installations of renewable energy, and increase the chilled water capacity. The total cost of the battery could not be accurately estimated but it would produce \$380,000 of savings each year, and reduce 547 metric tons of CO_2 per year. The battery would bring UNH one step closer to being a micro-grid, increase campus resiliency, allow for future installations of renewable energy, and increase the steam capacity of the cogeneration plant.

Table 15. Cost Comparison of TES vs. a Battery

	Chilled Water Thermal Energy Storage Tank	Battery Storage
Capital Cost	\$1,498,037	\$832,000
Other Costs	\$502,000- \$752,000[1]	\$277,511+ [2]
Total Cost	**\$2,000,037 - \$2,250,037**	**?**
Electricity Savings	\$49,095.92[3]	\$117,888.25
Demand Charge Reduction	\$34,641.01	\$279,254.19
Emission Reduction	163 metric tons CO_2 / yr	547 metric tons CO_2 / yr
Benefits	Harness Excess Steam Load Climate Resiliency Future Renewable Energy	Microgrid & Resiliency Future Renewable Energy Increase Steam Capacity

	Increase Chilled Water Capacity	

[1] This cost consists of the construction cost of a mechanical engineering firm, RMF Engineering, the estimated geotechnical costs of construction, and an estimated cost for operation and maintenance.
[2] The installation cost, assumed to be 30% of the capital cost, and the cost of fuel to charge the battery.
[3] Includes the decrease in cost of purchased electricity and the cost to produce the steam used with the absorption chillers.

Reflecting on the results of the analysis, the battery seems to be the best option in terms of electricity savings. However, this feasibility analysis was unable to determine the total cost of the battery. The outlined costs in Table 15 only include the capital cost of a battery and could have missed several crucial savings that the chilled water tank can deliver. Instead of providing a highly inaccurate figure, the total cost was left for further investigation. The costs of operation, maintenance, installation, and disposal of a battery were excluded from the analysis because adequate information could not be acquired. However, other sources have compared different storage options and have found that batteries are typically the most expensive option (Table 16). The highest prices recorded for a chilled water thermal energy storage tank, $200 per kWh, is much less than even the lowest price available for traditional and advanced batteries, $500 per kWh, and $350 per kWh.

Table 16. Comparing Batteries and Chilled Water Costs [3]

Typical Characteristics	Traditional Batteries	Advanced Batteries	Chilled Water TES Tank
Maturity Status	Excellent	Developing	**Excellent**
Safety Issues	Low	Yes	**Low**
Flexibility of Sizing	Very High	Very High	**High**
Ease of Permitting	Simple	Simple	**Simple**
Expected Lifetime (years)	7-15	7-10	**40+**
Round-trip Efficiency (%)	80-90	85-90	**Near 100**
Unit Capital Cost ($/kWh)			
Low	500	350	**80**
High	750	500	**200**

Besides the price of each technology, the two projects are very similar in efficiency, flexibility of sizing, and safety. However, the chilled water TES tank has a much longer expected lifetime than the battery storage options. The chilled water tank will last at least 4 times longer than the battery and for a lower capital cost. [3] Although the annual savings in electricity and demand charges per year are not as significant as the savings from a battery, the benefits over a 40 year lifetime are much greater for the chilled water TES tank than the benefits over a 10 year lifetime of a battery. Although a battery can provide dramatic energy savings and other benefits, a battery does not bring as many benefits to the campus as a chilled water thermal energy storage tank. A chilled water tank brings long lasting electricity savings, along with a crucial increase in cooling capacity and climate resiliency for campus.

Due to the complexity of the Philbrook chilled water plant, its electricity savings were estimated based on the historical data of the CWP. Further investigation should be conducted to determine more detailed benefits of each project to confirm and expand on the benefits of a long lasting chilled water tank versus a battery.

The maturity of each technology is also a large factor in the final recommendation. Thermal energy storage has been around for much longer than electrochemical batteries. Several college campuses have installed thermal energy storage systems with the only complaint being they wish they had purchased more. Princeton University and Bucknell University have experienced great success and savings from their TES tanks, and had the confidence and dedication to the technology, that they advised the University of New Hampshire to install their own TES tank. In addition, DN Tanks, another contributor to this project, has been in business for 35 years and every tank they have ever constructed is still in service today.

In contrast, there are not many case studies to reference about battery installations at college campuses with a cogeneration plant. Most battery projects were installed in conjunction with solar or wind energy that was already installed on campus. UMass is currently considering a battery project which will utilize their cogeneration plant. This was the only college campus trying to combine a battery with a cogeneration plant. However, their battery will also be charged by solar power. The battery portion of the feasibility analysis was researched with hesitation as a battery project solely connected to a cogeneration plant on a college campus has not been completed yet. UNH can be more confident in the maturity and success of a future TES project than a battery project because of several successful installations and the maturity of the technology.

In addition, the lack of information available for battery projects at college campuses decreased the accuracy of the analysis for a potential battery installed at the University of New Hampshire. As previously mentioned, several costs of batteries were omitted from this feasibility analysis resulting in a general estimate of the price. Although electricity savings seemed large, Lockheed Martin was unsure of the success of a battery at UNH. After analyzing the electricity bill for UNH, an analytics team at Lockheed Martin, determined that demand charge mitigation may provide a business case for an energy storage project, but it would be thin. Richard Brody, Director of Sales and Marketing for Energy Storage at Lockheed Martin, does not see a strong case for energy storage in this application at UNH.

This feasibility analysis was able to confidently determine the cost of a TES tank at the University of New Hampshire. The final cost, about $2,000,000 to $2,500,000, includes the design and construction of the tank, mechanical and geotechnical companies, and operation and maintenance. This price will not change significantly because all of the prices have been accurately estimated and confirmed with DN Tanks. However, the battery project analyzed in this report contains a countless number of missing costs that will cause the price of a battery to skyrocket. Moving forward, UNH should further analyze each project in more detail, but with emphasis on a chilled water thermal energy storage tank project.

Energy Efficiency

Although the goal of this fellowship was to find energy storage solutions, controllers for electric water heaters were analyzed as a potential energy efficiency project. Since there are several individual water heaters on campus, they use a lot of electricity and could contribute to high demand charges. By decreasing their electricity use, the University could decrease their energy bill. In order to determine if individual controllers could make a significant difference in the electricity usage of campus, five or six controllers should be installed on campus and monitored for a year. After the trial, the electricity savings and software benefits should be analyzed. If the systems prove to increase energy efficiency and reduce costs, more controllers should be installed after the testing period. Aquanta, a company who sells individual hot water controllers, has offered to participate in a trial of their devices at the University of New Hampshire. During this period UNH would only have to pay for the cost of the controllers. The fleet dashboard software would be included for free as this could be a learning opportunity for both parties. This opportunity should be taken advantage of as it could provide future energy savings for the campus.

Acknowledgements

My work would not have been successful without all of the assistance I received during the duration of this project. At the Energy Office, my mentor, Adam Kohler, along with Dave Bowley, and Matt O'Keefe went beyond their job descriptions to contribute to the success of this project, but also to help me learn. I would like to thank them for expanding my knowledge about energy and utilities along with the specific operations here on UNH campus, including the solar wall on the roof of Kingsbury, the cogeneration plant, the eco-line at the Rochester Landfill, and the Philbrook chilled water plant. Their dedication to sustainability and to ensure a comfortable living, learning, and research environment for students and faculty drove the success of this fellowship and will continue to stimulate the future success of the project.

Being surrounded by the dedication and passion at the Sustainability Institute also contributed to the success of this project. Megan Carney, Jenn Andrews, and the Sustainability Fellow Cohort were always willing to help and their dedication to their work did not go unnoticed. I would like to thank the cohort for keeping spirits high throughout the entire summer despite the feelings of doubt that sustainability work can sometimes bring.

During my research of energy storage technologies, I encountered several experts in the field who were more than willing to help. Ted Borer, Energy Plant Manager at Princeton University, and James Knight, Director of Energy and Utilities at Bucknell University, gave in depth descriptions of their chilled water systems along with advice during the feasibility analysis of a chilled water TES tank at UNH. Cameron Wise, regional manager of TES and biofuels at DN Tanks, also provided great information and advice during this study. He graciously proposed a budgetary proposal to strengthen my final recommendation. UniEnergy Technologies and Lockheed Martin also provided helpful information to the feasibility analysis of electrochemical storage. Matt Carlson, CEO of Aquanta, provided supportive information and resources to the research of hot water controllers. He is looking forward to potentially working with UNH to perform a test run of his systems on the Durham campus.

References

[1] UNH Sustainability Institute, "Analyzing the Business Case for New Greenhouse Gas Reduction Strategies at the University of New Hampshire," January 2017. [Online]. Available: http://sustainableunh.unh.edu/sites/sustainableunh.unh.edu/files/media/2017_wildcapenergystorage_final_0.pdf. [Accessed 7 August 2017].

[2] Energy Storage Association, "Energy Storage Technologies," Energy Storage Association, 2017. [Online]. Available: http://energystorage.org/energy-storage/energy-storage-technologies. [Accessed 7 August 2017].

[3] J. S. Andrepont, "Energy Storage - A Need for the Grid (and for Microgrids); an Opportunity for District Energy," in *International District Energy Association (IDEA) Annual Conference*, Scottsdale, 2017.

[4] "How Thermal Energy Works," DN Tanks, [Online]. Available: http://www.dntanks.com/what-we-do/thermal-energy-storage/how-tes-works/. [Accessed 25 07 2017].

[5] "Summary of Electric Rates," Eversource, 01 07 2017. [Online]. Available: https://www.eversource.com/Content/docs/default-source/rates-tariffs/nh-electric-rates.pdf. [Accessed 08 07 2017].

[6] A. K. Wolfe, "Evaluating Chilled-Water Storage for District Heating," HPAC Engineering, May 2017. [Online]. Available: www.hpac.com. [Accessed 20 June 2017].

[7] RMF Engineering and RFS Engineering, "Energy Utilities Progress Meeting No. 4," RMF Engineering, Baltimore, 2017.

[8] RMF Engineering and RFS Engineering, "Energy Utilities Progress Meeting No. 3," RMF Engineering, Baltimore, 2017.

[9] International District Energy Association, "Microgrids," Enconverse Media, 2017. [Online]. Available: http://www.districtenergy.org/topics/microgrids. [Accessed 31 July 2017].

[10] S. Boles, "What are the differences between Scope 1, 2 and 3 greenhouse gas emissions?," iCompli Sustainability , 2017. [Online]. Available: http://www.icomplisustainability.com/index.php/ask-the-expert/ghg-management/item/63-what-are-the-differences-between-scope-1-2-and-3-greenhouse-gas-emissions/63-what-are-the-differences-between-scope-1-2-and-3-greenhouse-gas-emissions. [Accessed 14 August 2017].

[11] U. o. N. H. S. Institute, *Campus Carbon Calculator,* 2017.

[12] T. Borer, "Explaining General Concepts about Thermal Energy Storage," Princeton.

[13] M. A. L'Heureux and L. Maley, *Durham Projections,* Durham, 2017.

[14] University of New Hampshire, "Campus Master Plan 2012," University of New Hampshire, Durham, 2012.

[15] U.S. Energy Information Administration, "Electricity," 2017. [Online]. Available: https://www.eia.gov/electricity/. [Accessed 19 July 2017].

[16] Aquanta, "FAQs," Aquanta Inc, 2017. [Online]. Available: https://aquanta.io/. [Accessed 10 July 2017].

[17] H. K. Trabish, "Utilities in hot water: REalizing the benefits of grid-integrated water heaters," UtilityDIVE, 20 June 2017. [Online]. Available: http://www.utilitydive.com/news/utilities-in-hot-water-realizing-the-benefits-of-grid-integrated-water-hea/445241/. [Accessed 30 June 2017].

[18] C. Woodford, "Batteries," Explain That Stuff, 9 March 2017. [Online]. Available: http://www.explainthatstuff.com/batteries.html. [Accessed 15 August 2017].

[19] X. Teng, *Chapter 2: Basic Concepts,* Durham: University of New Hampshire, 2017.

[20] STEAG, "STEAG large-scale battery systems for a more reliable power supply," STEAG, 2017. [Online]. Available: http://www.steag-grossbatterie-system.com/en/index.html#. [Accessed 26 June 2017].

[21] EOS , "EOS Aurora," EOS Energy Storage, 2017. [Online]. Available: http://www.eosenergystorage.com/products/. [Accessed 5 July 2017].

[22] G. Fitzgerald, J. Mandel, J. Morris and H. Touati, "The Economics of Battery Energy Storage: How mutli-use, customer-sited batteries deliver the most services and value to customers and the grid," Rocky Mountain Institute, Boulder, 2015.

