PE Complex Bottom-Up Energy Model

The Calvin College Physical Education Building
https://www.rdgusa.com/projects/calvin-college-spoelhof-fieldhouse-planning

Engineering 333 Section B Semester Project

To: Professor Heun and Jack Phillips

Date: May 18, 2017

Objective:

The Physical Education Complex is located in the North-end of Calvin College's campus, and supports many athletic, academic, event and recreational functions. Due to its heavy use, the complex contributes 20% of the College's electricity consumption. Monetarily, this equated to electricity costs of about $385,000 last year. With these financial implications, the College is searching for ways to reduce the cost. While there is little to no room for electricity cost rate reductions, there is opportunity for improvement through the implementation of more efficient components. However, the sources of electricity demand are largely unknown. Our objective is to develop a bottom-up electricity demand model for the PE complex. To create an accurate bottom-up demand model, a list of objectives was determined as follows:

- Accuracy of demand model within 2% of actual consumption rates
- Inclusion of all possible sources of demand
- Inventory of consumption rates (in units of watts)
- Estimates of service duty of each demand item (in units of time/year)

Methods & Procedures:

Given these objectives, the class was split into teams to develop the model. The team break down can be seen in Table 1.

Table 1: Team Breakdown

Section-Group	Responsibilities
B-Executive	Communication and overall organization
B-1	Lighting-T&T
B-2	Lighting-Venema
B-3	Lighting-Van Noord
B-4	HVAC
B-5	Computers and TVs
B-6	Pool Operations

Each team selected an executive team member that met often to keep the class organized and following the method of approach (Figure 1). The team began by creating inventories and model inputs. The primary purpose of the inventories was to compare the components that are in the PE complex to the electrical and mechanical schematics that are held in the physical plant. These schematics were a good source of information to identify which components were initially located in the fieldhouse (when it was first built), where these components are located, and how much power these components use (P). The model inputs illustrated the key variables that were researched, estimated, and adjusted to refine the model. The initial estimates created a level-zero model. Duty or usage cycles were refined to generate a level-one model estimate for the year 2016. Finally, in the level-two model, the usage was projected back to previous years based on the available schedules.

Results:

Using the methods described above each team created a model on the components and area of the building they were assigned. Then the executive team then compiled their results to determine the accuracy of their model to that of 2016's actual consumption. Once the 2016 model was verified each team back casted the model to the year 2010, and a comprehensive graph of the results is found in Figure 2. From the overall compilation of the modeled energy consumptions, the percentage that each component in the complex contributed to the overall can be found in Figure 3. Finally, after comparing the actual consumption to the predicted consumption for each year the percent errors were calculated and are shown in Table 2.

Table 2: Model Accuracy Analysis

Year	% Difference from Actual
2016	- 3.5 %
2015	- 10.5 %
2014	- 8.0 %
2013	- 7.3 %
2012	- 2.2 %
2011	- 4.4 %
2010	1.9 %

[- = over estimation]

A detailed analysis of how each of the teams ended up at the numbers that contributed to the overall results is found in Appendix 1 through Appendix 6. Additionally, suggestions on how to improve the efficiency of these designs can also be found in the Appendices.

Discussion & Assessment:

Although, the demand model was not accurate to within two percent of the actual demand, the model was consistently within 10%. The model also revealed that the majority of the demand was located in the HVAC systems (79%), followed by the Van Noord Lighting (8%). Therefore, the greatest potential for cost reductions are found in decreasing the amount of demand for ventilation, heating and cooling while increasing the efficiency of the lighting fixtures in the Van Noord Arena. The team believes that they were successful in determining the sources and estimations of power demand to help Calvin move forward to become better stewards of financial and energy resources.

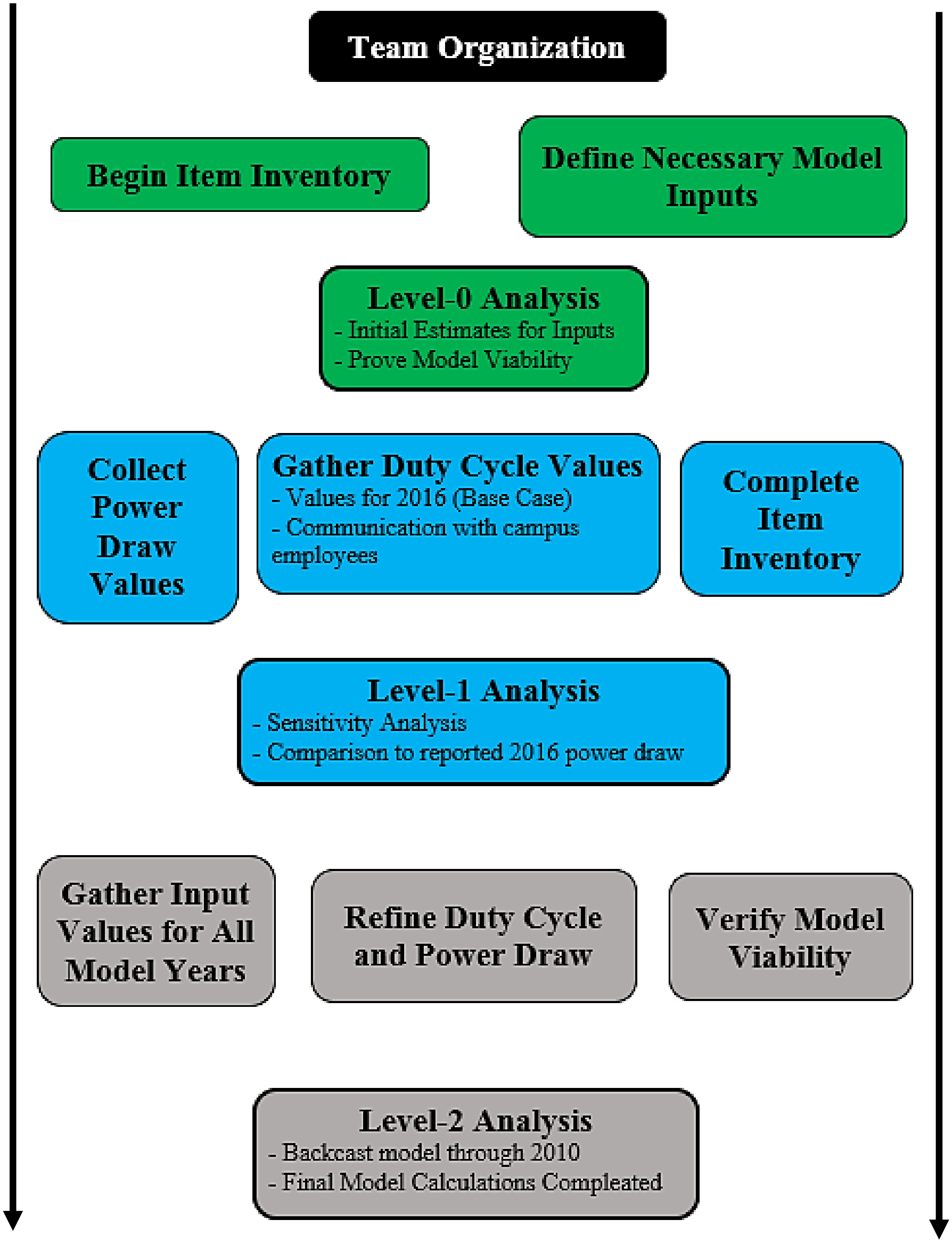

Figure 1: Method of Approach Diagram

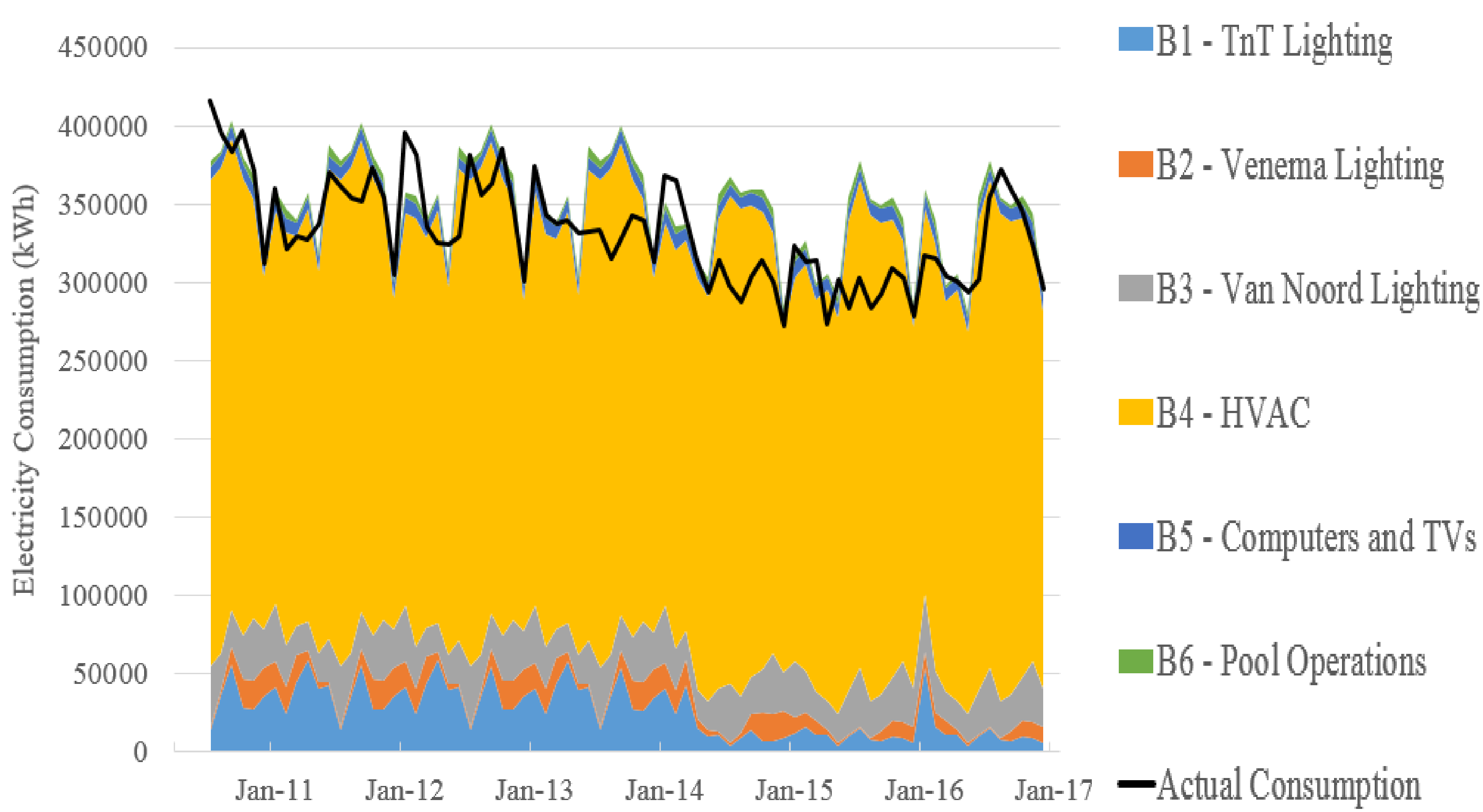

Figure 2: Model Comparison to Actual Results

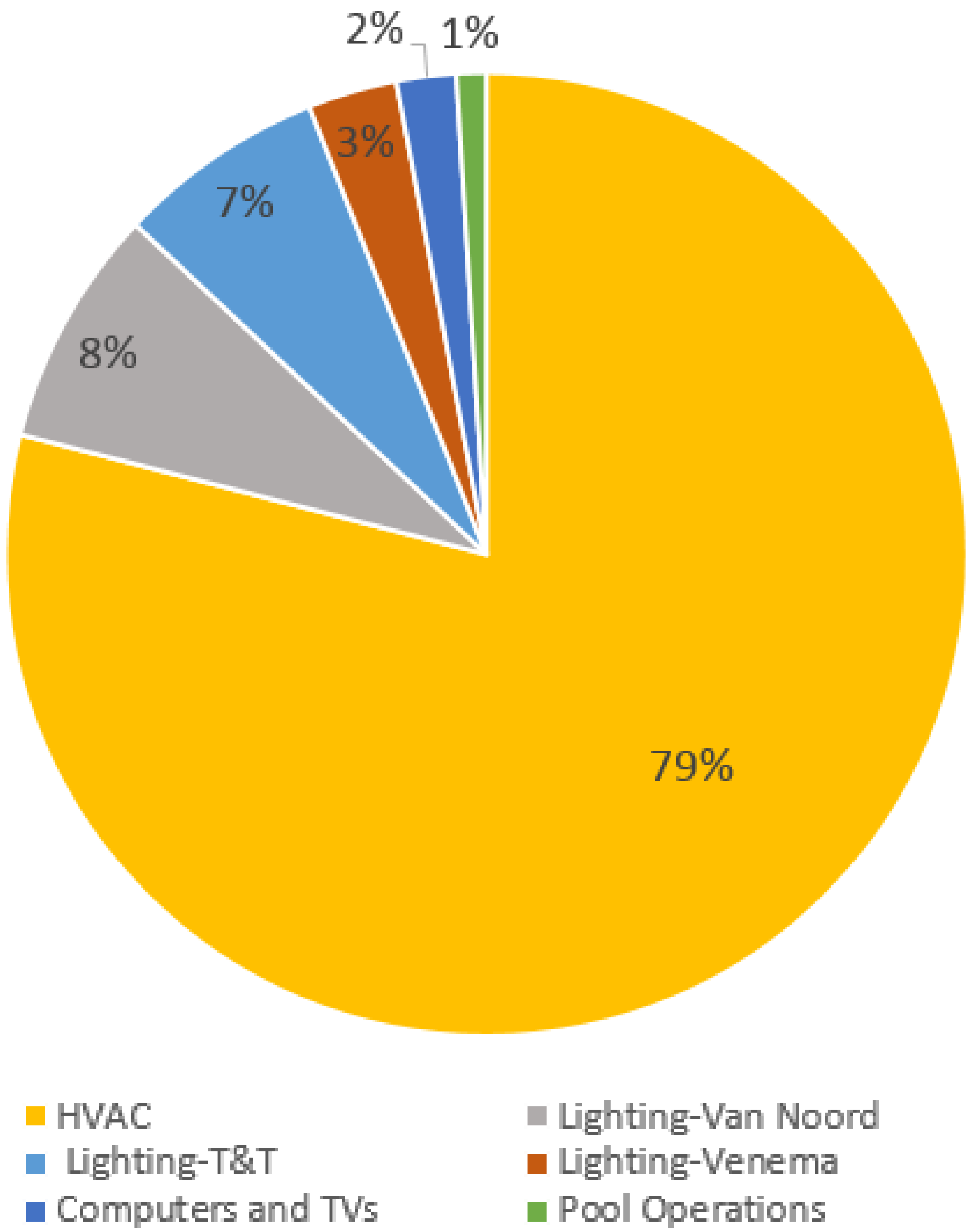

Figure 3. Average Consumptions Proportions by Group (2010-2016)

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PE Complex Bottom Up Energy Model

Appendix 1

Track and Tennis Center Lighting

Daniel Dick, Nathan Swaim, Jonathan Sager

Objective:

The objective of this report is to describe the work completed by the Track and Tennis Lighting Team (TNT) for the Bottom up Electricity Demand Model of the fieldhouse.