[23] EOS, "Cost Calculator," EOS Energy Storage, 2017. [Online]. Available: http://www.eosenergystorage.com/costcalculator/. [Accessed 6 July 2017].

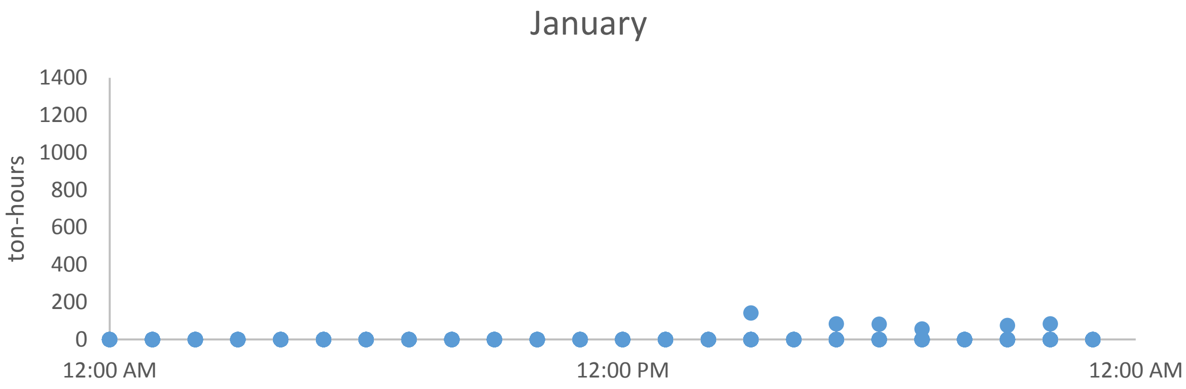
[24] Eversource, "Energy Reqards Request for Proposal (RFP) Program," Eversource, 2017. [Online]. Available: https://www.eversource.com/Content/nh/business/save-money-energy/programs-incentives/commercial-industrial-retrofit-program/energy-rewards-rfp-program. [Accessed 2 August 2017].

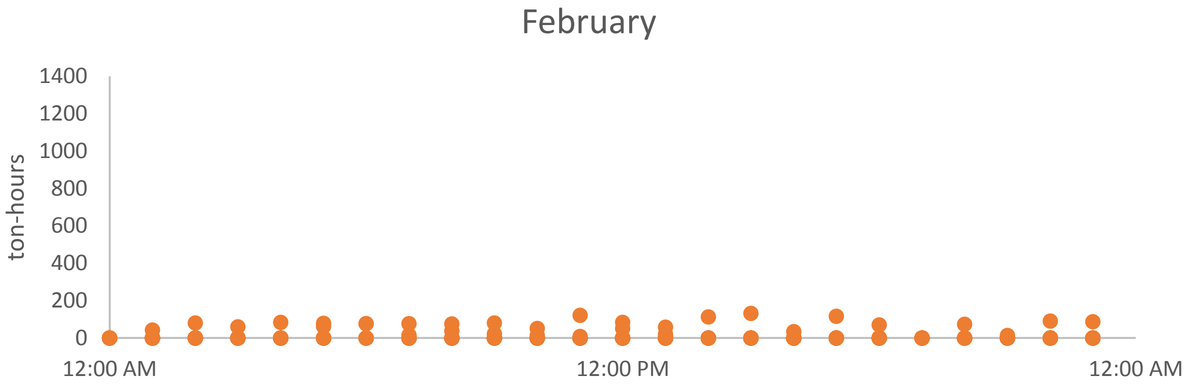
[25] Eversource, "New Equipment and Construction," Eversource, 2017. [Online]. Available: https://www.eversource.com/Content/nh/business/save-money-energy/programs-incentives/new-equipment-construction. [Accessed 2 August 2017].

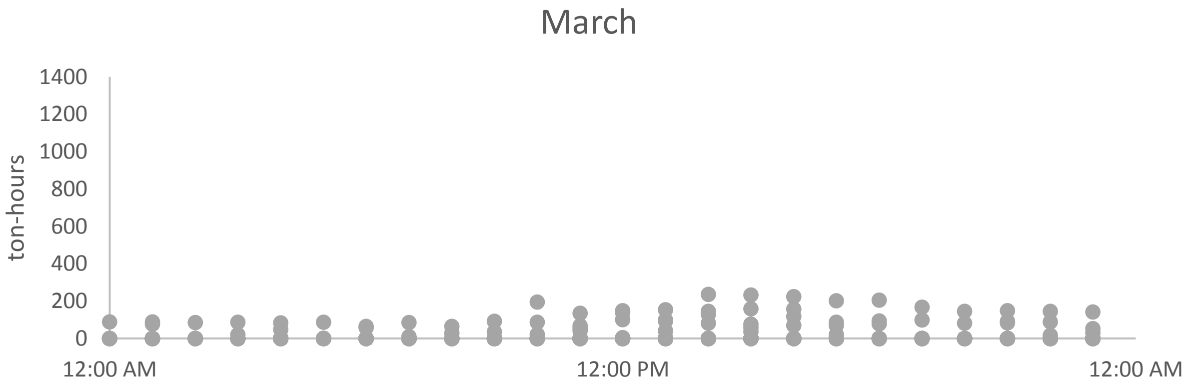
[26] B. C. Greene and D. M. Barrow, "Financing Energy Storage Projects: Assessing Risks - Part One," Renewable Energy World , 12 July 2017. [Online]. Available: http://www.renewableenergyworld.com/articles/2017/07/financing-energy-storage-projects-assessing-risks-part-one.html. [Accessed 1 August 2017].

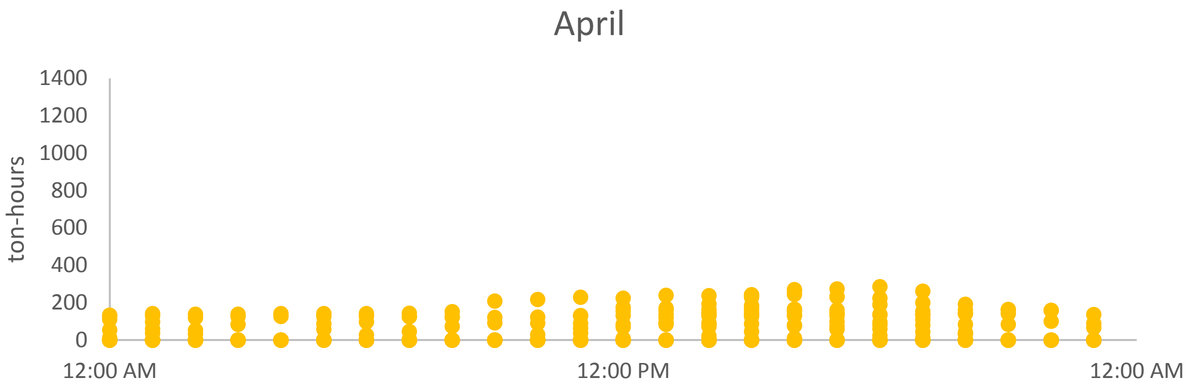
Appendix A: Chilled Water Hourly Load Profile of UNH

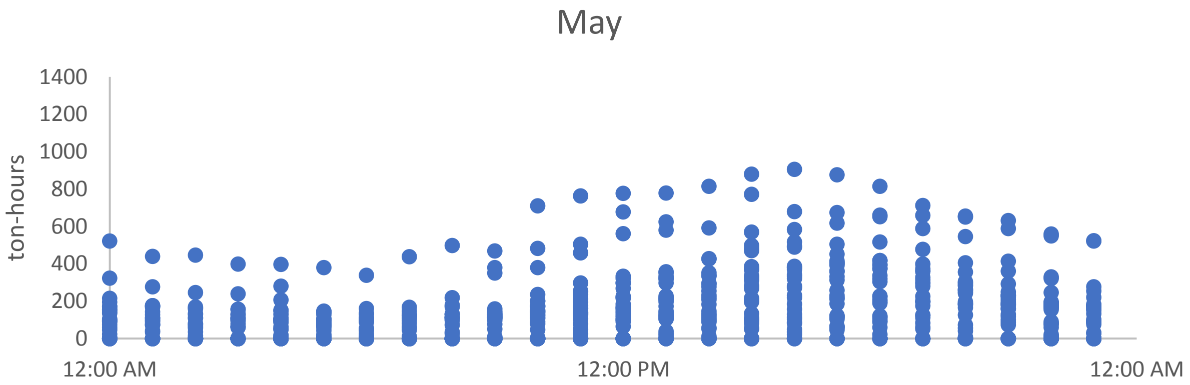
The hourly load profile of the chilled water usage at the Philbrook chilled water plant at the University of New Hampshire. During the heating season, the load profiles are flat with only a few dull peaks from 2 PM to 8 PM. During the cooling season, the load profiles show distinct peaks during the hottest periods of the day from 12 PM to 7 PM.