Research:

The research performed by the TNT team focused on three main components: inventory, power draw, and time usage. The team began by taking an inventory of all the lighting in the TNT. Using this inventory, the lighting was categorized based on power draw. The team did extensive web and database searches to find lighting units like those used in the TNT. The inventory was also compared to data submitted by Elvin Vindel, the Calvin Energy Recovery Fund (CERF) intern. Values found in the web research were refined and improved based on data from CERF.

Methods & Procedures:

With the inventory complete, the team focused on developing an initial 0 model to represent the energy use of the TNT center. Although this model relied heavily on researched estimates of power draw and time use, it helped display the power draw trends and focus the efforts of the team on certain aspects of the data. Of note in the zero model was the obviously large power draw of the main LED lighting in the TNT and the power draw of the double hanging fluorescent lights used in the large storage TNT storage area. Combining the TNT zero model with the zero models of the other PE complex teams it was discovered that the overall contribution of the TNT was very small +/- 5%

Using the zero model as a Basis the team performed a sensitivity analysis on all of the components in the TNT by varying the load percent +/- 10%. The sensitivity analysis highlighted the significance of LED lights and double hanging fluorescent lights in the overall energy analysis.

With a zero model in place and the sensitivity analysis complete the team began to more thoroughly examine the lighting usage in the TNT. Focusing on the LED and double hanging fluorescent lights an estimated power draw amount or load % for all the lighting in the TNT was assumed. Using 40%, a number obtained from Dan Slager, as an initial estimate a model was developed to represent the time usage of the TNT lights. Later in the semester the team gained access to documents from Alvin, the CERF intern who was monitoring the lighting usage in the TNT. This data had been collected since April 2014 from several power-draw sensors in the TNT and provided a much more complete picture of the energy use in the TNT. Using these numbers, the team could accurately calculate the power draw and energy use from April 2014 to 2016. The effect of campus events including: track meets, tennis matches and summer camps, on the overall TNT power draw was also examined. The team used Calvin College event data from 2015, data from CERF, and event observation to examine this effect. The power draw data from CERF was matched with Event Services data to get an overall picture of event effects. This data indicated that large increases in event use did not have a significant effect on Power Draw. To verify this data, the team visited several track and tennis events and observed the lighting use. Comparing event usage to days when no events were held, the team observed that there was no significant increase in light usage on event days. This observation matched the CERF and Event Services data comparison. Therefore, the team assumed that events do not have a significant impact on lighting use. Variation in the amount of energy draw from month to month may be linked to other factors such as student use, weather, and external events. Rather than investigate these possible effects more thoroughly, the team aided the HVAC team to model the energy draw from the pumps in the PE Complex. This restructuring was determined with input from the executive team based on the minimal effect of TNT lighting on the overall power draw +/-5%.

The final step in energy usage modelling was the back-casting of known data, 2014-2016, to 2009. Before this could be done however, a back-casting factor was examined. Using CERF data from the TNT for 2014-2016 the team investigated the effect of change from year to year. The CERF data indicated an increase of 1.1% in electricity draw for every year back. This number was compared to similar CERF data available for the Van Noord arena. The Van Noord data varied in the opposite direction of the TNT by 2% over the two years the data was available. The one percent increase observed from the CERF data may be connected to a decrease in power draw from the failure of some of the LED lights in the TNT. Jack Philips mentioned LED light failures Using this comparison the Team decided to back cast without decreasing or increasing the percentage of time usage (power draw) from year to year.

Results:

Figure 1 shows the fully back-casted model. It is important to note that for the years 2009, 2010, 2011, 2012, and 2013 none of the lighting fixtures were altered and the energy usage remained constant. For the years 2014, 2015, and 2016, the team used CERF data from Elvin. These recent years have a significant decrease in energy use compared to the previous 5 years due to the TNT lighting being changed over from the metal halides to the LED bulbs. The fully back-casted model is shown in Figure 1 and Table 1 with specific estimates for the team's predicted energy consumption. The overall energy usage is shown in a component basis in Figure 2. The 210 W LEDs are the biggest contributors to power draw in 2016.

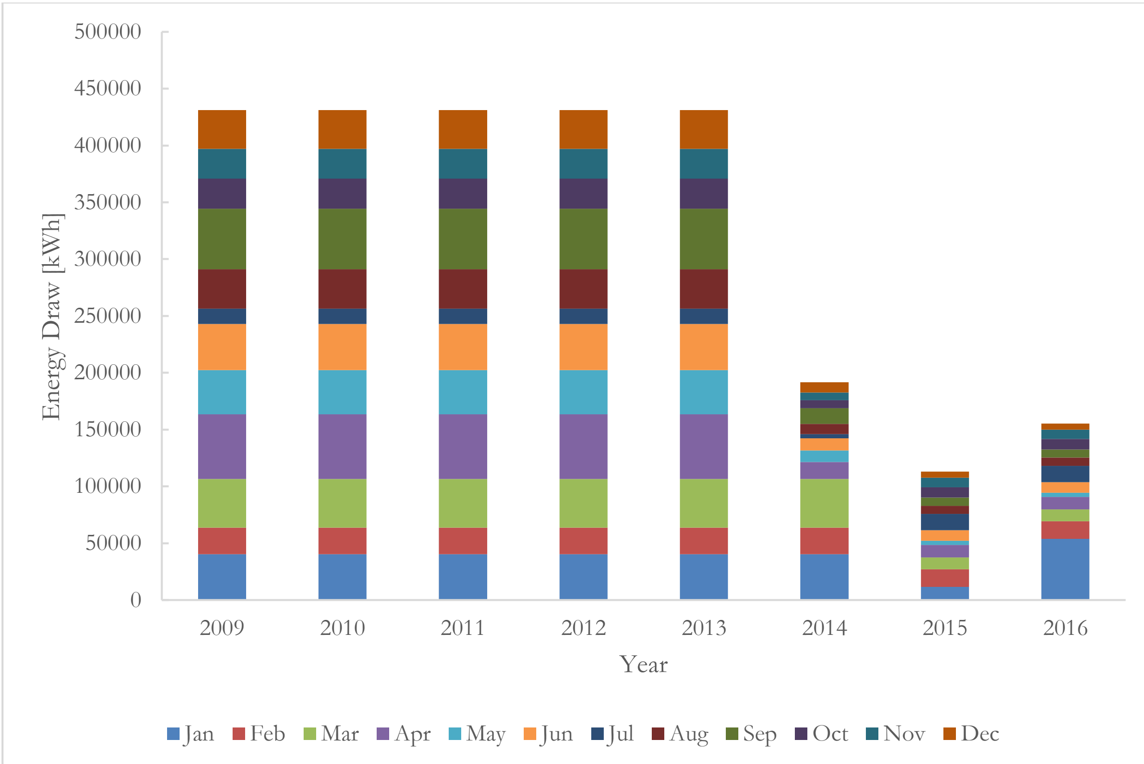

Figure 1: Fully back-casted energy demand model for TNT Lighting.

Table 1: Back-casted predicted consumption estimates

Year	*Predicted Consumption* [*kWh*]
2009	431142
2010	431142
2011	431142
2012	431142
2013	431142
2014	191595
2015	112891
2016	155269

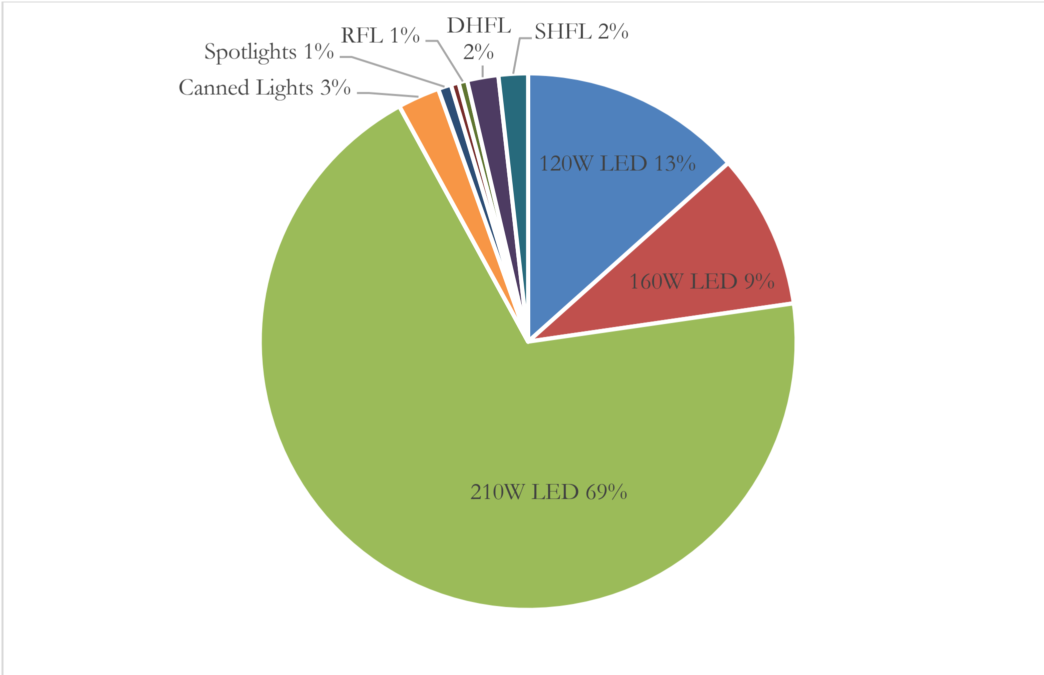

Figure 2: Energy consumption distribution in the TNT for the year of 2016.

Discussion & Assessment:

The team found the projected energy demand model to be accurate. The recent three years, 2016, 2015, and 2014 used recorded usage data from CERF and behave as expected. The years of 2013, 2012, 2011, and 2010 may not correspond with the exact energy consumption for those years. However, the projected data tells a story, describing the change in energy consumption initiated by the move to LED lights in April 2014. The metal halide lights were a massive energy drain. After these lights were replaced by the 210 W LED bulbs, the data confirms that energy consumption was reduced by 65%.

The TNT lighting made up 8% of the total Spoelhof Complex electric demand from 2009-2016. Although this is not a large number, the TNT was a significant player in the overall energy demand. However, because the energy consumption has been decreased by 65% through the implementation of LED lighting the current overall contribution of the TNT is significantly less around 2-4 % of the yearly demand. In this way, the TNT serves as an example of improvement for the rest of the Field House Complex. As shown by the TNT CERF project, implementing high efficiency lights has a big impact on energy draw. Having a knowledge of the location of energy consumption and being able to provide higher efficiency alternatives may have significant impact on reducing the overall power draw of the Field House Complex.

Future Projections:

After evaluation of the TNT lighting, the biggest contributor to energy draw costs and lighting costs in general is the factor of time usage. To reduce this cost, we suggest more modifications to the timer schedule that controls the current LED setup. By reducing the time that these lights are on, the energy draw can be decreased dramatically.

TNT lights are occasionally left on by accident for long periods of time. This could be minimized by implementing training for all campus staff. It could also be minimized by installing timers which could automatically shut off the lights when usage is not scheduled.

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APPENDIX 1.A: Energy Usage

Table 1.A.1 Energy Use in The TNT Separated by Power Draw

LED Lights CERF DATA	Type of Bulb	Units	Total Wattage/Unit	h On [h]	Total Off [kW*h]	Energy Draw [kW*h/year]
120W LED	LED	46	5520	2740	15124.8	41441.952
160W LED	LED	24	3840	2740	10521.6	28829.184
210W LED	LED	136	28560	2740	78254.4	214417.056

Other Lights	Type of Bulb	Units	Power/ bulb [W]	On Peak HRS.	Time usage [h/year]	Energy Draw [kW*h/year]
Metal Halide 2009-2014	Metal Halide	142	1085	12	4380	674826.6
Exit Signs	LED	8	0.04	24	8760	11.2128
Fire Alarms	LED	21	0.04	0.027	9.855	0.0165564
Canned Lights	Incandescent	16	65	12	4380	4555.2
Spotlights	Incandescent	5	65	12	4380	1423.5
Hanging Lights	Incandescent	3	65	24	8760	1708.2
Recessed Fluorescent Lights	Fluorescent	5	43	10	3650	3139
Double Hanging Fluorescent Lights	Fluorescent	18	43	10	3650	11300.4
Single Hanging Fluorescent Lights	Fluorescent	17	43	10	3650	5336.3

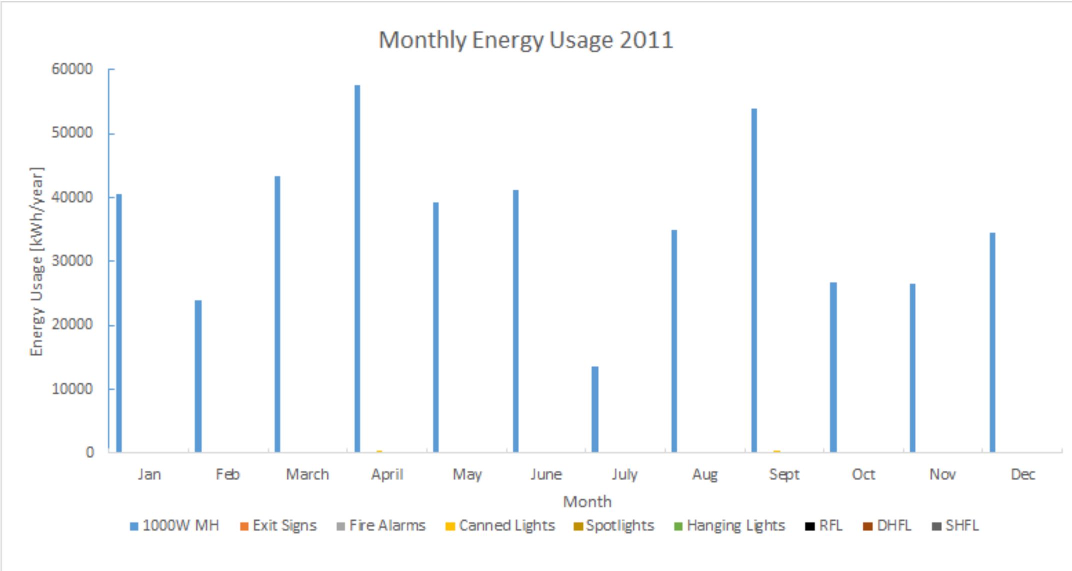

Figure 1.A.1: Energy use in TNT separated by month. Representative Graph Shown for 2011.