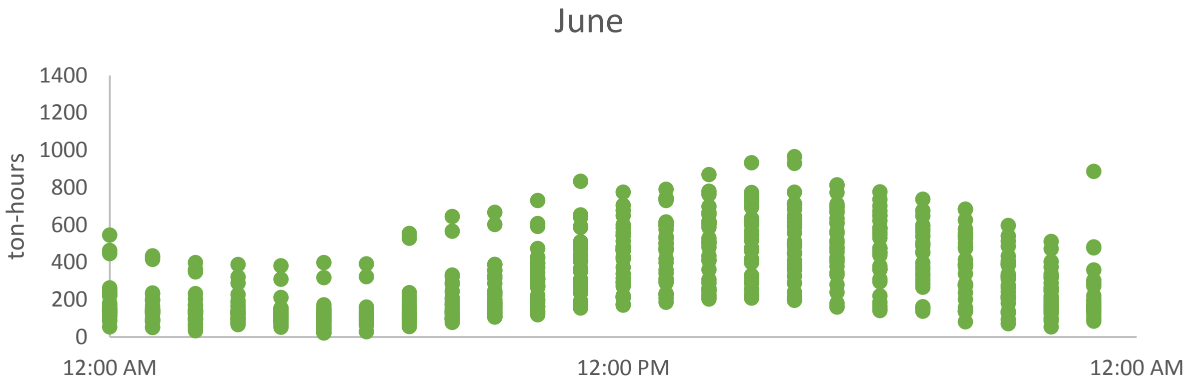


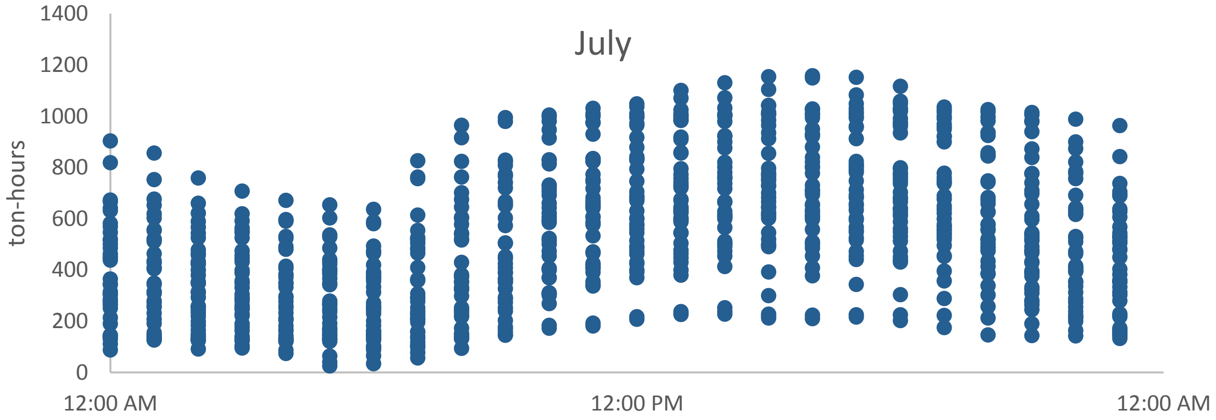


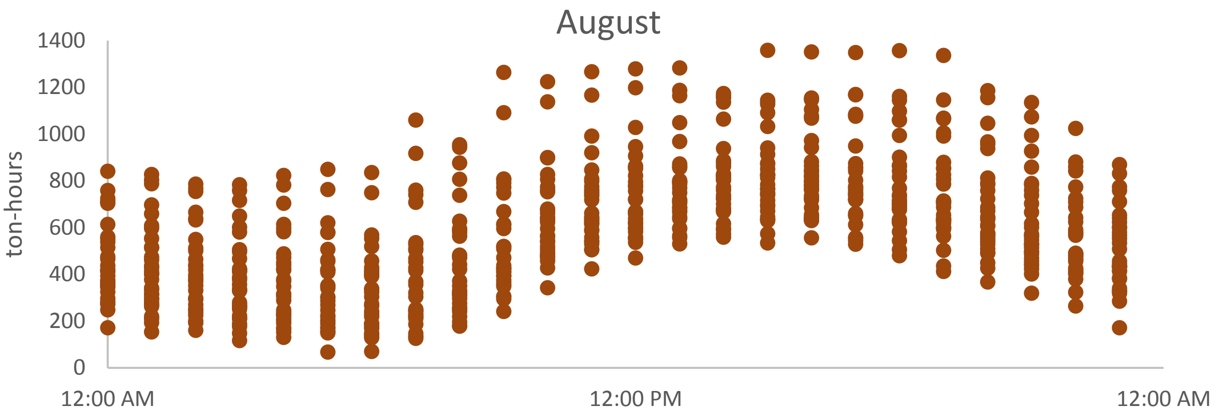


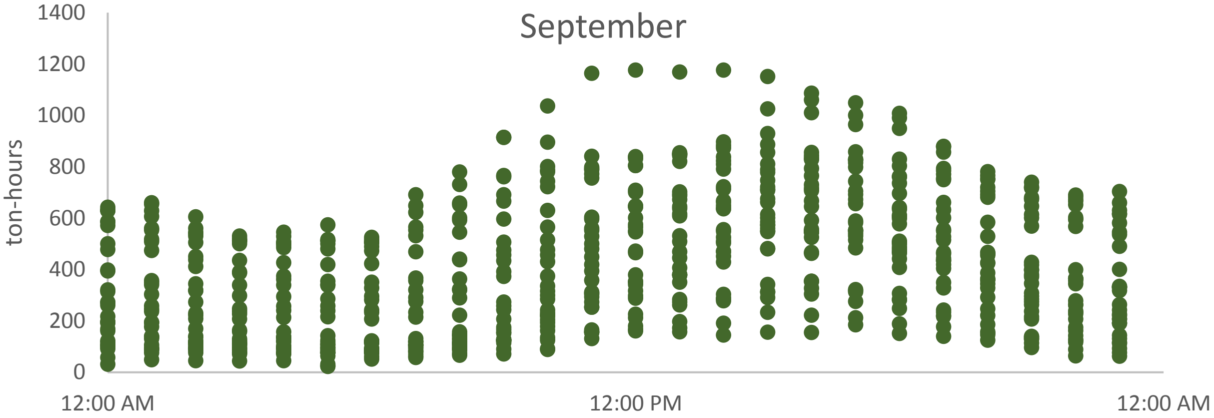

April
ton-hours
1400
1200
1000
800
600
400
200
0
12:00 AM
12:00 PM
12:00 AM

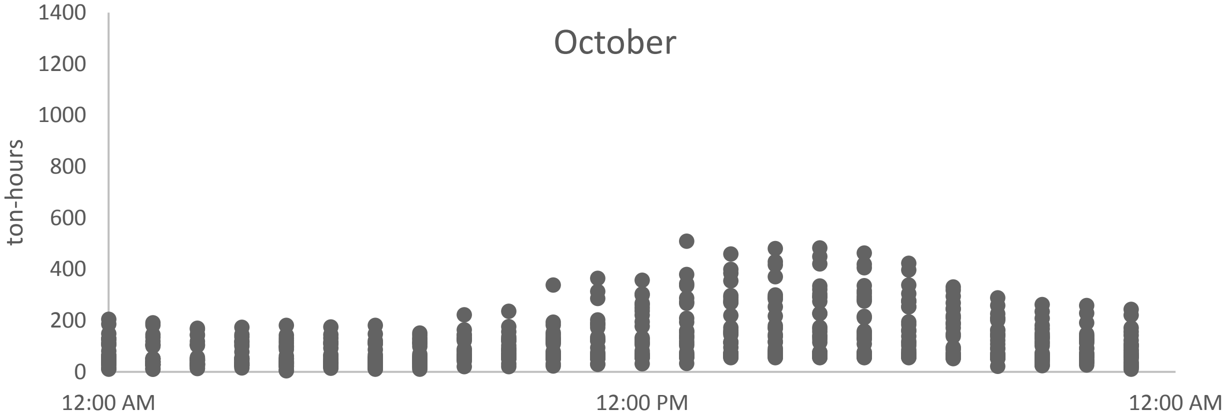

May
ton-hours
1400
1200
1000
800
600
400
200
0
12:00 AM
12:00 PM
12:00 AM

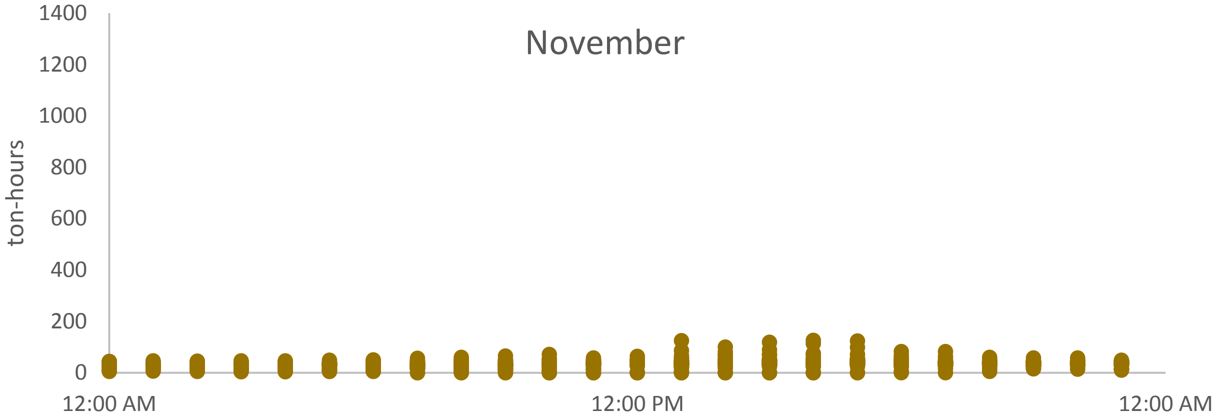

June
ton-hours
1400
1200
1000
800
600
400
200
0
12:00 AM
12:00 PM
12:00 AM

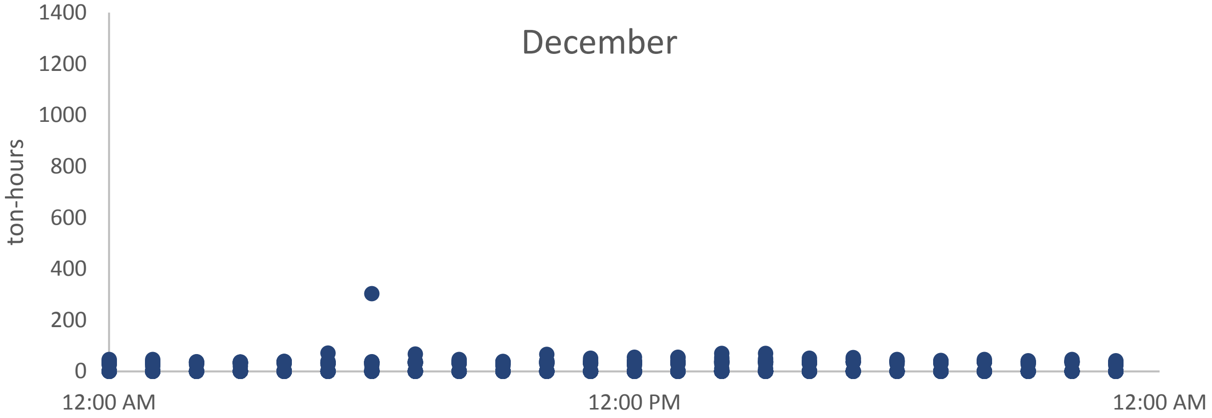

July
ton-hours
1400
1200
1000
800
600
400
200
0
12:00 AM
12:00 PM
12:00 AM


August
1400
1200
1000
800
600
400
200
0
ton-hours
12:00 AM
12:00 PM
12:00 AM


September
1400
1200
1000
800
600
400
200
0
ton-hours
12:00 AM
12:00 PM
12:00 AM


October
1400
1200
1000
800
600
400
200
0
ton-hours
12:00 AM
12:00 PM
12:00 AM


November
ton-hours
1400
1200
1000
800
600
400
200
0
12:00 AM
12:00 PM
12:00 AM


December
ton-hours
1400
1200
1000
800
600
400
200
0
12:00 AM
12:00 PM
12:00 AM

Appendix B: Chilled Water TES Electricity Savings

If the TES tank was to be discharged in 8 hours, the 8,180 ton-hour tank could discharge about 1023 tons per hour. Based off of the Philbrook CWP data from 2016, the average tons of chilled water required during the 8 peak hours in one day were found for each month. The TES tank would be able to provide the entire load during the 8 peak hours for the entire year.

The average tons of chilled water in one off-peak hour was determined for each month and multipled by the number of off-peak hours during the day to obtain the total chilled water tons during the off-peak period. Since the on-peak hours differed between each month, the off-peak hours also changed month to month. Instead of trying to determine the exact hours for each day of each month, the off-peak hours were estimated to avoid double counting within the data analysis.

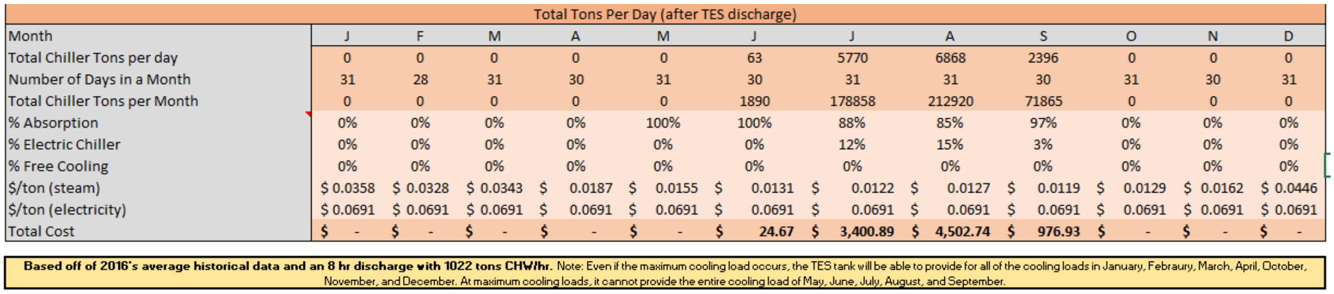
Tank Parameters	
Capacity	8180
Discharge	8
Tons/Hr	1022.5

Average Chiller Tons during PEAK HOURS												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Number of Peak Hours	8	8	8	8	8	8	8	8	8	8	8	8
Avg. Total Chiller Tons during Peak Hours	9.9	23.4	104.9	324.9	1620.5	3395	5181.6	5592.4	4095.5	1144.1	281.1	80.7
Total Chiller Tons after TES discharge	0	0	0	0	0	0	0	0	0	0	0	0

Average Chiller Tons for OFF PEAK HOURS												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Average Total Chiller Tons in one off-peak Hr	1	3	8	26	144	303	548	591	405	105	34	11
Number of Off-Peak Hours	16	16	16	16	16	16	16	16	16	16	16	16
Avg. Total Chiller Tons in off-peak Hrs	11	46	134	411	2304	4848	8768	9456	6480	1680	544	176
Could the TES tank provide this load?	Y	Y	Y	Y	Y	N	N	N	N	Y	Y	Y
Exess TES tank	0	0	0	0	0	63	5770	6868	2396	0	0	0

The remaining capacity of the TES tank, total capacity of the TES tank subtracted by the average chiller tons in the peak hours, was compared to the off-peak chilled water requirements. If the remaining capcity of the TES tank was larger than the off-peak demand, the TES could provide that load as well. If the remaining capacity of the TES tank was smaller than the off-peak demand, the TES could not provide the entire off-peak demand. In this instance, the remaining TES capacity was subtracted from the off-peak hour chilled water tons to determine the unsatisfied load.

The unsatisfied chilled water load per day was mutlipied by the number of days in each month to determine the total chilled water tons per month. With the TES tank, only June, July, August and September chilled water loads could not be entirely provided by the TES tank. Based off of the 2016 CWP data, the chilled water load distribution for each chiller was identified and applied to the remaining loads (Table 8). For example, in June 2016, 100% of the chilled water load was provided by the electric chiller. The price of steam per ton of chilled water and the price of electricity per ton of chilled water, were used in addition to the contribution percentage of each chiller to determine the total price to provide this load (Table 7).