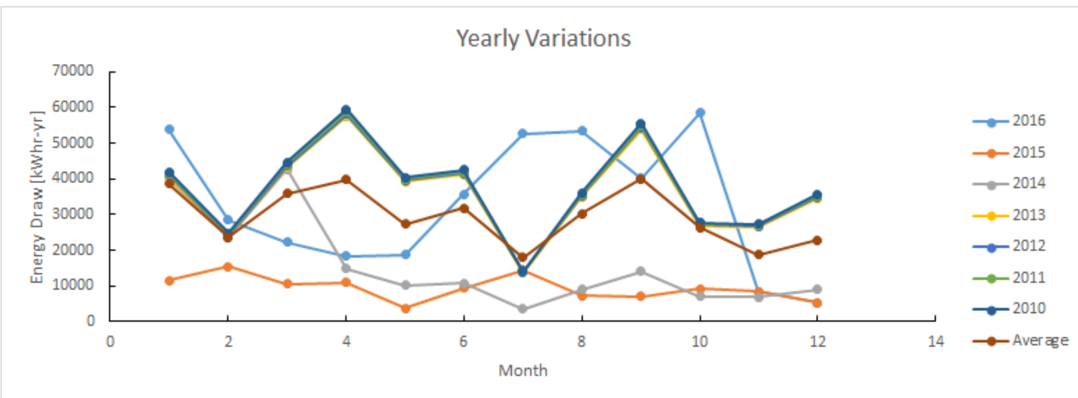

Figure 1.A.2: Energy use in TNT separated by Year

APPENDIX 1.B: Sensitivity Analysis

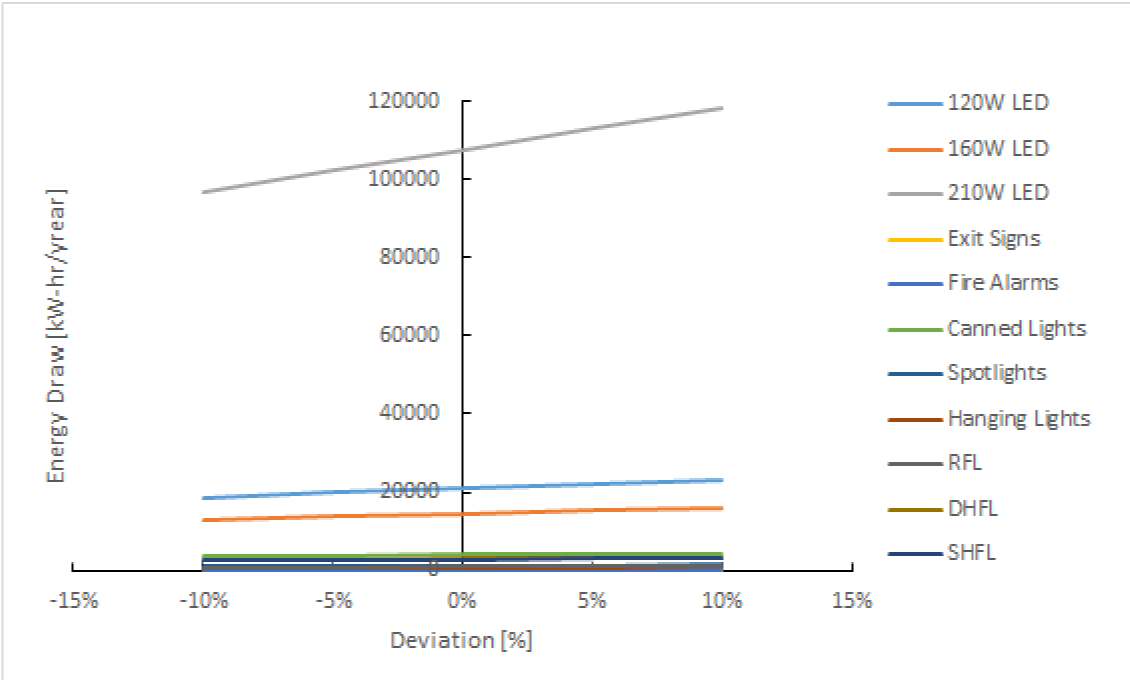

Figure 1.B.1: Sensitivity Analysis from 2015 Data, 210W LED Lights are the Biggest Contributors to Power Draw

APPENDIX 1.C: Back Casting Tables

Table 1.C.1:Example Back Casting Data Shown for 2016 Other Back casting to be Found in Google Drive Folder B-1 TNT

2016 Energy Usage Data Monthly Basis											
0.42	0.56	0.38	0.40	0.13	0.34	0.52	0.26	0.26	0.34	0.30	0.19
0.48	**0.25**	**0.20**	**0.16**	**0.17**	**0.32**	**0.47**	**0.47**	**0.36**	**0.52**	**0.07**	**0.05**
Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
7227602	2063394	1403218	1473195	489837	1249759	1930500	960646	947755	1235027	1111647	709896
5027897	1435405	976152	1024831	340756	869398	1342956	668275	659308	859149	773320	493841
37394983	10675821	7260130	7622184	2534376	6466146	9988237	4970299	4903604	6389924	5751566	3672940
419	120	81	85	28	72	112	56	55	72	64	41
1100	314	214	224	75	190	294	146	144	188	169	108
1361722	388755	264374	277559	92288	235462	363717	180991	178563	232686	209441	133749
425538	121486	82617	86737	28840	73582	113662	56560	55801	72714	65450	41796
255323	72892	49570	52042	17304	44149	68197	33936	33480	43629	39270	25078
281510	80368	54654	57380	19079	48677	75192	37416	36914	48103	43298	27650
1013435	289324	196756	206568	68684	175238	270690	134699	132892	173172	155872	99540
957133	273250	185825	195092	64868	165503	255651	127216	125509	163552	147213	94010

APPENDIX 1.D: Event Data

The event data in the TNT for the year is shown in the figure below (Figure. If this is compared to CERF data, there is no noticeable increase in energy use from the Fall semester to the Spring semester.

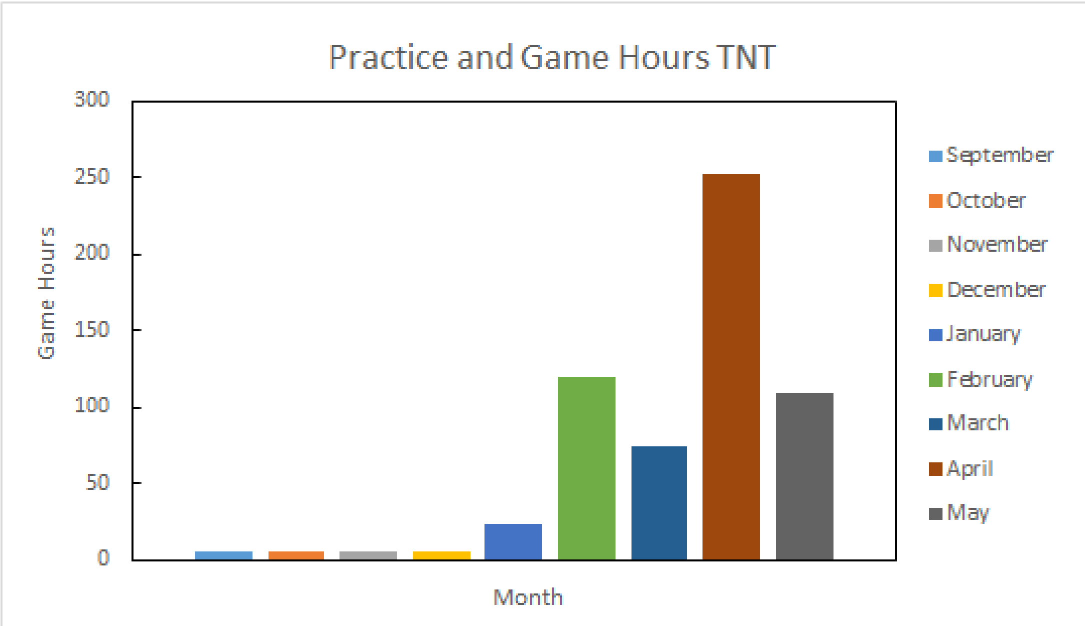

Figure 1.D.1: Event Use in the TNT

<u>*APPENDIX 1.E: Metal Halide Lights*</u>

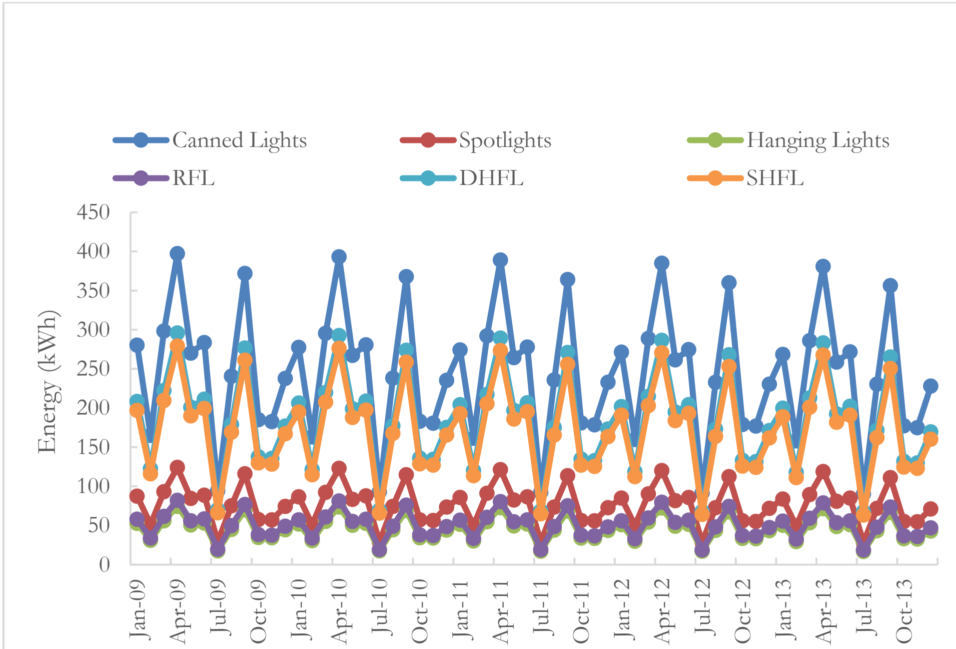

Figure 1.E.1: Energy Use for Other Lighting in the TNT

Figure 1.E.2 Energy Use for Metal Halides on Per Month Basis is Much Higher than Any of the Other Lighting in the TNT

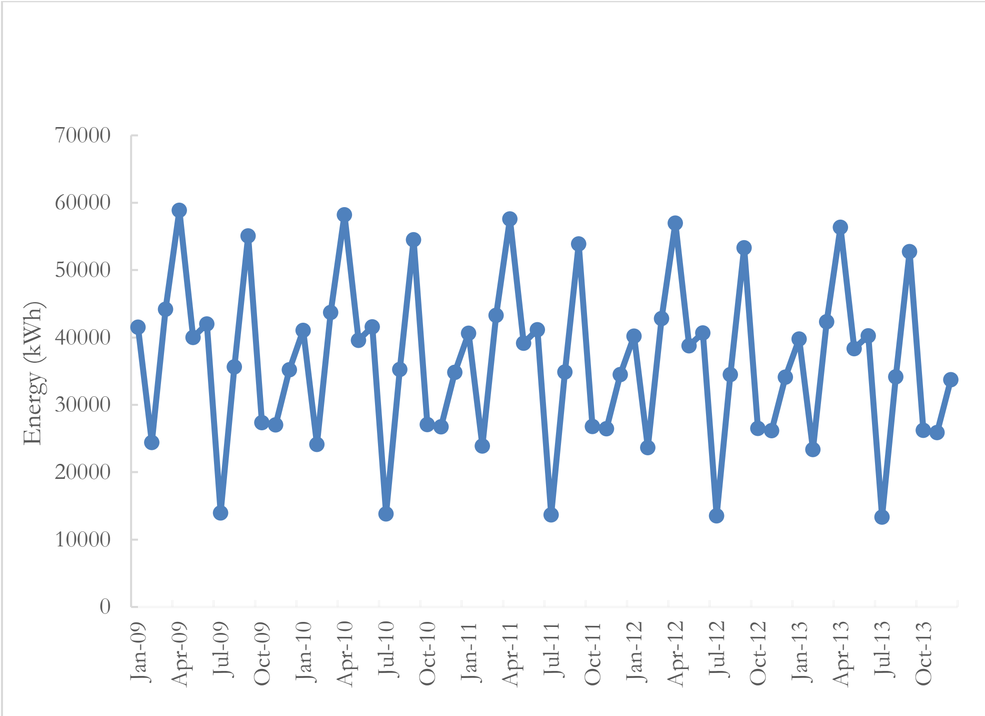

Figure 1.E.3: Energy Use of Metal Halides on a Monthly Basis

PE Complex Bottom Up Energy Model

Appendix 2

Venema Lighting

Ellen Reidy, Jordan Swets, and Joel Van Dyke

Objective:

The objective of this project was to quantify and analyze the energy use of a section of the Calvin College Field House Complex. Included in this the Venema Aquatic Center are the adjacent swimming locker rooms, as well as the Hoogenboom Gymnasium and its adjacent dance studios, Calvin Health Services, and the Steen Hospitality Suite in the Calvin College Field House Complex.