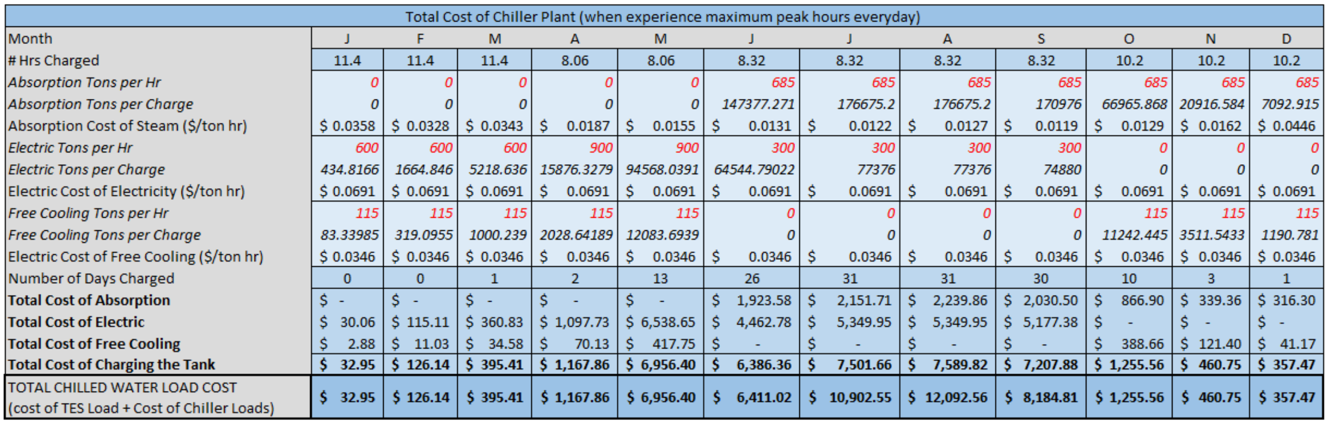


Total Tons Per Day (after TES discharge)												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Total Chiller Tons per day	0	0	0	0	0	63	5770	6868	2396	0	0	0
Number of Days in a Month	31	28	31	30	31	30	31	31	30	31	30	31
Total Chiller Tons per Month	0	0	0	0	0	1890	178858	212920	71865	0	0	0
% Absorption	0%	0%	0%	0%	100%	100%	88%	85%	97%	0%	0%	0%
% Electric Chiller	0%	0%	0%	0%	0%	0%	12%	15%	3%	0%	0%	0%
% Free Cooling	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
$/ton (steam)	$ 0.0358	$ 0.0328	$ 0.0343	$ 0.0187	$ 0.0155	$ 0.0131	$ 0.0122	$ 0.0127	$ 0.0119	$ 0.0129	$ 0.0162	$ 0.0446
$/ton (electricity)	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691
Total Cost	$ -	$ -	$ -	$ -	$ -	**$ 24.67**	**$ 3,400.89**	**$ 4,502.74**	**$ 976.93**	$ -	$ -	$ -

Based off of 2016's average historical data and an 8 hr discharge with 1022 tons CHW/hr. Note: Even if the maximum cooling load occurs, the TES tank will be able to provide for all of the cooling loads in January, Febraury, March, April, October, November, and December. At maximum cooling loads, it cannot provide the entire cooling load of May, June, July, August, and September.

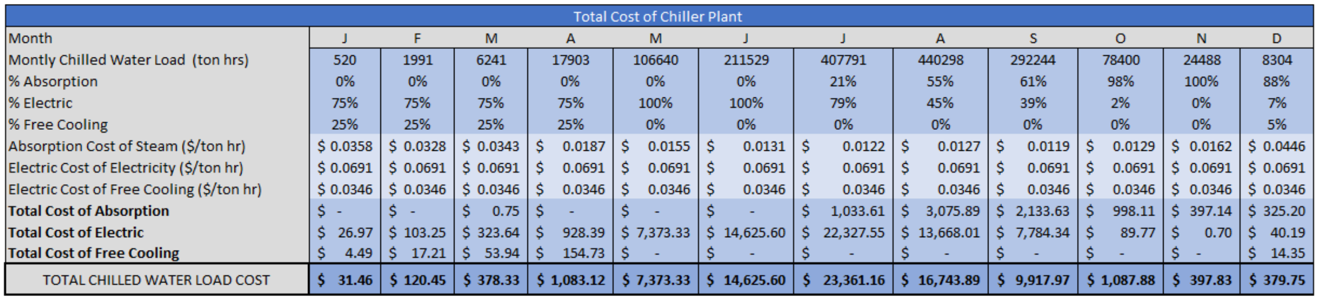
The cost to charge the TES tank was also calculated. Each month varied in chilled water load distributions, number of days charged and hours to charge the tank, based on which chiller would charge the tank. In January, February, and March, when chilled water loads were low and there was no steam available, the TES tank would be charged for 11.4 hours each charging cycle with 600 tons per hour of electric chiller and 115 tons per hour of free cooling. In April and May, as cooling needs began to rise, the TES tank would be charged for 8.06 hours each charging cycle with 900 tons per hour of electric chiller and 115 tons per hour of free cooling. In June, July, August, and September, when cooling loads maximized and absorption chilling became accessible, the TES tank would be charged for 8.32 hours each charging cycle with 685 tons per hour of absorption chiller and 300 tons per hour of electric chiller. In October, November, and December, the 2016 CWP data suggests that there is still absorption cooling available. Therefore, the TES tank would be charged for 10.2 hours with 685 tons per hour from the absorption chiller and 115 tons per hour from the free cooling.

The number of charging cycles was multipled by the capacity (ton-hour) of each chilling method and then multipled by the cost per ton hour to determine the total cost of each machine. The sum of the cost of the absorption chiller, electric chiller, and free cooling was the total cost to charge the tank. The total cost to charge the tank and the total cost to provide the remaining loads were added together to obtain the total cost of chilled water for each month.



Total Cost of Chiller Plant (when experience maximum peak hours everyday)												
Month	J	F	M	A	M	J	J	A	S	O	N	D
# Hrs Charged	11.4	11.4	11.4	8.06	8.06	8.32	8.32	8.32	8.32	10.2	10.2	10.2
Absorption Tons per Hr	*0*	*0*	*0*	*0*	*0*	*685*	*685*	*685*	*685*	*685*	*685*	*685*
Absorption Tons per Charge	*0*	*0*	*0*	*0*	*0*	*147377.271*	*176675.2*	*176675.2*	*170976*	*66965.868*	*20916.584*	*7092.915*
Absorption Cost of Steam ($/ton hr)	$ 0.0358	$ 0.0328	$ 0.0343	$ 0.0187	$ 0.0155	$ 0.0131	$ 0.0122	$ 0.0127	$ 0.0119	$ 0.0129	$ 0.0162	$ 0.0446
Electric Tons per Hr	*600*	*600*	*600*	*900*	*900*	*300*	*300*	*300*	*300*	*0*	*0*	*0*
Electric Tons per Charge	*434.8166*	*1664.846*	*5218.636*	*15876.3279*	*94568.0391*	*64544.79022*	*77376*	*77376*	*74880*	*0*	*0*	*0*
Electric Cost of Electricity ($/ton hr)	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691
Free Cooling Tons per Hr	*115*	*115*	*115*	*115*	*115*	*0*	*0*	*0*	*0*	*115*	*115*	*115*
Free Cooling Tons per Charge	*83.33985*	*319.0955*	*1000.239*	*2028.64189*	*12083.6939*	*0*	*0*	*0*	*0*	*11242.445*	*3511.5433*	*1190.781*
Electric Cost of Free Cooling ($/ton hr)	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346
Number of Days Charged	0	0	1	2	13	26	31	31	30	10	3	1
Total Cost of Absorption	$ -	$ -	$ -	$ -	$ -	$ 1,923.58	$ 2,151.71	$ 2,239.86	$ 2,030.50	$ 866.90	$ 339.36	$ 316.30
Total Cost of Electric	$ 30.06	$ 115.11	$ 360.83	$ 1,097.73	$ 6,538.65	$ 4,462.78	$ 5,349.95	$ 5,349.95	$ 5,177.38	$ -	$ -	$ -
Total Cost of Free Cooling	$ 2.88	$ 11.03	$ 34.58	$ 70.13	$ 417.75	$ -	$ -	$ -	$ -	$ 388.66	$ 121.40	$ 41.17
Total Cost of Charging the Tank	**$ 32.95**	**$ 126.14**	**$ 395.41**	**$ 1,167.86**	**$ 6,956.40**	**$ 6,386.36**	**$ 7,501.66**	**$ 7,589.82**	**$ 7,207.88**	**$ 1,255.56**	**$ 460.75**	**$ 357.47**
TOTAL CHILLED WATER LOAD COST (cost of TES Load + Cost of Chiller Loads)	**$ 32.95**	**$ 126.14**	**$ 395.41**	**$ 1,167.86**	**$ 6,956.40**	**$ 6,411.02**	**$ 10,902.55**	**$ 12,092.56**	**$ 8,184.81**	**$ 1,255.56**	**$ 460.75**	**$ 357.47**

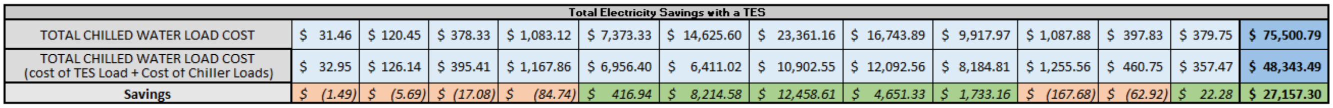
The cost of the chilled water plant without the TES tank was also calculated. The process was identical to the cost of the remaining chilled water load after the TES tank was discharged. However, instead of allocating part of the load to the TES tank, the entire monthly chilled water load was provided by a combination of the absorption chiller, electric chillers, and free cooling heat exchanger.



Total Cost of Chiller Plant

Month	J	F	M	A	M	J	J	A	S	O	N	D
Montly Chilled Water Load (ton hrs)	520	1991	6241	17903	106640	211529	407791	440298	292244	78400	24488	8304
% Absorption	0%	0%	0%	0%	0%	0%	21%	55%	61%	98%	100%	88%
% Electric	75%	75%	75%	75%	100%	100%	79%	45%	39%	2%	0%	7%
% Free Cooling	25%	25%	25%	25%	0%	0%	0%	0%	0%	0%	0%	5%
Absorption Cost of Steam ($/ton hr)	$ 0.0358	$ 0.0328	$ 0.0343	$ 0.0187	$ 0.0155	$ 0.0131	$ 0.0122	$ 0.0127	$ 0.0119	$ 0.0129	$ 0.0162	$ 0.0446
Electric Cost of Electricity ($/ton hr)	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691	$ 0.0691
Electric Cost of Free Cooling ($/ton hr)	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346	$ 0.0346
Total Cost of Absorption	$ -	$ -	$ 0.75	$ -	$ -	$ -	$ 1,033.61	$ 3,075.89	$ 2,133.63	$ 998.11	$ 397.14	$ 325.20
Total Cost of Electric	$ 26.97	$ 103.25	$ 323.64	$ 928.39	$ 7,373.33	$ 14,625.60	$ 22,327.55	$ 13,668.01	$ 7,784.34	$ 89.77	$ 0.70	$ 40.19
Total Cost of Free Cooling	$ 4.49	$ 17.21	$ 53.94	$ 154.73	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 14.35
TOTAL CHILLED WATER LOAD COST	**$ 31.46**	**$ 120.45**	**$ 378.33**	**$ 1,083.12**	**$ 7,373.33**	**$ 14,625.60**	**$ 23,361.16**	**$ 16,743.89**	**$ 9,917.97**	**$ 1,087.88**	**$ 397.83**	**$ 379.75**

The cost of the chilled water without the TES tank, and the cost of the chilled water production with the TES tank were compared annually and monthly. Overall, the TES tank saves $27,157.30 annually. However, it is interesting that the operation of the TES tank in this manner does not provide consistent monthly savings. Further research should be conducted to determine an optimal operation of the TES tank during these months to further increase the savings.