Research:

To begin, the group had to get an inventory of their specified locations. The class decided to have a representative from each group, which acted as the main point person. This group was referred to as the Executive Team. The Executive Team decided to have all groups do an entire inventory of a specified sections whether or not the team would do the analysis on the inventory later. This meant Group B2 was in charge of counting all of the lights, appliances, and anything else that required electrical energy in the Venema Aquatic Center, which also included the locker rooms, the Steen Hospitality Suite, and any offices. After inventories were completed, teams slit to do their analysis. These analyses were broken up into the 2016 year, 2016 year by months, and then lastly a back casting model until 2010 broken up by months.

Research also had to be done on event schedules, years of replacements, and hours of operation. These were all important to get accurate calculations. The hours of operation were the most important in accurately representing the Field House Complex energy consumption. Group B2 got this data by using Calvin College's event schedules, talking to the swim coach, and using observations on when lights are turned on and off.

Methods & Procedures:

The main part of this project was making a model for the energy consumption of the Field House Complex. This involved three different iterations. The first breakdown of 2016 yearly usage was straight forward. Group B2 took an average of all times lights where on and expanded that out for an entire year. This included meet times, practices, and other special events. At first, the team didn't have a good understanding of the wattage each light used. After doing more research, Group B2 was able to get a more accurate account for energy consumption.

The second main iteration of the project involved including the differences in months in the analysis. This meant instead of just mentally accounting for the changes in seasons, to actually show the change in numbers. There's a huge difference in lighting usage during swim season verses at the end of school when not many things are happening in the pool. The team had to account for things such as practices in the Hoogenboom, summer camps in the pool and Hoogenboom, and Calvin College's club, Dance Guild, which happens every semester. All of these things happen on top of classes and normal daily usage. This iteration helped give the class a better understanding of how usage and activities affected energy consumption.

The last iteration involved back casting the model to previous years. This helped the class know if their model was working correctly. The original assignment was to back cast the model to 2007, but because the Field House Complex was being built up until 2010, back casting couldn't accurately be completed for 2007-2009. However, there were still major changes that happened since 2010. For example, the switch from metal halide lights to LED's happened in 2014. This saw a huge shift in energy consumption since the large metal halides accounted for 455 W compared to 240 W that the new, large LED's used. The smaller metal halides used 290 W, while the replacement LED's use 120 W. This will be discussed more in the results section.

Results:

After the sensitivity analysis was performed for all the areas that Group B2 covered, the areas that were found to be most sensitive to usage were the event lighting in the Venema Aquatic center, the Health Services lights, the lights in the pool locker rooms, and the lights in the Hoogenboom Gymnasium. The Venema event lights were the largest power draw out of any of the fixtures that Team B2 studied. The lights required 1000 W bulbs and there are 50 fixtures with these bulbs in them that operate for around six hours for each swim meet. The reason the other three areas were sensitive to change was that they operated for the largest amount of time throughout the year. Health Services is required to be open during the weekdays for a set amount of hours, the pool locker room lights are rarely turned off, and the Hoogenboom is used almost constantly throughout the day. Results for this sensitivity analysis can be seen in Appendix 2.C.

From the data collected, the months that draw the most power are October through March. September draws about half as much power as these months. The data for this can be seen in Appendix 2.D, Figure 2.D.1, and Appendix 2.E, Figure 2.E.1. The months that Calvin College has practices are the months that draw the most power. The only sources for power over the summer months when classes are not in session in the athletic complex are Health Services summer hours and summer camps. As the summer camps do cumulatively add up to as many hours as classes, they do not contribute to power draw as much as practices do during normal school months.

The results from back casting back to 2010 show a drop in power draw from 2014 to 2015. This is because of the CERF campaign to change to more efficient light fixtures. The metal halide lights that were replaced in July of 2014 drew more than twice the power that the new LED arrays do. Since the places where these lights were used are sensitive to power usage change, this change drastically reduced the power consumed in Venema and Hoogenboom. All other areas were unaffected by the CERF changeover. When back casting the 2016 data to 2015 and the 2014 data to 2010, the numbers remained unchanged as per executive decision in class. The results for back casting can be seen in Appendix 2.E.

Discussion & Assessment:

If the point of this project was to cut down on the energy used in the Fieldhouse, there are not many useful or original recommendations to make on this front. The power consumption of the lights in this section is about 3% of the total energy consumption of the Field House Complex. In the interest of saving as much energy as possible, the following steps should be applied. Technology will keep progressing, and lighting could one day become efficient to the degree that it makes economic sense for the school to once again replace the fixtures currently in use. The largest draw is from the event lights above the pool, which run 1000 Watt lamps, but if they are replaced with something more efficient, care should be taken to ensure the new lights can provide the same coverage and brightness as the originals. Pool lighting needs to be bright enough that the swimmers can see and be seen beneath the surface of the water by spectators and lifeguards alike. As for the lights that have been replaced by CERF already, they can remain until, as discussed before, the fixtures become markedly more efficient again. The most efficient solution would be to simply lower the lights nearer the surface, which would require fewer lumens from each panel, but this too would risk impairing the view from the stands.

In conclusion, further energy conservation in this part of the building is extremely possible, but very limited by the requirements of the building functions. All changes made to the system must not violate the safety of the people using the facility. While these reductions in energy consumption may be small in comparison to the overall energy usage of the Field House, they are still improvements.

Future Projections:

The energy consumption of the Venema Aquatic Center, the adjacent swimming locker rooms, Steen Hospitality Suite, Calvin Health Services, Hoogenboom Gymnasium and its adjacent dance studios will continue to drop as Calvin College continues to work toward conservation. Eventually this will plateau as the limit of lighting and heat efficiency is approached from above. Even the most efficient lights can waste energy if a careless hand leaves them on when they are unnecessary. The sheer size and design of the Field House Complex prevents a lighting scheme focused on natural light. Perhaps one day these areas will consume no energy, but this would involve a great amount of resigning and technological improvements.

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APPENDIX 2.A: Responsibilities

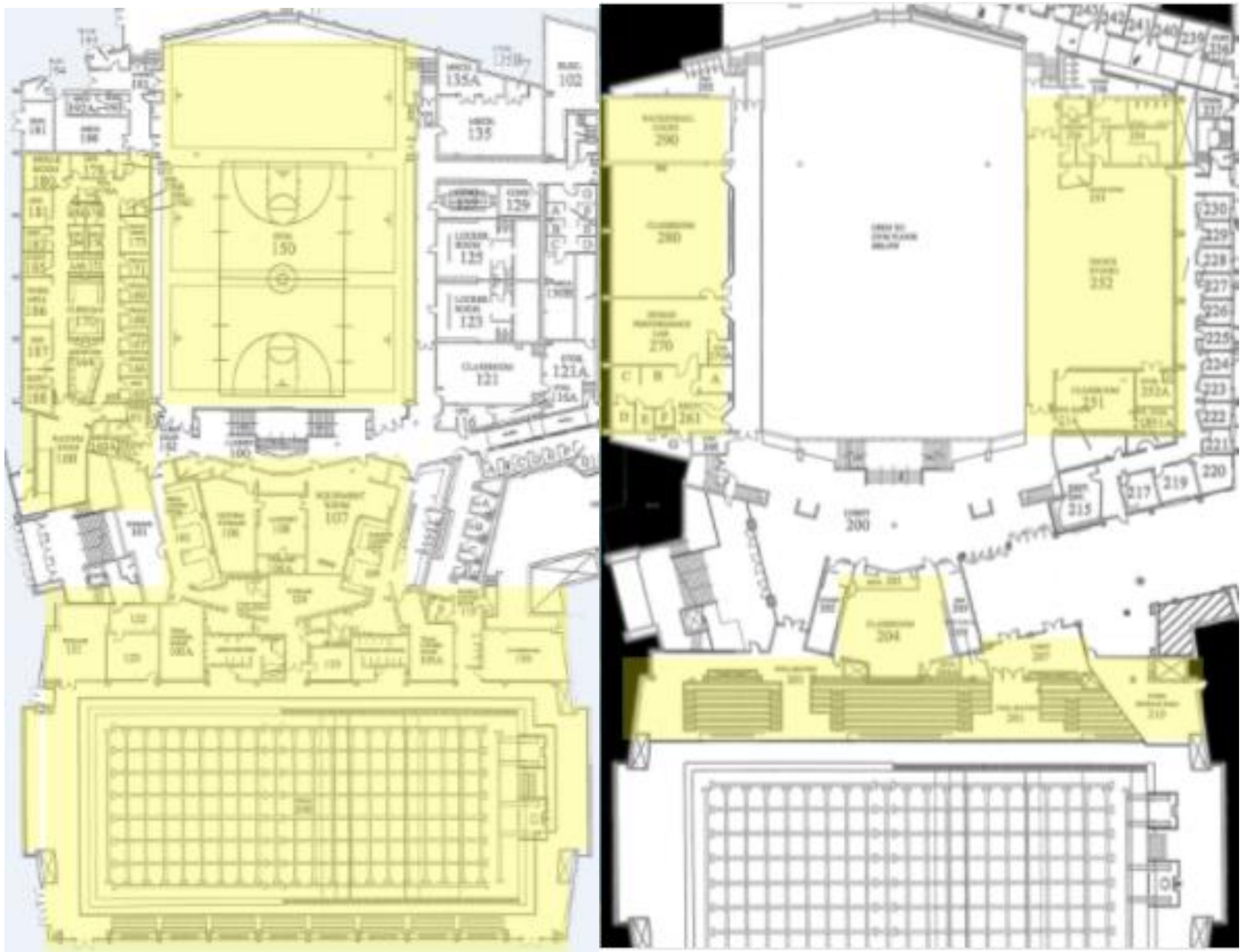

Figure 2.A.1: Breakdown of Group B-2's responsibilities

APPENDIX 2.B: Initial Gantt Chart

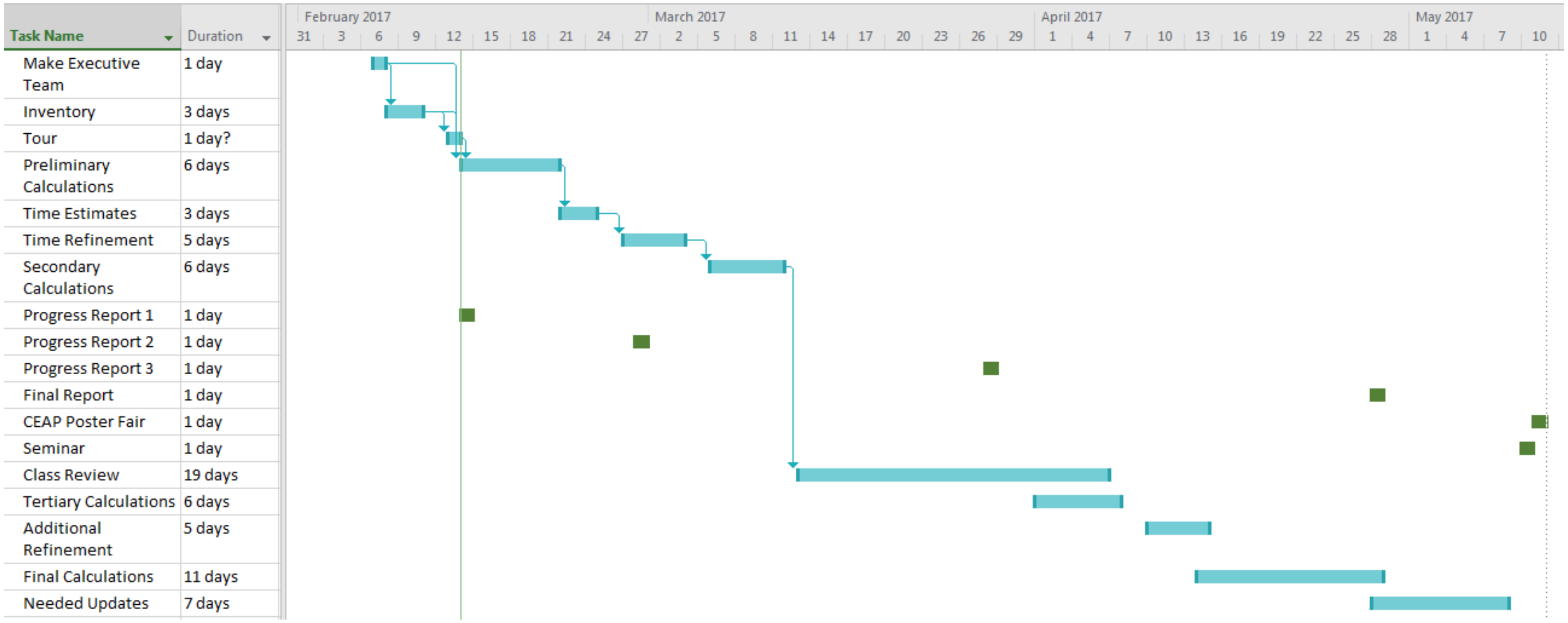

Figure 2.B.1: Gantt Chart for Group B-2's Schedule

APPENDIX 2.C: Sensitivity Analysis

Table 2.C.1: Sensitivity Analysis of Specific Lights

Sensitivity	-15%	-10%	-5%	0%	5%	10%	15%
Pool LED Lights	19856	21024	22192	23360	24528	25696	26864
Pool Event Lights	64906.782	68724.828	72542.874	76360.92	80178.966	83997.012	87815.058
Pool Other Lights	11069.72	11720.88	12372.04	13023.2	13674.36	14325.52	14976.68
Storage Lights + Laundry	416.976	441.504	466.032	490.56	515.088	539.616	564.144
Locker Lights	27699.12	29328.48	30957.84	32587.2	34216.56	35845.92	37475.28
Class/Office Lights	2144.448	2270.592	2396.736	2522.88	2649.024	2775.168	2901.312
Steen	4035.732	4273.128	4510.524	4747.92	4985.316	5222.712	5460.108
Dance Studios	8418.944	8914.176	9409.408	9904.64	10399.872	10895.104	11390.336
Health Services	31109.388	32939.352	34769.316	36599.28	38429.244	40259.208	42089.172

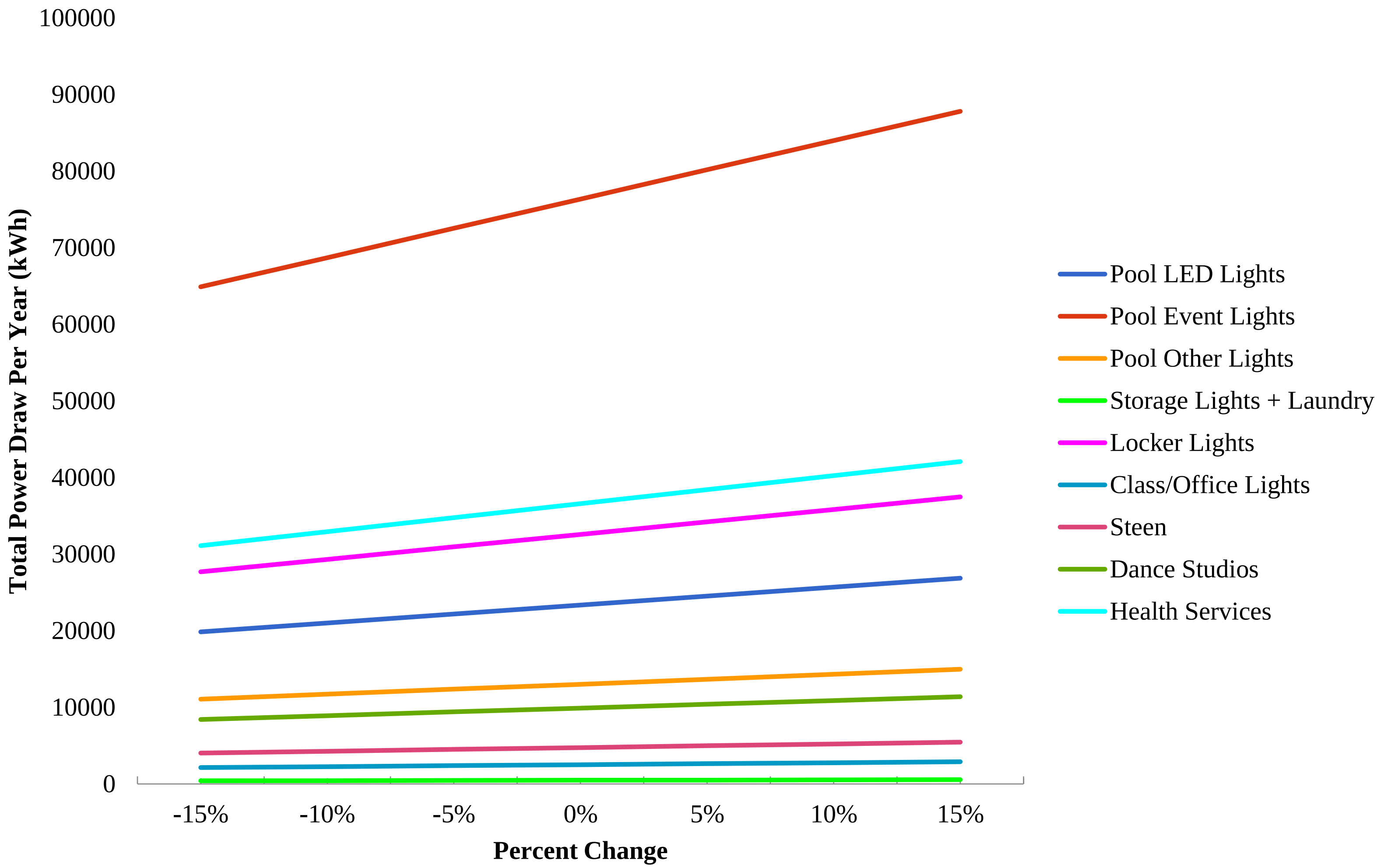

Figure 2.C.1: Sensitivity Analysis for Group B2

APPENDIX 2.D: Total Energy Usage Breakdown

Table 2.D.1: Model of Energy Consumption for Each Area for 2015 - 2016

Month	Hoogenboom/Venema				Health Services	Concerts	Total (kWh/month)
	Practices	Meets/Games	Off-Hours	Classes			
Jan	6864.1	698.56	1053.92	617.0	744.42	5.94	**9983.9**
Feb	6309.1	698.56	1053.92	557.2	744.42	5.94	**9369.2**
Mar	6985.1	349.28	1053.92	617.0	744.42	5.94	**9755.6**
Apr	0.0	0	1053.92	597.1	744.42	5.94	**2401.3**
May	0.0	0	391.84	617.0	721.15	5.94	**1735.9**
Jun	0.0	0	391.84	0.0	697.89	0.00	**1089.7**
Jul	0.0	0	391.84	0.0	697.89	0.00	**1089.7**
Aug	257.2	0	391.84	0.0	697.89	0.00	**1346.9**
Sep	3379.9	0	1053.92	597.1	744.42	5.94	**5781.2**
Oct	7242.3	698.56	1053.92	617.0	744.42	5.94	**10362.1**
Nov	7008.7	698.56	1053.92	597.1	744.42	5.94	**10108.6**
Dec	6985.1	1047.84	1053.92	617.0	744.42	5.94	**10454.2**
Total	45031.5	4191.36	9998.72	5433.2	8770.15	5.94	**73430.9**

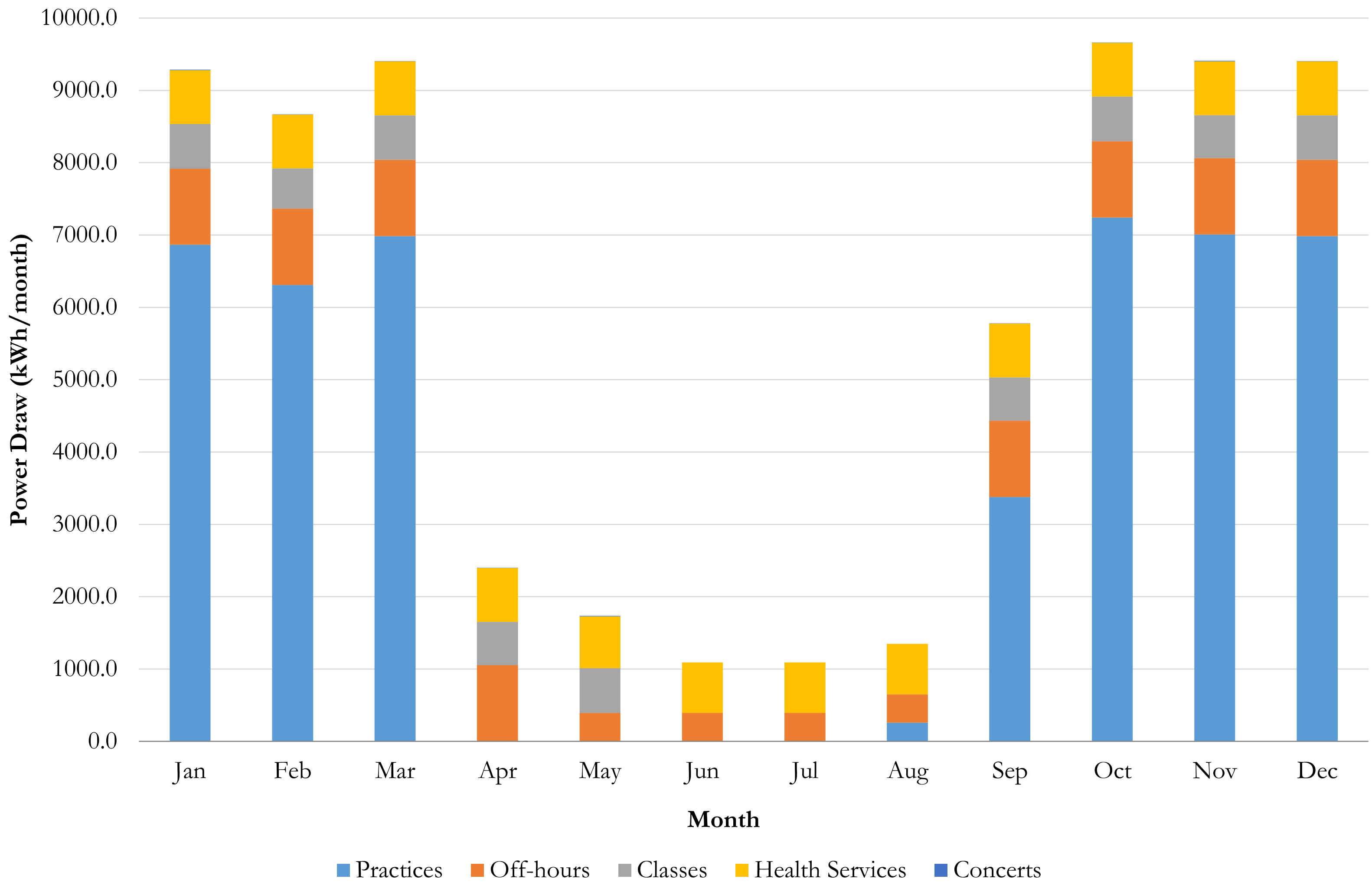

Figure 2.D.1: 2016 Hoogenboom and Venema Lighting Power Draw

APPENDIX 2.E: Back Casting Model

Table 2.E.1: Back Casted Model of Energy Consumption for Each Area for 2010 - 2014

Month	Hoogenboom/Venema				Health Services	Concerts	Total (kWh/month)
	Practices	Meets/Games	Off-Hours	Classes			
Jan	9474.929143	928.224	2916.914	1693.826714	744.42	5.936	15764.24586
Feb	8729.232	928.224	2916.914	1529.908	744.42	5.936	14854.63
Mar	9664.506857	464.112	2916.914	1693.826714	744.42	5.936	15489.71157
Apr	0	0	2916.914	1639.187143	744.42	5.936	5306.453143
May	0	0	1133.11	1693.826714	721.15	5.936	3554.025714
Jun	0	0	1133.11	0	697.89	0	1831
Jul	0	0	1133.11	0	697.89	0	1831
Aug	1044.655714	0	1133.11	0	697.89	0	2875.655714
Sep	4676.374286	0	2916.914	1639.187143	744.42	5.936	9982.827429
Oct	10709.16257	928.224	2916.914	1693.826714	744.42	5.936	16998.47929
Nov	10363.70571	928.224	2916.914	1639.187143	744.42	5.936	16598.38286
Dec	9664.506857	1392.336	2916.914	1693.826714	744.42	5.936	16417.93557
Total	64327.07314	5569.344	27867.752	14916.603	8770.15	53.424	121504.3471

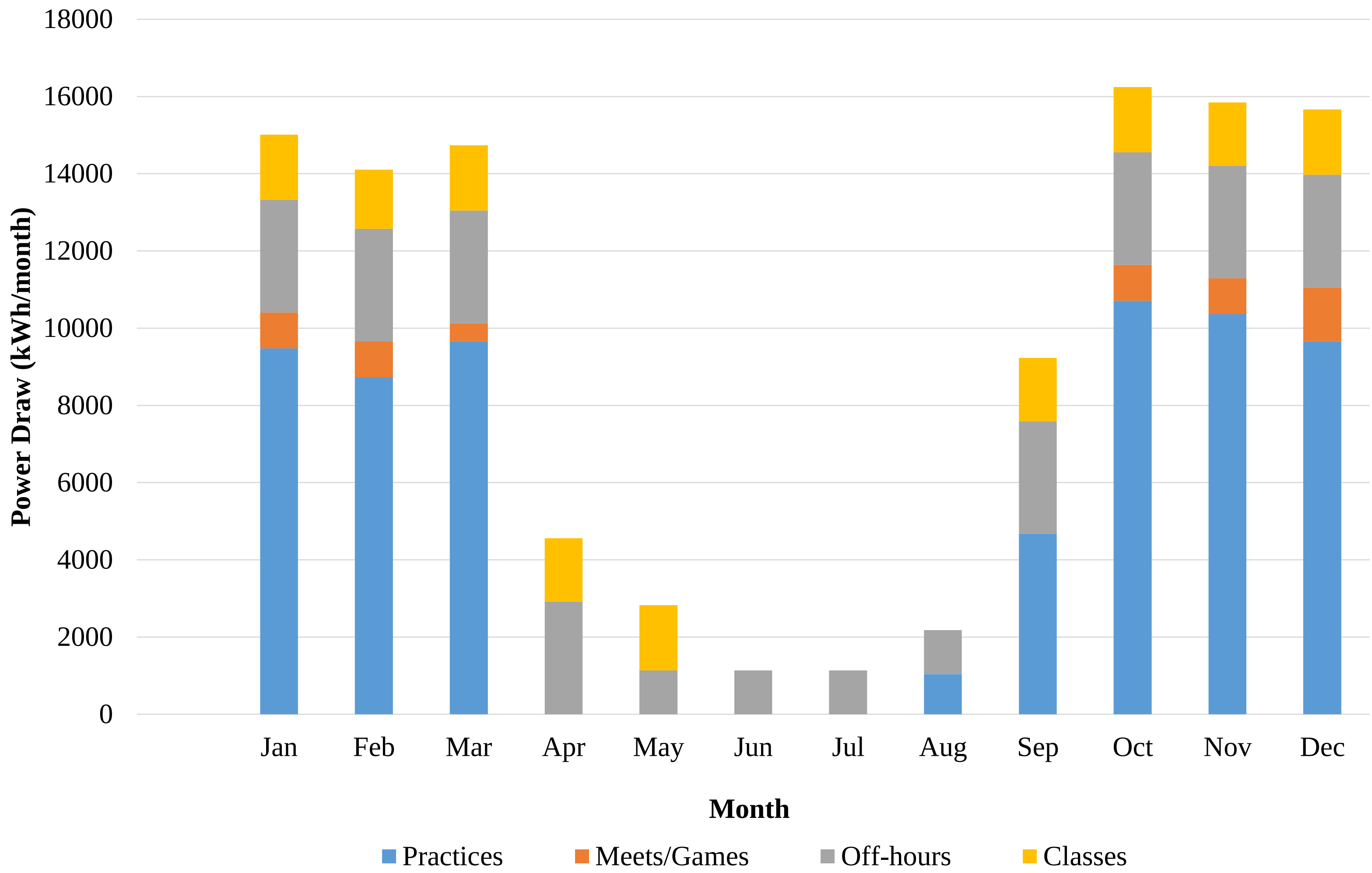

Figure 2.E.1: 2014 Back Casted Hoogenboom and Venema Lighting Power Draw

PE Complex Bottom Up Energy Model

Appendix 3

Van Noord Lighting

Connor Macdonald, Josiah Markvluwer, Justin Rohlicek

Objective:

In the class bottom up model, the energy usages include: lighting, HVAC, computers/outlets, and pool operations. A large portion of the Spoelhof Fieldhouse Complex's energy is consumed by the lighting in the Van Noord Arena, the class rooms adjacent to the arena, the locker rooms, and the surrounding hallways. Since Van Noord Arena's lighting consumes the most energy, it's analysis is the most detailed. In order to get a bottom-up estimate for the amount of energy the lighting in the arena has used, first an estimate will need to be made for the amount of lights in the building, their wattages, and the amount of hours that the lights are on.