Total Electricity Savings with a TES

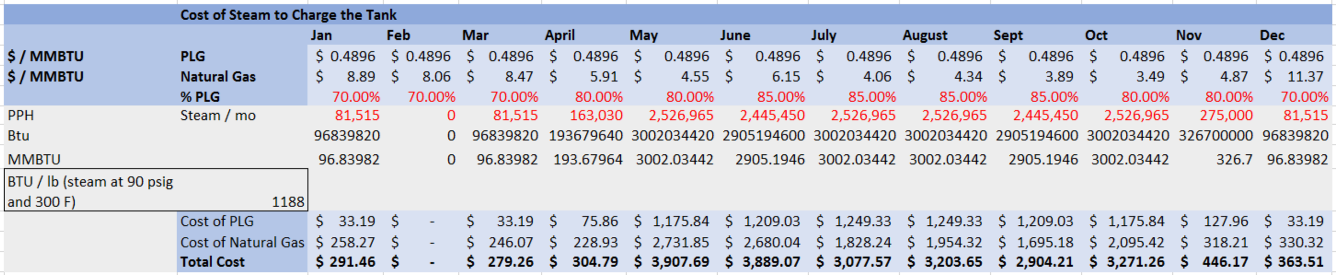
TOTAL CHILLED WATER LOAD COST	$ 31.46	$ 120.45	$ 378.33	$ 1,083.12	$ 7,373.33	$ 14,625.60	$ 23,361.16	$ 16,743.89	$ 9,917.97	$ 1,087.88	$ 397.83	$ 379.75	**$ 75,500.79**
TOTAL CHILLED WATER LOAD COST (cost of TES Load + Cost of Chiller Loads)	$ 32.95	$ 126.14	$ 395.41	$ 1,167.86	$ 6,956.40	$ 6,411.02	$ 10,902.55	$ 12,092.56	$ 8,184.81	$ 1,255.56	$ 460.75	$ 357.47	**$ 48,343.49**
Savings	*$ (1.49)*	*$ (5.69)*	*$ (17.08)*	*$ (84.74)*	*$ 416.94*	*$ 8,214.58*	*$ 12,458.61*	*$ 4,651.33*	*$ 1,733.16*	*$ (167.68)*	*$ (62.92)*	*$ 22.28*	**$ 27,157.30**

Appendix C: Cost of Steam to Charge the TES Tank

The steam is a byproduct of the electricity generation that occurs with or without the need for steam across campus. Using steam to charge a TES tank with an absorption chiller gives the wasted steam a purpose. Therefore, the cost to create this steam was considered a “saving” in the economic analysis. The total amount of steam (MMBTU) to charge the tank each month was calculated based on the number of charges of the TES tank each month, the thermodynamic properties of the steam, the heat rate of the turbine, and the amount of steam in pounds to chill one ton of chilled water using the absorption chiller. Then, the total cost to generate this amount of steam each month was calculated based off of the price of natural gas and processed landfill gas (PLG) from 2016 and the blending ratio of natural gas and PLG.

Assuming the TES tank would be charged at most once a day, the absorption chiller took 11.9 hours to charge, the absorption chiller capacity was 685 tons, and 10 pounds of steam was required to produce one ton of chilled water, the pounds of steam to charge the TES tank in one day was determined for each month.

Based off of the number of charges each month required the total pounds of steam per month was calculated (Table 5). The steam usually enters the absorption chiller at 300 degrees Fahrenheit and at 90 psig and has a heat rate of 1188 BTU/lb, according to steam tables. The heat rate was used to convert the pounds of steam per month into BTU per month. Using the prices of natural gas and PLG, in $/MMBTU, and the specific blend of the gases each month, the total price of the steam was determined.



	Cost of Steam to Charge the Tank												
		Jan	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**
$ / MMBTU	**PLG**	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896	$ 0.4896
$ / MMBTU	**Natural Gas**	$ 8.89	$ 8.06	$ 8.47	$ 5.91	$ 4.55	$ 6.15	$ 4.06	$ 4.34	$ 3.89	$ 3.49	$ 4.87	$ 11.37
	% PLG	70.00%	70.00%	70.00%	80.00%	80.00%	85.00%	85.00%	85.00%	85.00%	80.00%	80.00%	70.00%
PPH	Steam / mo	81,515	0	81,515	163,030	2,526,965	2,445,450	2,526,965	2,526,965	2,445,450	2,526,965	275,000	81,515
Btu		96839820	0	96839820	193679640	3002034420	2905194600	3002034420	3002034420	2905194600	3002034420	326700000	96839820
MMBTU		96.83982	0	96.83982	193.67964	3002.03442	2905.1946	3002.03442	3002.03442	2905.1946	3002.03442	326.7	96.83982
BTU / lb (steam at 90 psig and 300 F)	1188												
	Cost of PLG	$ 33.19	$ -	$ 33.19	$ 75.86	$ 1,175.84	$ 1,209.03	$ 1,249.33	$ 1,249.33	$ 1,209.03	$ 1,175.84	$ 127.96	$ 33.19
	Cost of Natural Gas	$ 258.27	$ -	$ 246.07	$ 228.93	$ 2,731.85	$ 2,680.04	$ 1,828.24	$ 1,954.32	$ 1,695.18	$ 2,095.42	$ 318.21	$ 330.32
	Total Cost	**$ 291.46**	**$ -**	**$ 279.26**	**$ 304.79**	**$ 3,907.69**	**$ 3,889.07**	**$ 3,077.57**	**$ 3,203.65**	**$ 2,904.21**	**$ 3,271.26**	**$ 446.17**	**$ 363.51**

Each year, the TES tank would be able to harness $21,938 of steam to charge the TES tank. Instead of wasting the steam, and the money required to create it, the TES tank can utilize this steam and satisfy the campus’ cooling needs more efficiently.

Appendix D: UNH Electricity Load Profiles

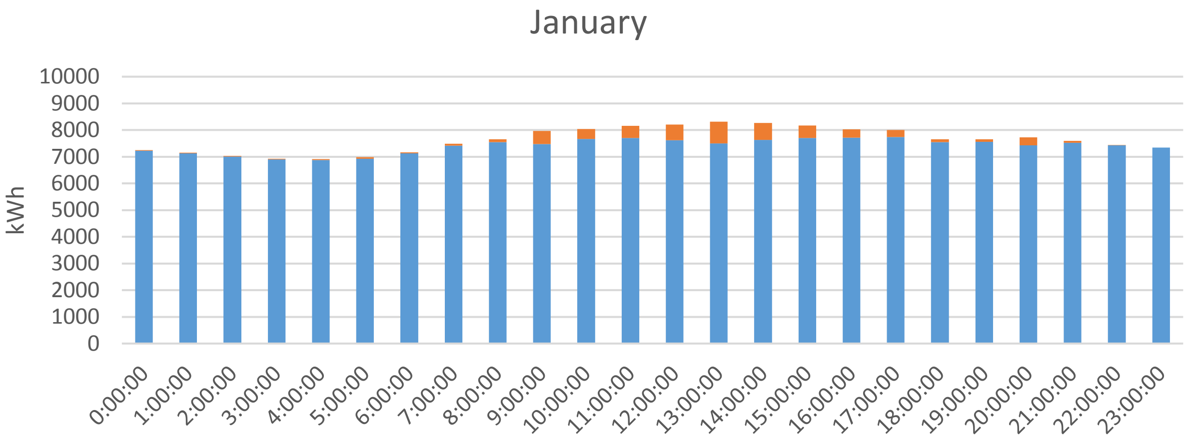
Hourly Load Profiles

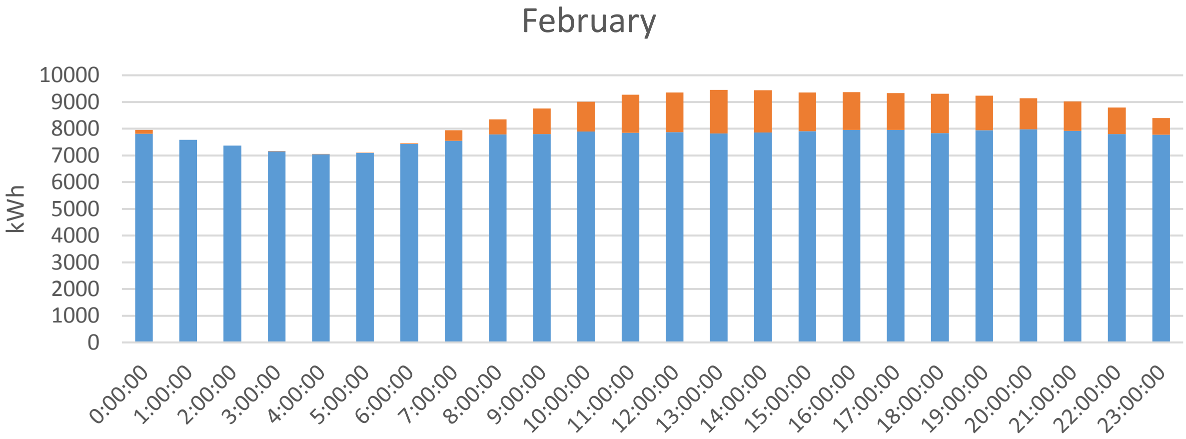
The Hourly Load Profile of the electricity usage at the University of New Hampshire. Overall the trends of each month have a similar shape but vary in sharpness of peaks. There is a drop in electricity usage from about 2 AM to 6 AM when all buildings on campus are closed. Then, the electricity usage gradually increases for the rest of the day when academic buildings are in full operation. The peak times most occur from 8 AM to 7 PM each month.

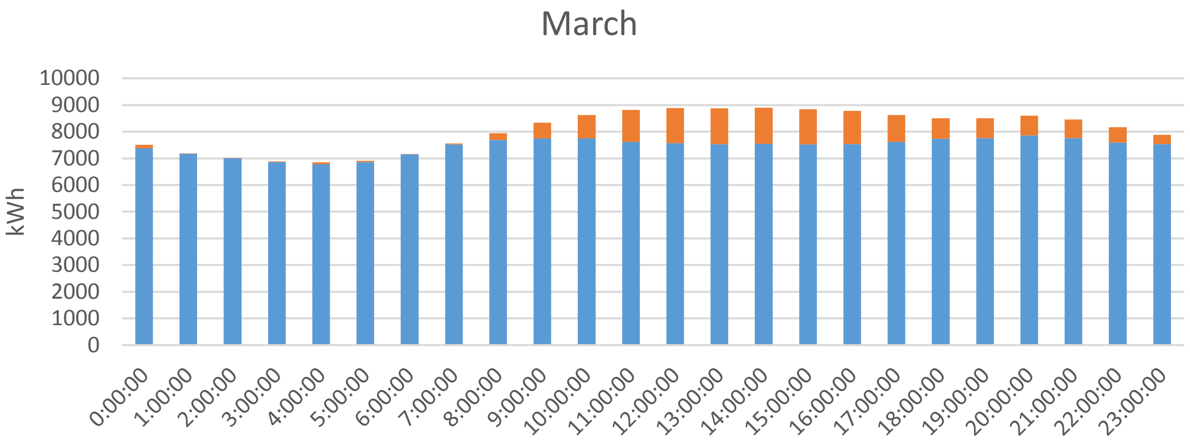
🟦 Produced Electricity

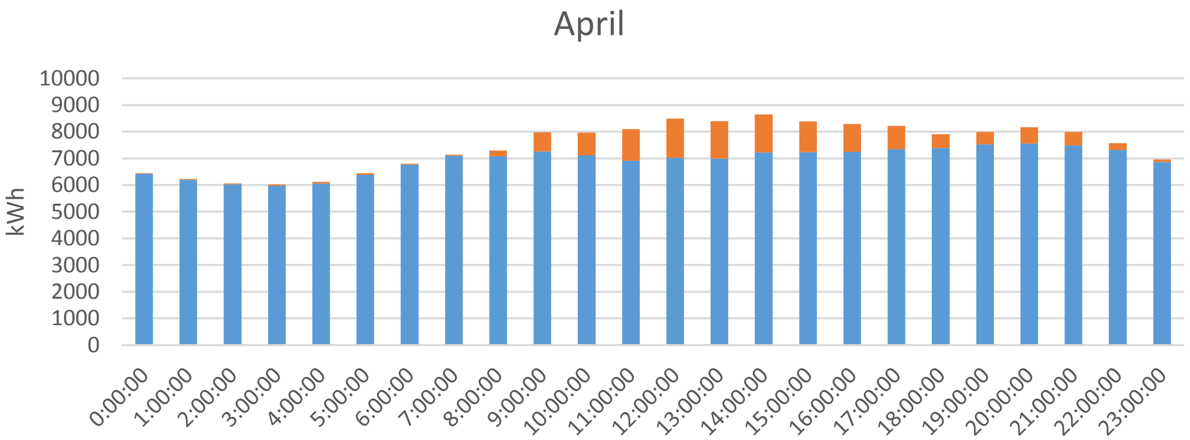
🟧 Purchased Electricity

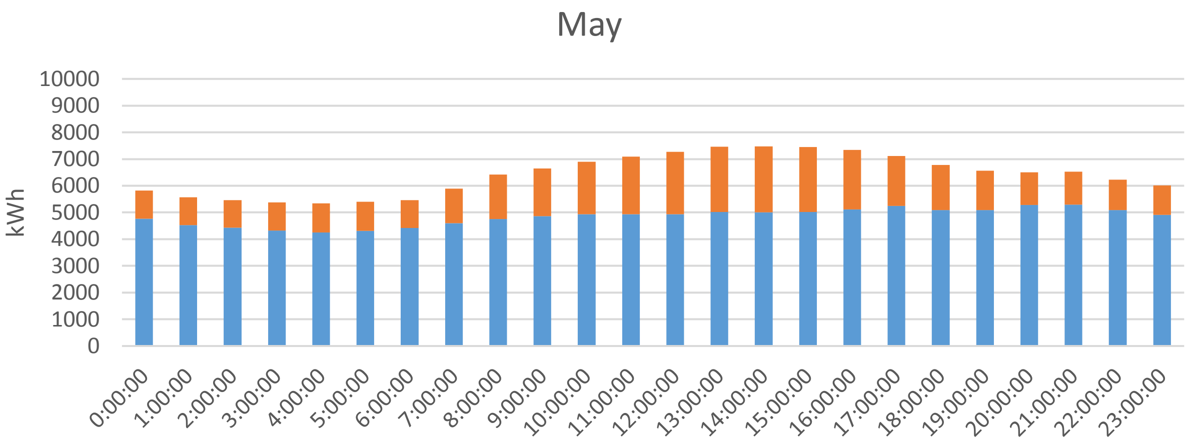
— Total Electricity

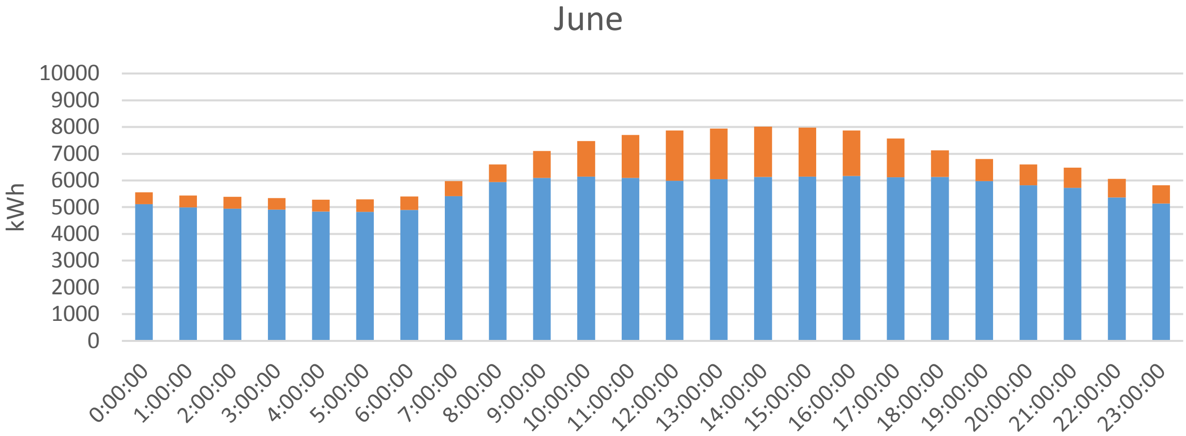


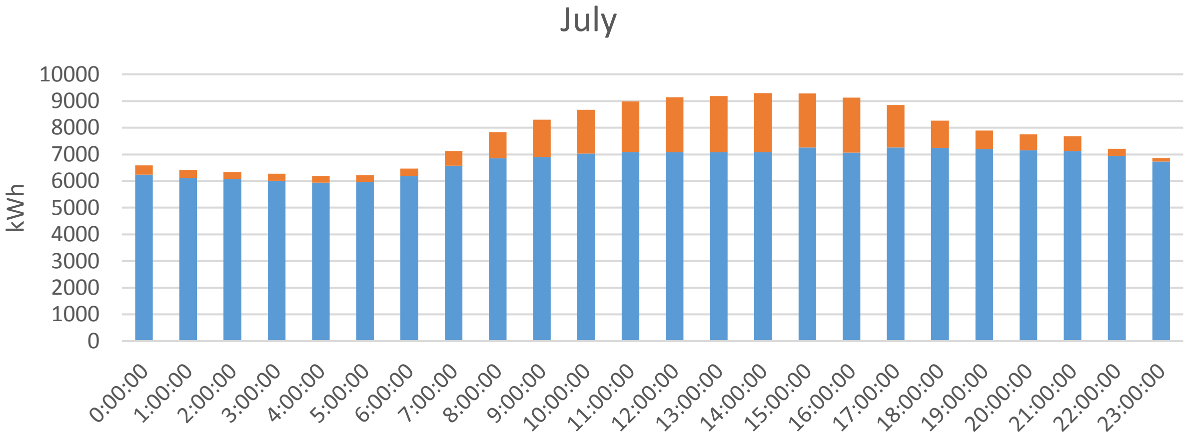


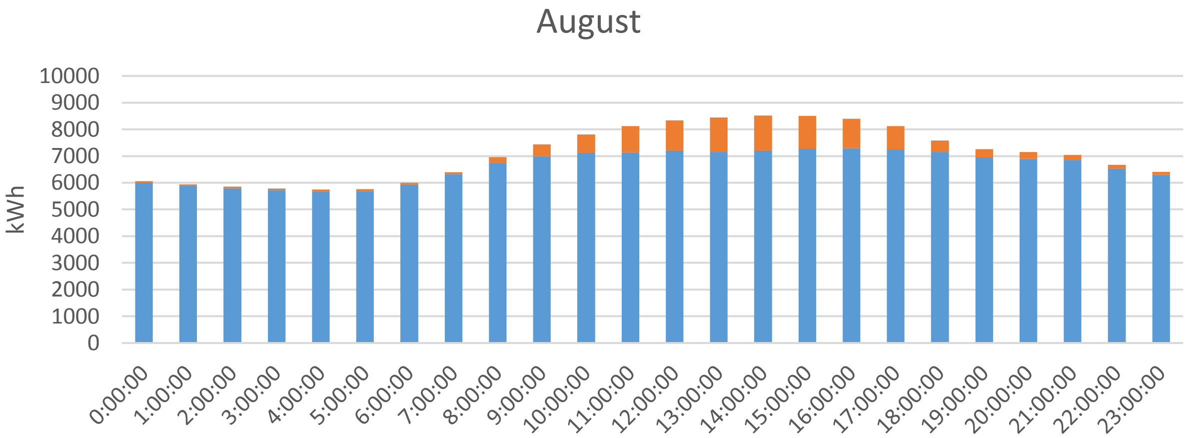

March
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00

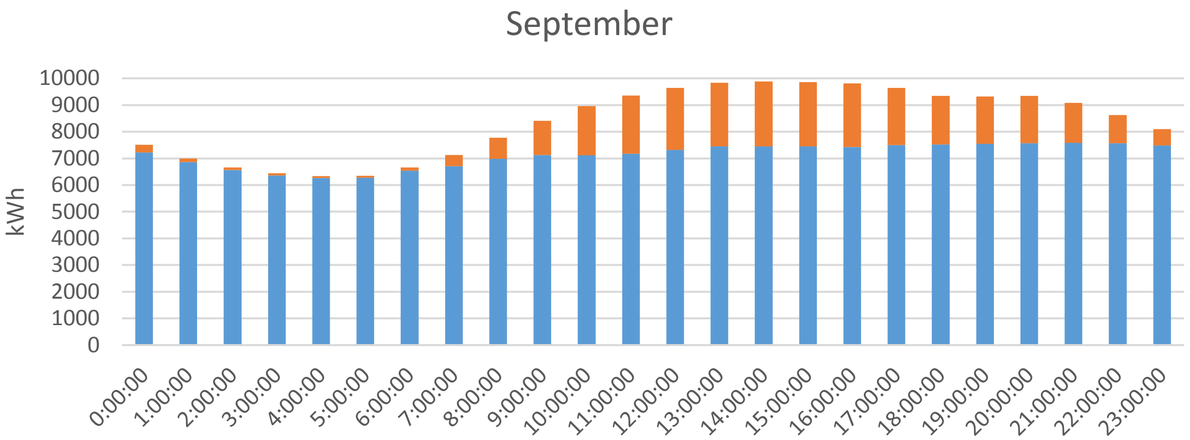

April
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00

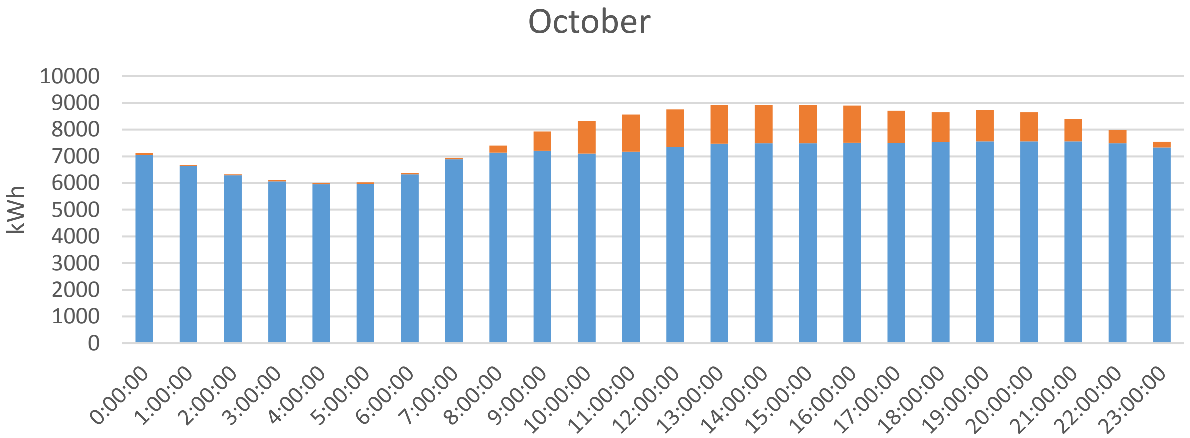

May
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00

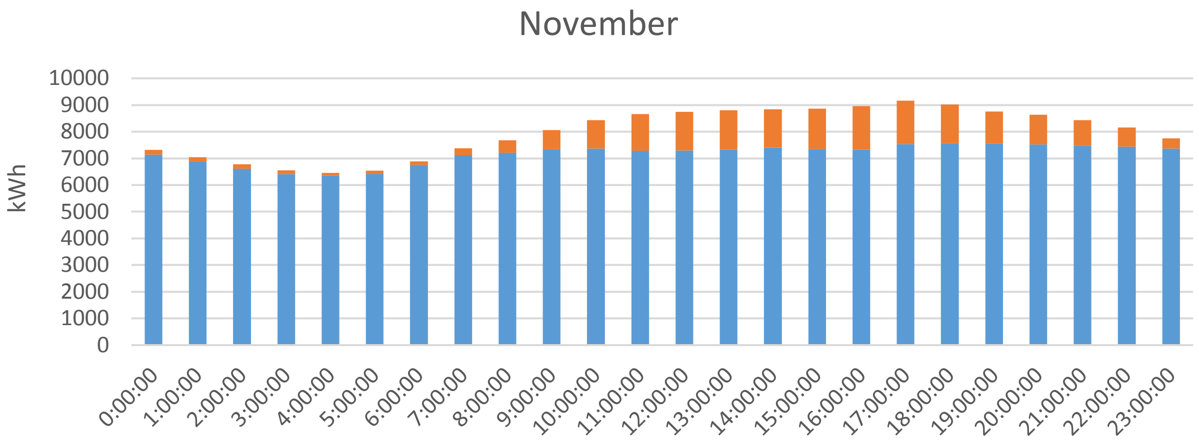

June
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00

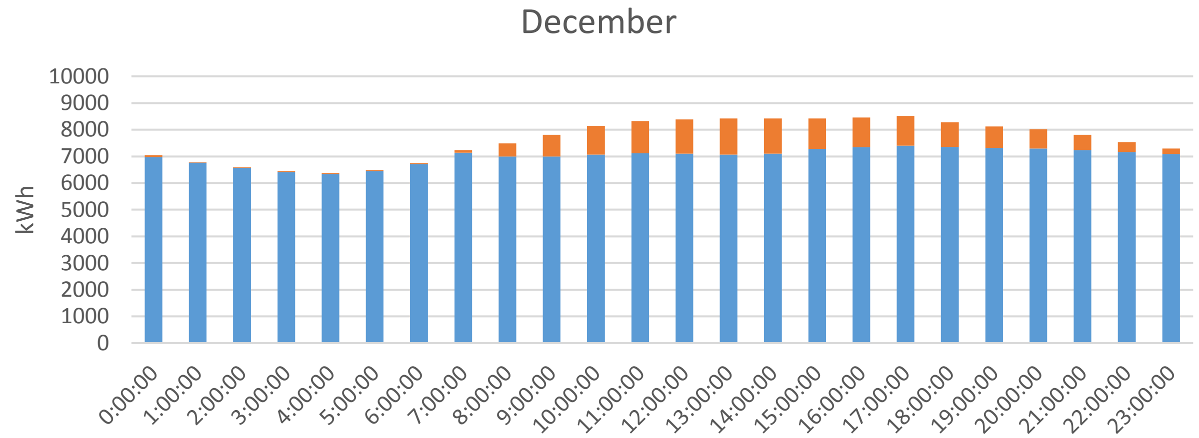

July
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00


August
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00


September
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00


October
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00


November
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00


December
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0:00:00
1:00:00
2:00:00
3:00:00
4:00:00
5:00:00
6:00:00
7:00:00
8:00:00
9:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
18:00:00
19:00:00
20:00:00
21:00:00
22:00:00
23:00:00