Research:

After looking at the sensitivity analysis the key contribution was from the overhead metal halide lighting. After looking at different replacement options at commercial lighting vendors LED lighting seems like a great alternative to explore. Especially with LED Lamps. Commercial LED lamps produce 20% the lumens per watt of power used and have similar lifetime bulb cycle. One setback to replacing the bulbs would be the large upfront cost the gym. Each LED lamp cost approximately $200 each and the gym would require double the LED fixture to reach a similar lumen range to the MH lighting. This upfront cost would be approximately $70,000 for 300 lamps to cover the arena ceiling. In the scheme of things considering how much is spent on electricity usage this is a viable option.

Methods & Procedures:

The team was tasked with collecting lighting data from the Van Nord Arena. For creating a base case model the team began by delegating out the gym into sections for recording lighting power draw. The lighting data quantities were collected and compiled into excel the team contacted the physical plant to retrieve data on each light sources power draw. For the base case the team made assumptions on light usage to obtain a rough value of the power draw on an annual basis. The team next completed a sensitivity analysis where each light source was categorized and varied by 10% in the plus and minus direction. The sensitivity study allowed the team to hone into what light sources had the largest impact on power draw. Next the team focused on breaking down the data into monthly usage and researching hours of operation within the fieldhouse.

Results:

Using our initial yearly model, we found the hours that the Van Noord Arena were in use per month. Once the monthly data was found, it was plugged into the monthly model and graphed. Belo in Table 1 can be found the 2016 monthly energy usage.

Table 1: 2016 Monthly Energy Usage

Month	Predcited Consumption	Units
January	36199.124	[kW-hr]
February	26485.364	[kW-hr]
March	18390.564	[kW-hr]
April	18390.564	[kW-hr]
May	18390.564	[kW-hr]
June	27641.764	[kW-hr]
July	38396.284	[kW-hr]
August	23594.364	[kW-hr]
September	23016.164	[kW-hr]
October	27641.764	[kW-hr]
November	28974.484	[kW-hr]
December	24172.564	[kW-hr]

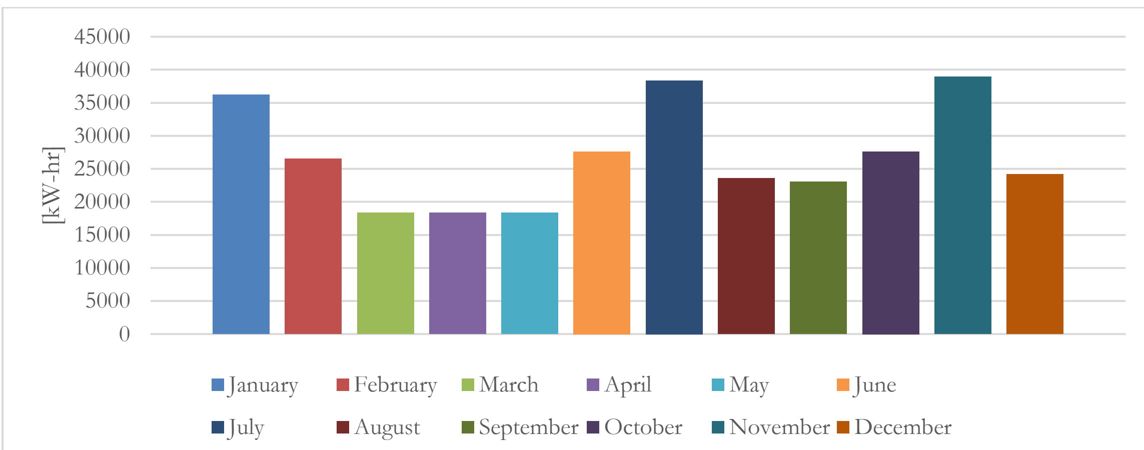

Figure 1: 2016 Monthly Energy Usage in Van Noord Arena

Once our 2016 model was finished, we began back casting for the Van Noord Arena. When looking into the past seven years, we found that nothing had been majorly changed in the Arena for the last six to seven years. What this means, is that there were no major light changes or new LED rows put in. We looked into adding a back casting factor of 1.1% which was used by the lighting team in the Venema, but found that this was not a sufficient result because we had no proof or good reasoning to add that back casting factor. We then decided to back cast using no factor. Below in Table 2 and Figure 2, the graphs look the exact same for every year and again the reasoning for this is because we can find no change in the last seven years except for random bulb replacements. For our model, the Van Noord Arena uses the around the same amount of energy for the last eight years.

Table 2: Van Noord Arena Yearly Energy Usage

Month/Year	*Predcited Consumption*	Units
2016	321293.568	[kW-hr]
2015	321293.568	[kW-hr]
2014	321293.568	[kW-hr]
2013	321293.568	[kW-hr]
2012	321293.568	[kW-hr]
2011	321293.568	[kW-hr]
2010	321293.568	[kW-hr]
2009	321293.568	[kW-hr]

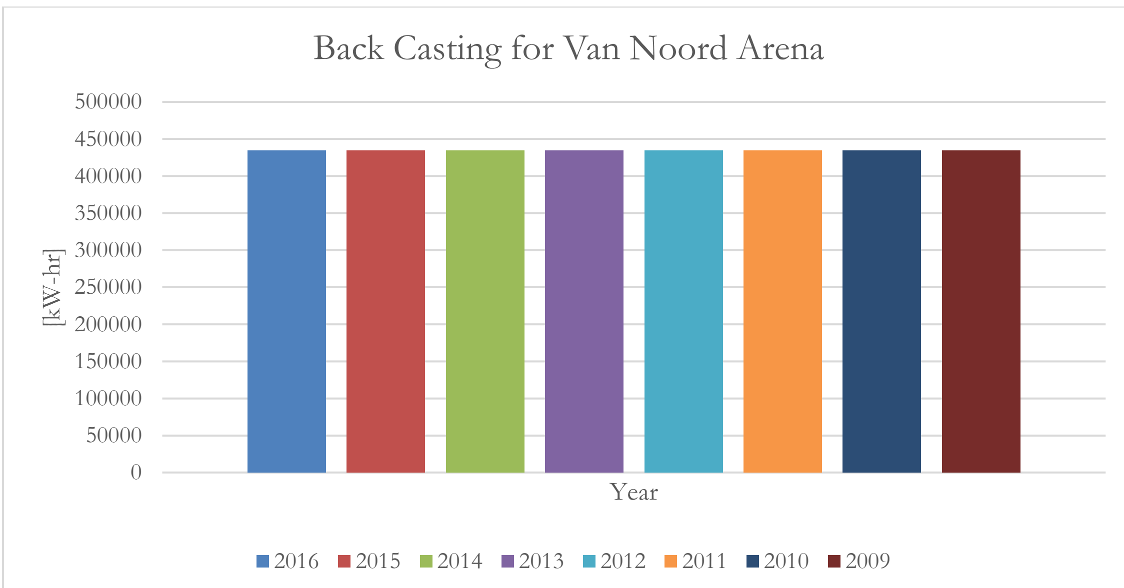

Figure 2: Yearly Energy Usage in Van Noord Arena

<u>Discussion & Assessment:</u>

The lighting in the Van Noord Arena and its surrounding areas account for 8% of the energy consumption of the Speolhof Fieldhouse Complex. The key to getting the most accurate model of the lighting energy consumption was to determine a more defined estimation of the energy usage in the main gym. The techniques that were used to do this was a count of the lighting, an observation of hours of usage, and a sensitivity analysis.

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3.A: Yearly Model

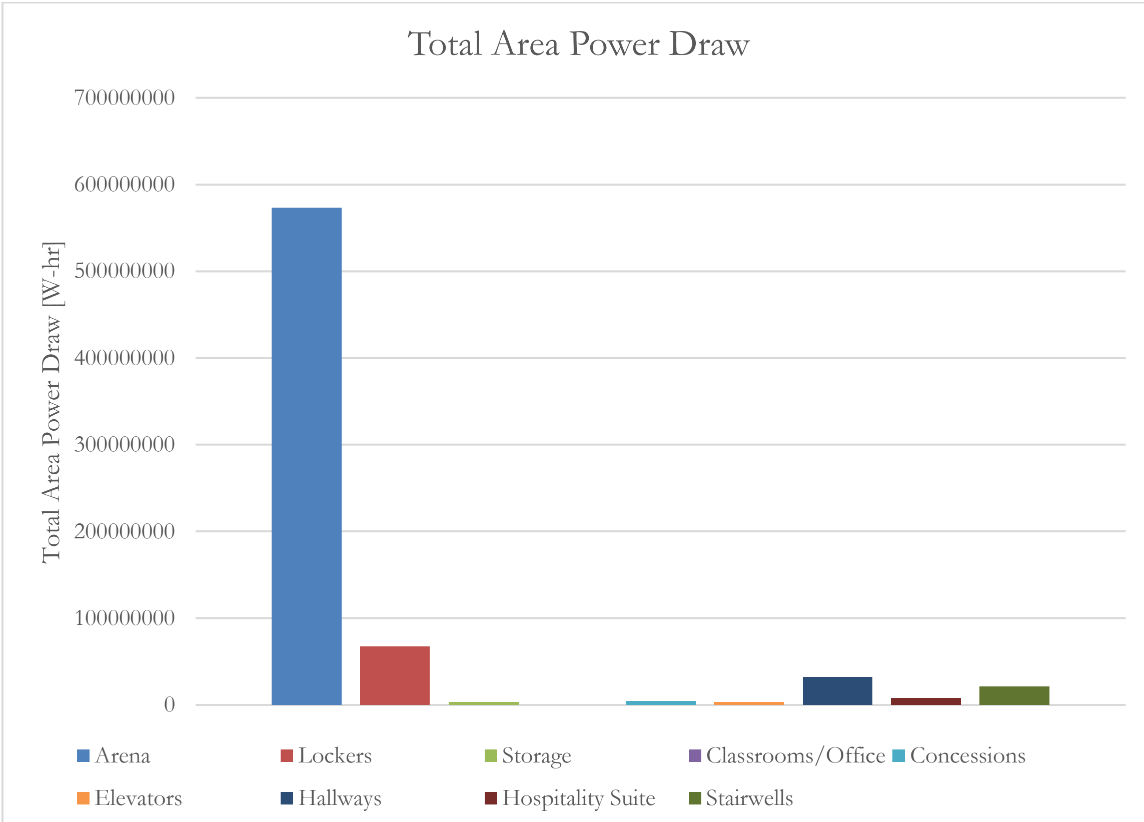

Figure 3.A.1: Total Area Power Draw in the Van Noord Arena

3.B: Monthly Usage Data

Combined Monthly Usage (2016)					
Month	Sports			Summer Camp	Total Month
	Games	Game Hours	Practices		
	[games/month]	[hr/month]	[hr/month]	[hr/month]	[hr/month]
January	16	32	122	0	154
February	7	14	56	0	70
March	0	0	0	0	0
April	0	0	0	0	0
May	0	0	0	0	0
June	0	0	0	80	80
July	0	0	0	173	173
August	0	0	0	45	45
September	4	8	32	0	40
October	8	16	64	0	80
November	13	26	152	0	178
December	5	10	40	0	50

Figure 3.B.1: Van Noord Arena Monthly Usage for 2016

3.C: Monthly Model 2016

January						
Categories	Fixtures	ulbs/Fixtu	ower Draw [Watt	tal Power [Watt	hr/month	[W-hr]
Arena						
North Gym						
CFL	18	36	57	2052	372	763344
MH	18	36	250	9000	372	3348000
South Gym						
CFL	18	36	57	2052	372	763344
MH	18	36	57	2052	372	763344
Main Arena						
WEST CFL	12	24	57	1368	154	210672
WEST MH	12	24	250	6000	154	924000
MIDDLE LEFT CFL	44	88	57	5016	154	772464
MIDDLE LEFT MH	44	88	400	35200	154	5420800
MIDDLE RIGHT MH	6	12	400	4800	154	739200
NORTHEAST MH	6	12	400	4800	154	739200
EAST CFL	4	8	57	456	154	70224
EAST MH	4	8	250	2000	154	308000
SOUTH MH	28	56	1000	56000	154	8624000
Lockers						
Long Lights	50	100	57	5700	372	2120400
Short Lights	56	56	57	3192	372	1187424
Mens Bathroom	57	57	57	3249	372	1208628
Womens Bathroom	57	57	57	3249	372	1208628
Storage						
Long Hall Storage East low	18	36	93	3348	15.5	51894
Hall Storage south lower	8	16	93	1488	15.5	23064
Long Hall Storage West low	18	36	93	3348	15.5	51894
Hall Storage north lower	8	16	93	1488	15.5	23064
Long Hall storage East upp	10	20	93	1860	15.5	28830
Hall Storage North Upper	6	12	93	1116	15.5	17298
Long Hall Storage West upp	10	20	93	1860	15.5	28830
Hall Storage South upper	6	12	93	1116	15.5	17298
Class/Office						
Square Ceiling Lights	16	48	57	2736	372	1017792
Concessions						
Standard Lights	18	18	57	1026	372	381672
Hallway						
Standard Lights	127	127	57	7239	372	2692908
Elevators						
Standard Lights	6	12	57	684	372	254448
Hospitality Suite						
Standard Lights	20	20	57	1140	372	424080
Lamp lighting	11	11	57	627	372	233244
Stairwells						
Standard Lights	42	84	57	4788	372	1781136
					Total:	36199.124

Figure 3.C.1: Sample Model for Month of January

3.D: Back Casting

YEAR	2016	2015	2014	2013	2012	2011	2010	2009
	[kW-hr]	[kW-hr]	[kW-hr]	[kW-hr]	[kW-hr]	[kW-hr]	[kW-hr]	[kW-hr]
January	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
February	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
March	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
April	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
May	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
June	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
July	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
August	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
September	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
October	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
November	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
December	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124	36199.124
Total:	434389.488	434389.488	434389.488	434389.488	434389.488	434389.488	434389.488	434389.488

Figure 3.D.1: Back Casting Model for Van Noord Arena

PE Complex Bottom Up Energy Model

Appendix 4

HVAC

John Lee, Zach Mouw, Daniel Wharton, Sam Hanover, and Jay Noyola

Objective:

To develop a bottom-up understanding of the HVAC electricity demand in the PE complex. This bottom-up model predicts the annual electricity consumption for the HVAC in the PE complex for each year back until 2010, when the Van Noord Arena was added to the complex.