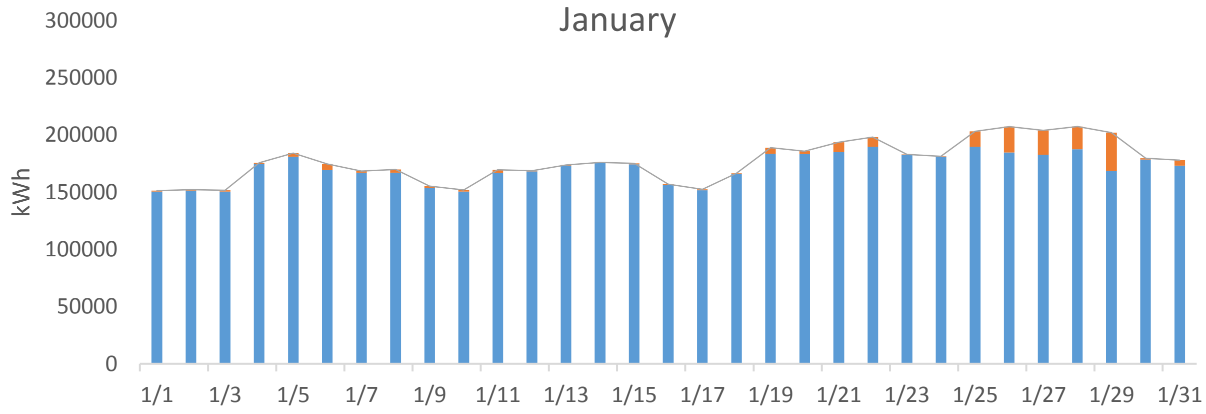
Daily Load Profiles

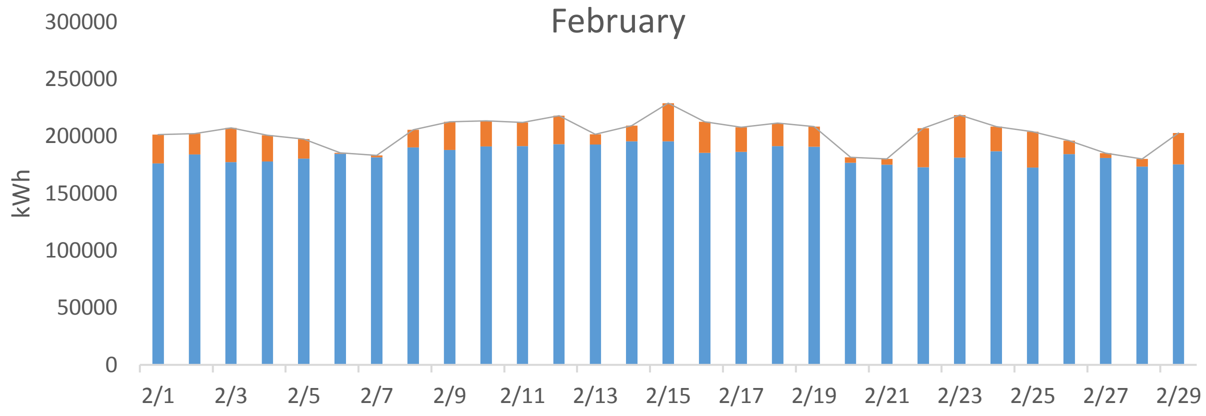
The daily load profiles of electricty consumption at the Univeristy of New Hampshire. During the week days, there is an increase in both electricity purchase and production to satisfy the campus demand. During the week students are attending classes, faculty are in their offices and laboratories, and dining halls and academic buildings are in full operation. On the weekends, there is a noticeable decrease in electricity purchases. The cogeneration plant is able to produce most if not all of the electricity needs on the weekends when classes are not in session, students and faculty may not be on campus, and the electricity requirements reduce. During holdiays and breaks, such as winter break in late December and early January, spring break in March, and Thanksgiving break in November, there is a noticeable dip in the demand curve. During these periods of time, the operation of UNH is significantly less and the University is often closed. In the summer months, July, August, and September, the electricity purchases are at their maximum. Althought there are less students on campus during the summer, cooling the buildings requires a significant amount of energy.