Research:

Most of the research for this project was done in communication with the physical plant and Calvin facilities staff. Talking to them gave great insight on how the HVAC system is run and where it is located. Research was done to find out the hours of operation of the HVAC system, the percent load of each of the units, and whether the complex HVAC system fluctuates during specific hours.

The complex does indeed fluctuate in electricity draw and research was done to find out why more or less electricity is consumed during some hours and the changes to the HVAC units. Talking to the Calvin staff gave us details of peak hours and off hours. The PE complex HVAC system works harder when more people are in the building to cycle air in and out. The main time for that is during events in the Van Noord arena. The only major change in peak hours seemed to be that all four of the air handler units in the Van Noord kick on to help circulate air. This is a large change in power draw during those event hours. Research was done to find all of the event hours from 2010-16 and the extra power draw was added to the total. School is also not a consistent schedule and is composed of many breaks, the largest being summer break. The down hours of the fieldhouse were determined from school scheduling and the Calvin staff explained to the team which units shut off and run at a lower power draw.

To determine the electricity demand of the HVAC in the PE complex research was done to find how the electricity demand is calculated. It was determined that the rated wattage multiplied by the percent power draw multiplied by the hours of operation gave the power draw in kilowatt hours. The exact methods and procedures of calculating the monthly and yearly power draw will be discussed in the next section. Appendix A shows the project's initial planning and schedule.

Methods & Procedures:

The estimated electricity demand of HVAC in the fieldhouse was achieved by estimating and researching the following:

1. Unit Rated Wattage

Blueprints of the electrical panel boards were read to gather the rated wattage of each unit. This was taken to be the wattage each unit would be drawing when operating at 100% load.

2. Percent Power Draw when Operating

Because each unit is designed to operate at less than 100% load under normal operation, the average power-draw each unit demands was estimated by reading variable frequency drive displays whenever possible and relying on physical plant experts for estimates on the rest.

3. Unit Operation Schedule

Aside from certain duty-cycle assumptions (Appendix B), the unit operation schedule was taken to be the same as the building hours.

Variation in the HVAC portion of the Spoelhof Fieldhouse Complex bottom-up electricity demand model was dictated by three main historical factors. These historical factors were the driving force behind the variation of the back casted results. By researching how these factors changed in the past on a monthly basis, the HVAC demand model could be back casted as far as needed.

1. Van Noord Arena Event Hours

Two additional air-handling units in the Van Noord Arena are turned on for large-scale events and basketball games. Using historical data on tournaments and basketball games hosted in the Van Noord Arena, a back-casted additional HVAC load was calculated.

2. Calvin College Academic Calendar

After consulting with the Physical Plant, it became clear that the HVAC systems of the Fieldhouse complex were under a reduced load and operating schedule during academic recesses. To account for a reduced load during breaks and vacations, HVAC demand was discounted 50% during those days.

3. General Historical Temperature Variation

The electricity demand of Air-handling units 1 and 11 were determined to be weather-dependent. AHU-11 is operated on an extended schedule when the weather is cold, and AHU-1 has a higher power draw during hot and humid months. Taking 2016 to be the base case, each year was split into two seasons. Based on 2016 total degree days in Grand Rapids, "Winter" was designated to be from October to May, and "Summer" from June to September. During the winter season, the operating schedule of AHU-11 was modified to reflect its actual 24-hour performance. During the summer months, AHU-1's additional seasonal load was reflected in a 15% increase to its power draw during the hotter months of the year.

<u>Results:</u>

Using the methods described above, the team was able to estimate the power consumption of HVAC in the fieldhouse complex. Table 1 shows the results of these calculations back to 2011, and Figure 1 presents this data graphically. Figure 2 splits HVAC into its various components, revealing that air handling units are the largest consumer of energy in the Fieldhouse Complex.

<u>Discussion & Assessment:</u>

Table 1 and Figure 1 show how the HVAC uses the most power consumption in the fieldhouse. Looking into more detail in Table 1, the HVAC accounts anywhere from 78% of the yearly power consumption to 92%. From Figure 1 the back casting model of the HVAC power consumption does follow the usual patterns of the peaks and valleys of the actual power consumption. This is due to the fact that over the years Calvin has stayed relatively consistent on break days and number of events. Therefore, the data shows that

Calvin has a usual trend in power consumption, but does have odd months that do not follow the pattern and are not as predictable. Figure 2 shows a further breakdown of the HVAC power consumption. As seen in the figure, the main consumer is air handler units. Other fans and pumps add to the power consumption, but air handler units make up most of the HVAC power consumption, and in turn most of the power consumption of the fieldhouse. In the future it would be optimal to make the air handling units more efficient, as that would have the largest effect on the overall power consumption.

Suggested Modifications and Improvements:

1. **Achieve De-stratification with fans**

Installing large fans in the Van Noord arena could provide significant savings for Fieldhouse complex. During the winter, using the fan can save energy by preventing warm air from stratifying near the ceiling. In the summer, increased circulation allows the thermometer to be set higher while still experiencing the same level of comfort. Big Ass Fans is a company that produces large fans suited for this operation. Their data, which may be slightly optimistic, suggests that energy savings of 30% can be achieved by using their fans. During normal operation, the Van Noord consumes 1200 kWh/day, and 2400/ day during large events. If we assume a total increase in efficiency of 20% and an electricity cost of 0.10$/kWh, this is a savings of about 25 dollars per day or 8,760 dollars per year. The team would roughly estimate that fitting the Van Noord arena with fans would be a 50,000-dollar project, so this investment would pay for itself in less than 10 years. This is very interesting modification that should be seriously considered.

2. **Inspect and Improved Ducting**

Research revealed that fixing leaks and improperly insulated ducting is one of the easiest ways to increase the efficiency of an existing HVAC system. Ducting should be inspected closely to make sure that no leakage is occurring. The research stated that leakage of 10% can produce a reduced of efficiency of 30%, which would be a significant expense.

Table 1: Comparison of the Actual Consumption to the Predicted Consumption

Year	Predicted Consumption [kWh]	Total Fieldhouse Consumption [*kWh*]	Percentage of Total **PE Complex Demand**
2011	3275260	4145000	79%
2012	2374216	4225000	78%
2013	3289148	4033000	82%
2014	3283572	3771000	87%
2015	3294626	3579000	92%
2016	3315108	3883000	85%

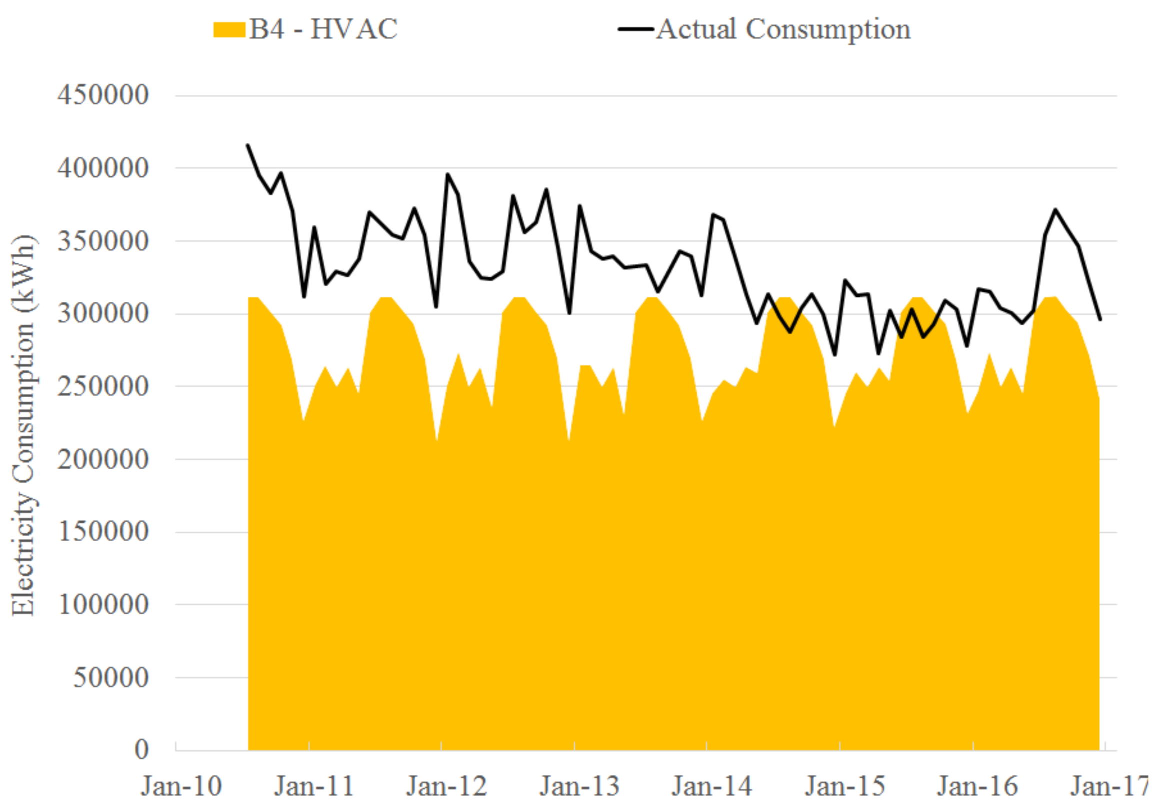

Figure 1: Plot of the Actual Consumption to the Predicted Consumption

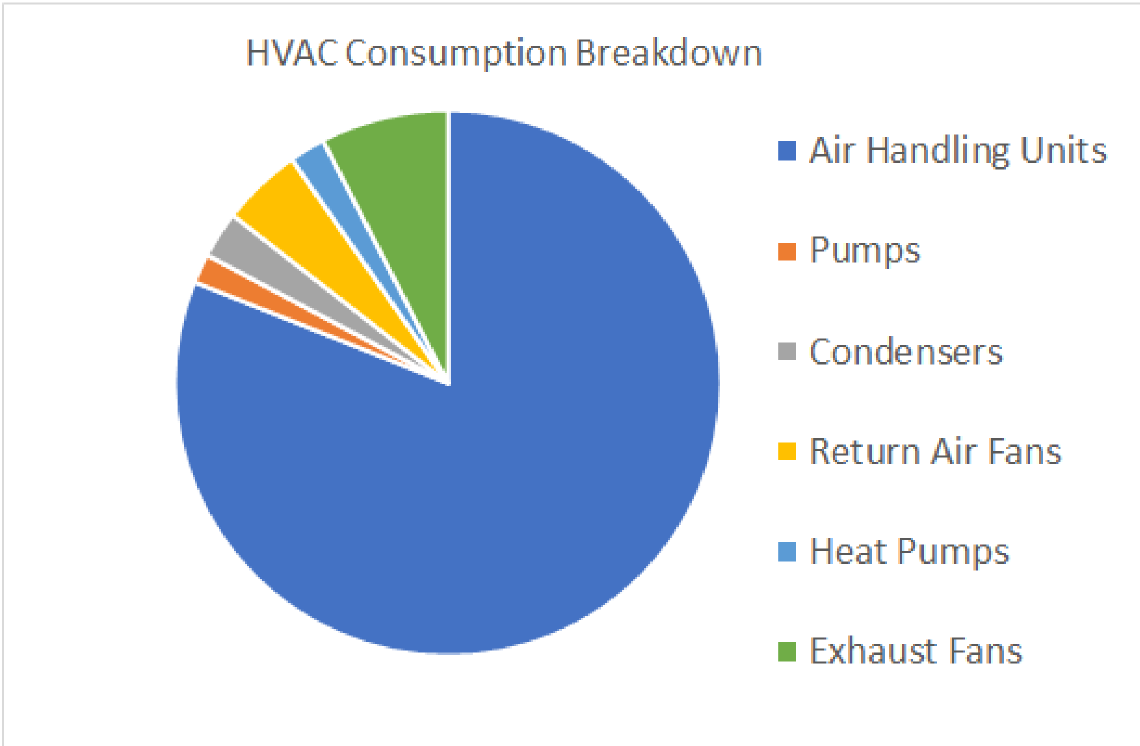

Figure 2: The breakdown of power draw from each of the HVAC components

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APPENDIX 4.A: Initial Gantt Chart