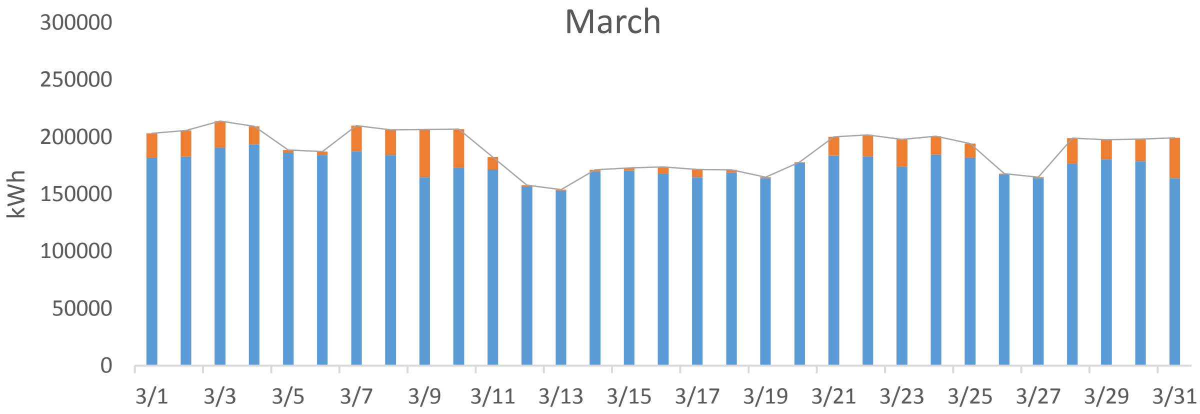
🟦 Produced Electricity

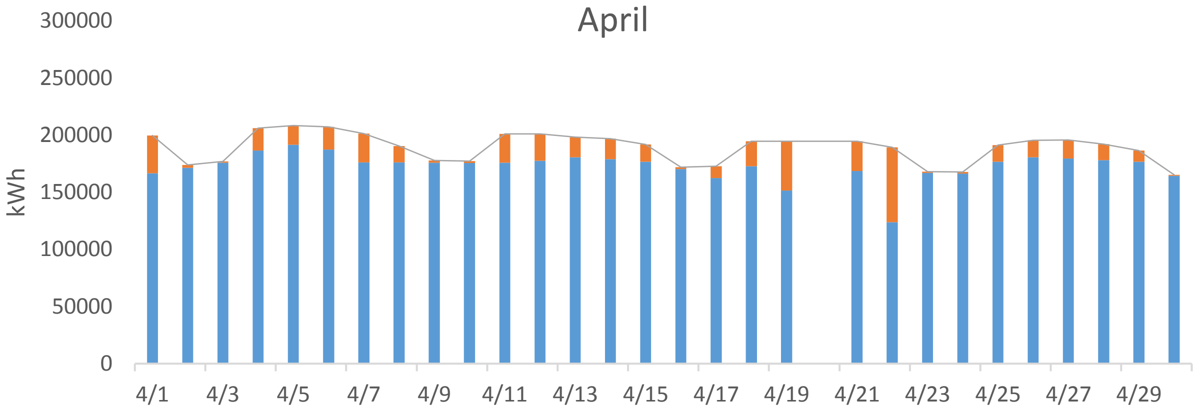
🟧 Purchased Electricity

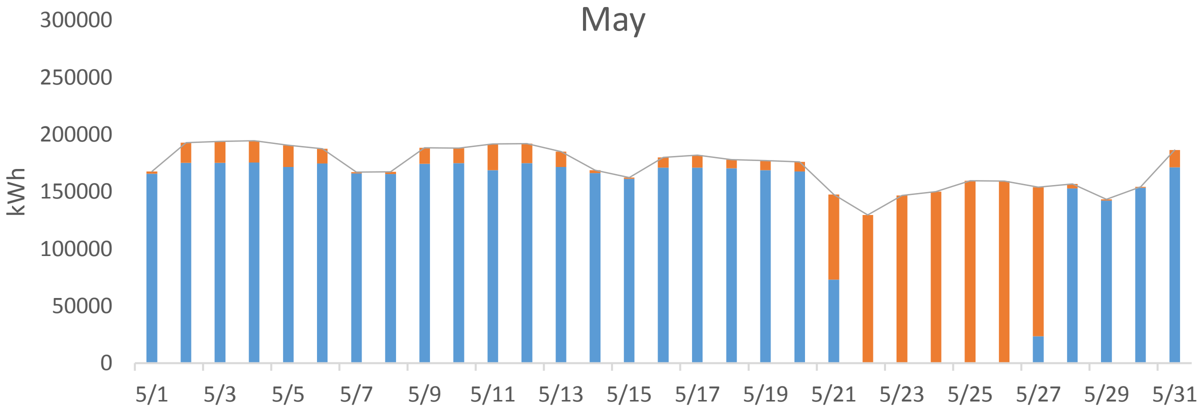
— Total Electricity

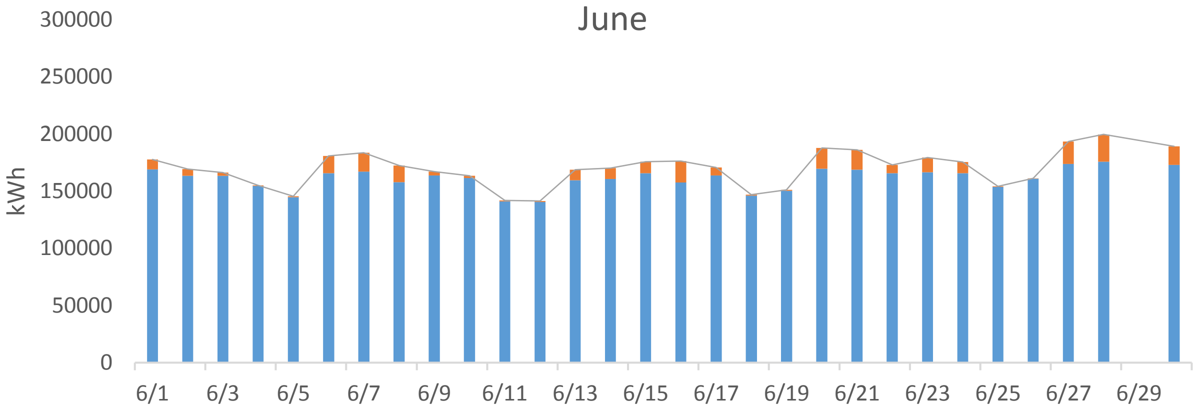


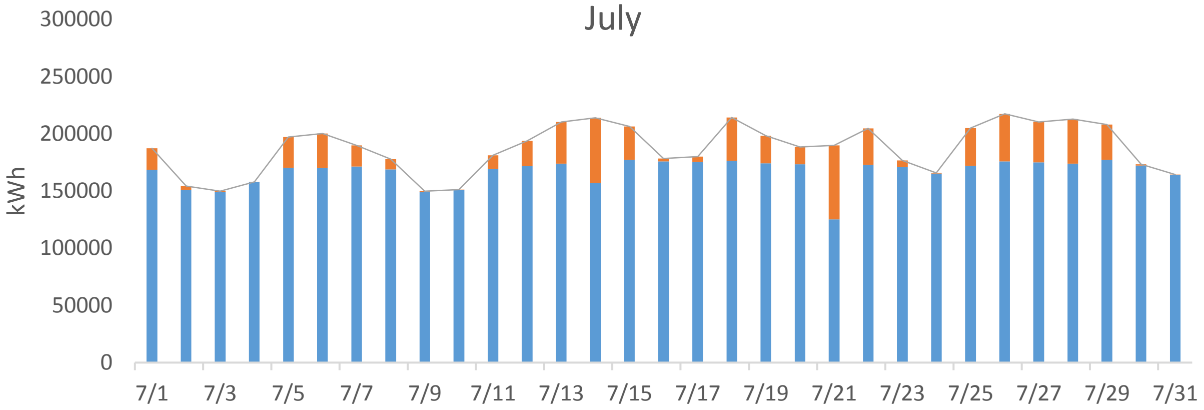


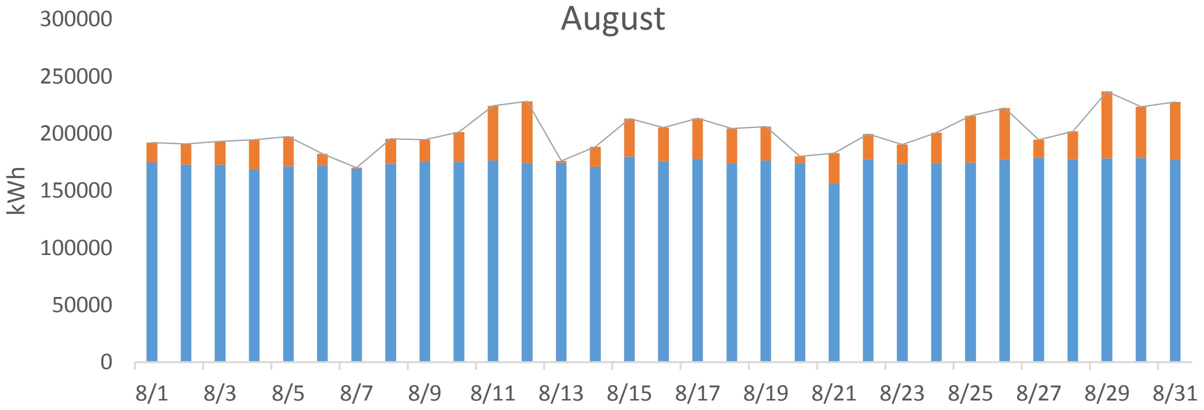

March
300000
250000
200000
150000
100000
50000
0
kWh
3/1
3/3
3/5
3/7
3/9
3/11
3/13
3/15
3/17
3/19
3/21
3/23
3/25
3/27
3/29
3/31

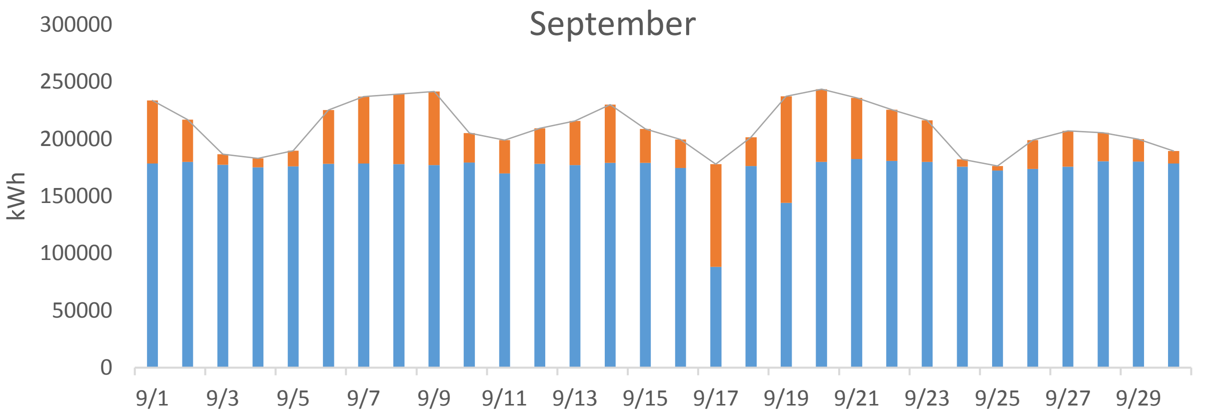

April
300000
250000
200000
150000
100000
50000
0
kWh
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
4/25
4/27
4/29

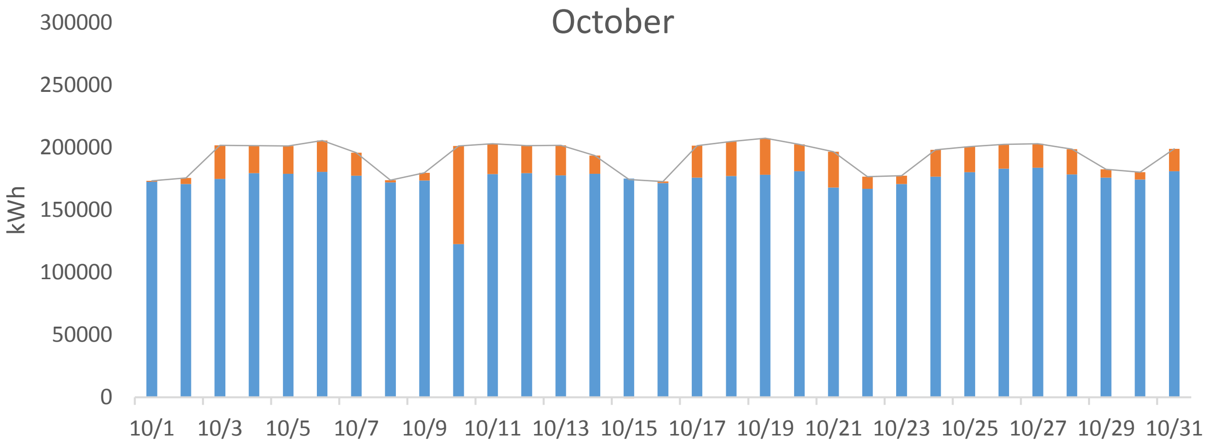

May
300000
250000
200000
150000
100000
50000
0
kWh
5/1
5/3
5/5
5/7
5/9
5/11
5/13
5/15
5/17
5/19
5/21
5/23
5/25
5/27
5/29
5/31

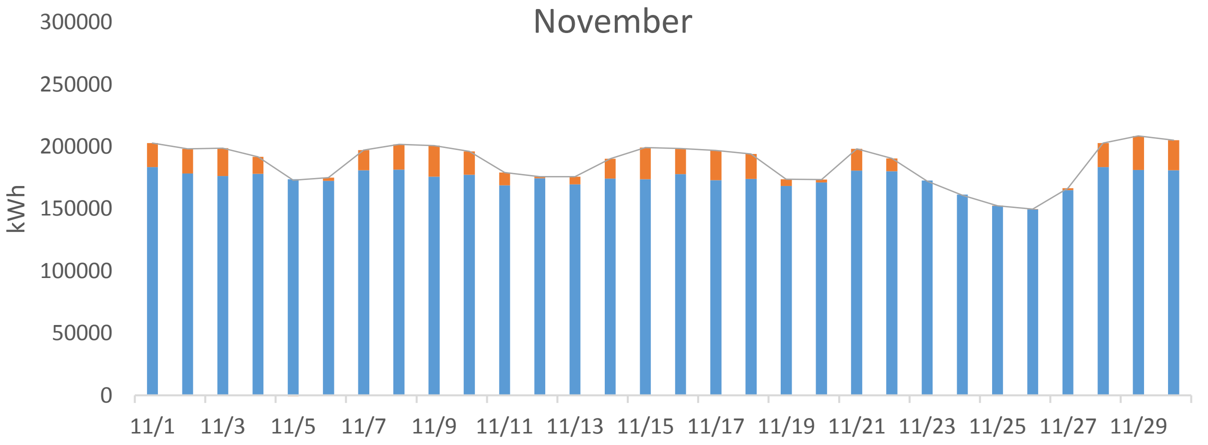

June
kWh
300000
250000
200000
150000
100000
50000
0
6/1
6/3
6/5
6/7
6/9
6/11
6/13
6/15
6/17
6/19
6/21
6/23
6/25
6/27
6/29

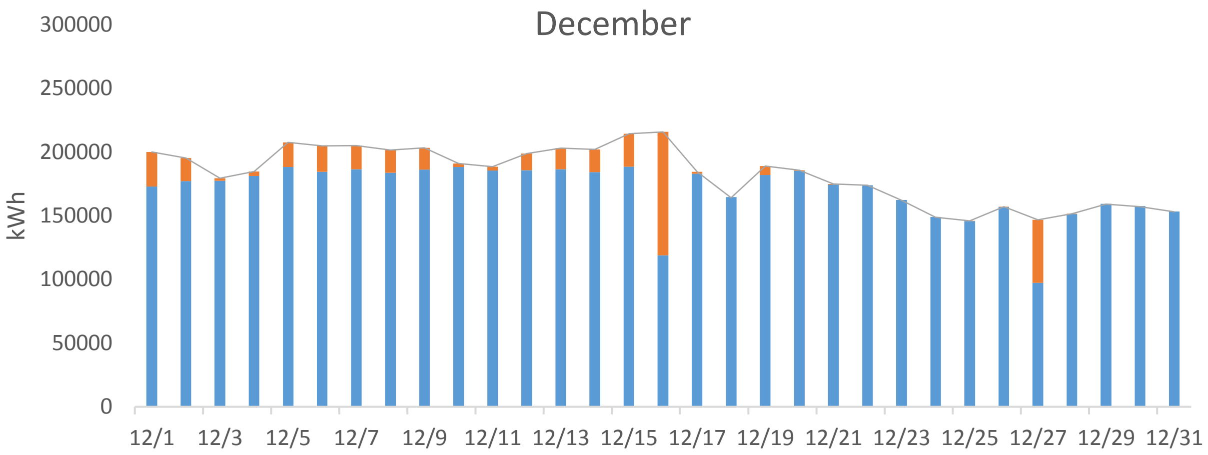

July
kWh
300000
250000
200000
150000
100000
50000
0
7/1
7/3
7/5
7/7
7/9
7/11
7/13
7/15
7/17
7/19
7/21
7/23
7/25
7/27
7/29
7/31


August
kWh
300000
250000
200000
150000
100000
50000
0
8/1
8/3
8/5
8/7
8/9
8/11
8/13
8/15
8/17
8/19
8/21
8/23
8/25
8/27
8/29
8/31


September
kWh
300000
250000
200000
150000
100000
50000
0
9/1
9/3
9/5
9/7
9/9
9/11
9/13
9/15
9/17
9/19
9/21
9/23
9/25
9/27
9/29


October
kWh
300000
250000
200000
150000
100000
50000
0
10/1
10/3
10/5
10/7
10/9
10/11
10/13
10/15
10/17
10/19
10/21
10/23
10/25
10/27
10/29
10/31


November
kWh
300000
250000
200000
150000
100000
50000
0
11/1
11/3
11/5
11/7
11/9
11/11
11/13
11/15
11/17
11/19
11/21
11/23
11/25
11/27
11/29


December
kWh
300000
250000
200000
150000
100000
50000
0
12/1
12/3
12/5
12/7
12/9
12/11
12/13
12/15
12/17
12/19
12/21
12/23
12/25
12/27
12/29
12/31

Appendix E: Incentives from Eversource

Energy Rewards Request for Proposal (RFP) Program

This is an incentive program that is offered by Eversource. In order to qualify the project must cost at least $150,000 and produce a minimum of 100,000 kWh in electricity savings. A battery project would qualify for this incentive. If the project is considered in the future the University of New Hampshire should apply for this incentive.

The following forms would have to be completed to apply for the incentive:

- Project Track Proposal Information Form
- Measure Information Form
- Site Information Form
- Bidders Certification Form
- Sample Customer Letter of Intent
- RFP 2016 BCR Estimator

All of these forms can be found on the Eversource website under the Smart Energy Solutions for Businesses. Any further questions about this incentive specifically should be directed to Gary LaCasse at 603-634-3216 or gary.lacasse@eversource.com.

New Equipment and Construction

Eversource offers a “New Equipment and Construction Program” which offers rebates designed to help purchase more energy efficient equipment and other quantifying measures where kWh savings can occur. [25] This program offers rebates and technical assistance to help customers choose energy efficient technologies. In order to receive the rebates, they must be approved before the purchase and installation of the technology.

Some applications that are available include:

- Lighting and Controls
- Electric Motors
- Variable Frequency Drives
- Heating, Ventilation & Air Conditioning
- Chillers
- Air Compressors
- Custom Projects
- Municipal Heating Equipment

To apply for this rebate program, the University of New Hampshire should contact their Account Executve at 866-554-6035. The proposal and estimate of the rebate amount will be reviewed or an offer will be made to install certain energy efficiency equipment. The actual rebate amount will depend on the final installed product. [25]