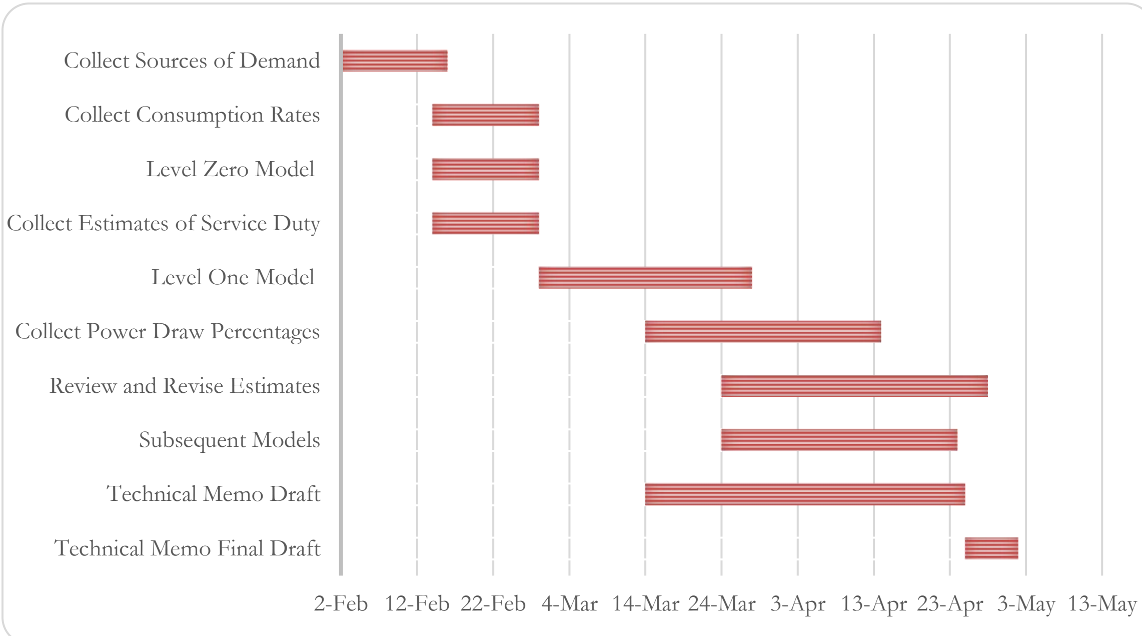

Figure 4.A.1: Initial Team Planning

APPENDIX 4.B: Duty Cycle Assumptions

Summary of Air Handling Units Operation Duty Schedules Gathered from Physical Plant

1. Van Noord Air Handler Units
   - Only two are operational always (24 hrs.)
   - Other two are only operational during events

   ** ***Will contribute to monthly differences and breakdown***

2. Summer Schedule Changes
   - Look at summer operational hours
   - The air handler operational time is adjusted to accommodate different schedule

2. Air Handlers that are ***always operational***
   - MAU
   - Health Services (only in winter) AHU -11
   - AHU 25, AHU 26, AHU 27, AHU 28 [pool locker rooms]
   - AHU 1 [Most Sensitive Variable]

4. AHU 9 operates ***30 min past closing times***

5. ***All other units are operational from opening hours to closing hours***
   - ***10 pm - 5 am [7 hrs]***

Note: T&T HVAC change occurred in 2013
- Light changes also occurred around this time

Group 4's Seasonal Assumptions

- Assume School hours start Sept 1
- Summer hours start June 1
- Winter Season runs from Oct 1 to May 1

APPENDIX 4.C: AHU Operation Summary

Table 4.C.1: Air Handlers Daily Power Consumption and Operation Summary

Typical Daily Operation							
Air Handler Unit	**Service Area**	**Schedule Notes**	**Rated Wattage [W]**	**Power Draw [%]**	**Discounted Wattage [W]**	**Daily Schedule [hrs]**	**Daily Power Consumption (kWh)**
AHU 1 (Dectron)	Pool	24-hr Operation	181704	70.00%	127193	24	3053
AHU 2	AFC South Lockers	5 am - 10 pm Operation	16780	70.00%	11746	17	200
AHU 3	Level 1 Weights/Fitness	5 am - 10 pm Operation	10356	66.00%	6835	17	116
AHU 4	AFC North Lockers	5 am - 10 pm Operation	23014	48.00%	11047	17	188
AHU 5	Athletic Training	5 am - 10 pm Operation	6712	45.00%	3020	17	51
AHU 6	Level 1 Central Lobby	5 am - 10 pm Operation	21574	58.00%	12513	17	213
AHU 7 (Dectron)	Spectator Area	Venema Event Only	24931	60.00%	14959	0	0
AHU 8	Fitness Area	5 am - 10 pm Operation	19177	94.00%	18027	17	306
AHU 9	Level 2 Central Lobby	5 am - 10:30 pm Operation	31163	67.00%	20879	17.5	365
AHU 10	Existing Recreation Gym Lockers	5 am - 10 pm Operation	10548	64.00%	6751	17	115
AHU 11	Health Services	24-hr Operation in Winter Only	10392	46.00%	4780	17	81
AHU 12	Existing Office Area	5 am - 10 pm Operation	10068	36.00%	3625	17	62
AHU 13	T&T Facility	5 am - 10 pm Operation	46026	35.00%	16109	17	274
AHU 14	T&T Facility	5 am - 10 pm Operation	46026	38.00%	17490	17	297
AHU 15	Arena	Two AHU's = 24 hr Operation Four AHU's = Arena Event Only Operation	53217	45.00%	23948	24	575
AHU 16	Arena		53217	45.00%	23948	0	0
AHU 17	Arena		53217	47.00%	25012	0	0
AHU 18	Arena		53217	47.00%	25012	24	600
AHU 19	Hospitality Area	5 am - 10 pm Operation	5082	40.00%	2033	17	35
AHU 20	Existing East Gym	5 am - 10 pm Operation	23012	36.00%	8284	17	141
AHU 21	Existing Gym	5 am - 10 pm Operation	46026	40.00%	18410	17	313
AHU 22	Human Performance Area	5 am - 10 pm Operation	24931	40.00%	9972	17	170
AHU 23	North Office Area	5 am - 10 pm Operation	10356	40.00%	4142	17	70
AHU 24	Existing Rec. Gym Lobby	5 am - 10 pm Operation	25813	40.00%	10325	17	176
AHU 25	Public Pool Locker Area	24-hr Operation	3308	40.00%	1323	17	22
AHU 26	Women's Pool Locker Area	24-hr Operation	7288	40.00%	2915	17	50
AHU 27	Men's Pool Locker Area	24-hr Operation	7288	40.00%	2915	17	50
AHU 28	Pool Equipment Area	24-hr Operation	7288	40.00%	2915	17	50
MAU -1		24-hr Operation	3987	40.00%	1595	24	38
Total Daily Consumption							**7609**

**** Refer to Monthly Appendix 4.E for AHU-11 Power Draw*

**** Refer to Appendix 4.E for AHU 16 and AHU 17 Power Draw*

APPENDIX 4.D: Other HVAC Components

Table 4.D.1: HVAC Component Power Draw

Miscellaneous Other HVAC Components					
Component	Service Area	Power Draw [%]	Rated Wattage [W]	Daily Schedule [hrs]	Daily Power Consumption (kWh)
PMP-01	SF-104	40.00%	2302	8	7.4
PMP-02	SF-104	40.00%	2043.92	8	6.5
PMP-03	SF-104	40.00%	2043.92	8	6.5
PMP-04	SF-104	40.00%	2043.92	8	6.5
PMP-05	SF-104	40.00%	1006	8	3.2
PMP-07		40.00%	1630	8	5.2
PMP-19		40.00%	1176	8	3.8
PMP-21	HT-200	40.00%	2043.92	8	6.5
PMP-22	HT-200	40.00%	2043.92	8	6.5
PMP-23		40.00%	1176	8	3.8
PMP-29	SF-001	40.00%	1006	8	3.2
PMP-31		40.00%	3644	8	11.7
PMP-32		40.00%	1176	8	3.8
PMP-33	VA-003	40.00%	1630	8	5.2
PMP-34	VA-003	40.00%	767	8	2.5
PMP-35	VA-003	40.00%	2302	8	7.4
PMP-36	SF-001	40.00%	6712	8	21.5
PMP-3A	VA-003	40.00%	2043.92	8	6.5
PMP-3B	VA-003	40.00%	2043.92	8	6.5
PMP-4A	VA-003	40.00%	2043.92	8	6.5
PMP-4B	VA-003	40.00%	2043.92	8	6.5
PMP-5A	VA-003	40.00%	2043.92	8	6.5
PMP-5B	VA-003	40.00%	2043.92	8	6.5
PMP-A	VA-003	40.00%	2043.92	8	6.5
PMP-B	VA-003	40.00%	2043.92	8	6.5
COND-1A		40.00%	14748.25	4	23.6
COND-1B		40.00%	14748.25	4	23.6
COND-2		40.00%	6129.39	4	9.8
COND-4		40.00%	911.13	4	1.5
COND-6		40.00%	1295.19	4	2.1
CMP-05	VA-003	40.00%	24931	4	39.9
CMP-06	VA-003	40.00%	24931	4	39.9
CP-1		40.00%	24901.62	4	39.8
CP-2		40.00%	24901.62	4	39.8
CP-3		40.00%	24901.62	4	39.8
RAF-01		40.00%	12945	17	88.0
RAF-02		40.00%	12945	17	88.0
RAF-03	VN-310	40.00%	6712	17	45.6
RAF-04	VN-301	40.00%	6712	17	45.6
RAF-05	VN-330	40.00%	2302	17	15.7
RAF-07		40.00%	3644	17	24.8
RAF-08		40.00%	3644	17	24.8
RAF-09		40.00%	3644	17	24.8
RAF-13	HT-200	40.00%	6568.5	17	44.7
RAF-14	HT-200	40.00%	6568.5	17	44.7
HP-1		40.00%	31163.06	8	99.7
HP-2		40.00%	31163.06	8	99.7

EF-01	HT-200	40.00%	2302	17	15.7
EF-02	HT-200	40.00%	5274	17	35.9
EF-3A		40.00%	3644	17	24.8
EF-3B		40.00%	2302	17	15.7
EF-04	VN-330	40.00%	1006	17	6.8
EF-05	HT-200	40.00%	1630	17	11.1
EF-06	VN-330	40.00%	864	17	5.9
EF-08		40.00%	767	17	5.2
EF-09		40.00%	1176	17	8.0
EF-10	VN-330	40.00%	1329	17	9.0
EF-11A		40.00%	767	17	5.2
EF-11B		40.00%	767	17	5.2
EF-13		40.00%	31163	17	211.9
EF-14		40.00%	31163	17	211.9
EF-15		40.00%	19177	17	130.4
EF-16		40.00%	120	17	0.8
EF-21		40.00%	1006	17	6.8
TOTAL					**1779.8**

APPENDIX 4.E: Backcasted Results

Table 4.E.1: 2010 Backcasted

Year	Month	Number of Days [days]	Number of Reduced Load (50%) Break Days [days]	Operation Type	Additional Arena Event Hours (AHU 16 & 17) [hrs]	Additional Seasonal Hours (AHU 11) [hrs]	Additional Seasonal Load (AHU 1) [kWh]	Total Additional Power Draw [kWh]	Misc. HVAC Components	Reduced Break Power Draw [kWh]	Predicted Power Draw [kWh]
2010	January	31	10	Class		217	0	1037	55173	46946	245155
2010	February	28	0	Class		196	0	937	49833	0	263833
2010	March	31	9	Class		217	0	1037	55173	42251	249850
2010	April	30	4	Class		210	0	1004	53393	18778	263900
2010	May	31	9	Class		217	0	1037	55173	42251	249850
2010	June	30	0	Summer		0	19624	19624	53393	0	301298
2010	July	31	0	Summer		0	20278	20278	55173	0	311341
2010	August	31	0	Summer		0	20278	20278	55173	0	311341
2010	September	30	0	Class	12	0	19624	20212	53393	0	301886
2010	October	31	0	Class	8	217	0	1429	55173	0	292492
2010	November	30	3	Class	8	210	0	1396	53393	14084	268986
2010	December	31	14	Class	6	217	0	1331	55173	65724	226670
											3286602

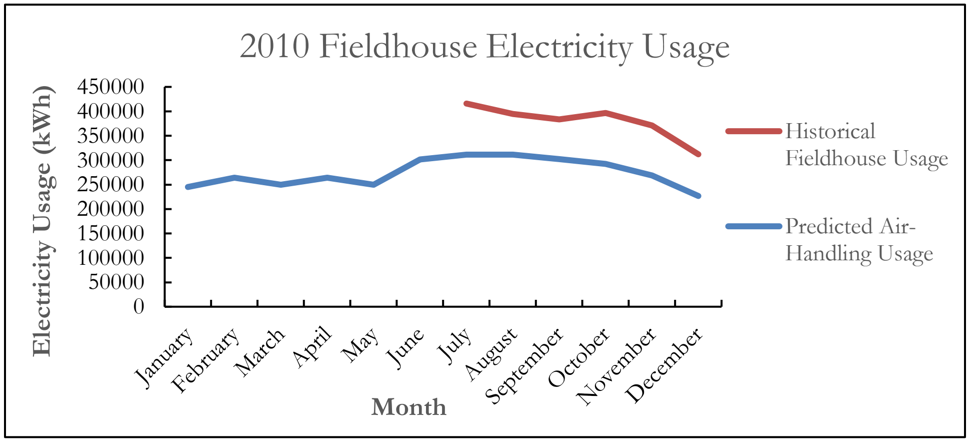

Figure 4.E.1: 2010 Backcasted Comparison

Table 4.E.2: 2011 Backcasted

Year	Month	Number of Days [days]	Number of Reduced Load (50%) Break Days [days]	Operation Type	Additional Arena Event Hours (AHU 16 & 17) [hrs]	Additional Seasonal Hours (AHU 11) [hrs]	Additional Seasonal Load (AHU 1) [kWh]	Total Additional Power Draw [kWh]	Misc. HVAC Components	Reduced Break Power Draw [kWh]	Predicted Power Draw [kWh]
2011	January	31	9	Class	20	217	0	2017	55173	42251	250829
2011	February	28	0	Class	16	196	0	1720	49833	0	264616
2011	March	31	9	Class	4	217	0	1233	55173	42251	250045
2011	April	30	4	Class	0	210	0	1004	53393	18778	263900
2011	May	31	10	Class	0	217	0	1037	55173	46946	245155
2011	June	30	0	Summer	0	0	19624	19624	53393	0	301298
2011	July	31	0	Summer	0	0	20278	20278	55173	0	311341
2011	August	31	0	Summer	0	0	20278	20278	55173	0	311341
2011	September	30	0	Class	8	0	19624	20016	53393	0	301690
2011	October	31	0	Class	16	217	0	1821	55173	0	292884
2011	November	30	3	Class	16	210	0	1787	53393	14084	269378
2011	December	31	17	Class	10	217	0	1527	55173	79808	212783
											3275260

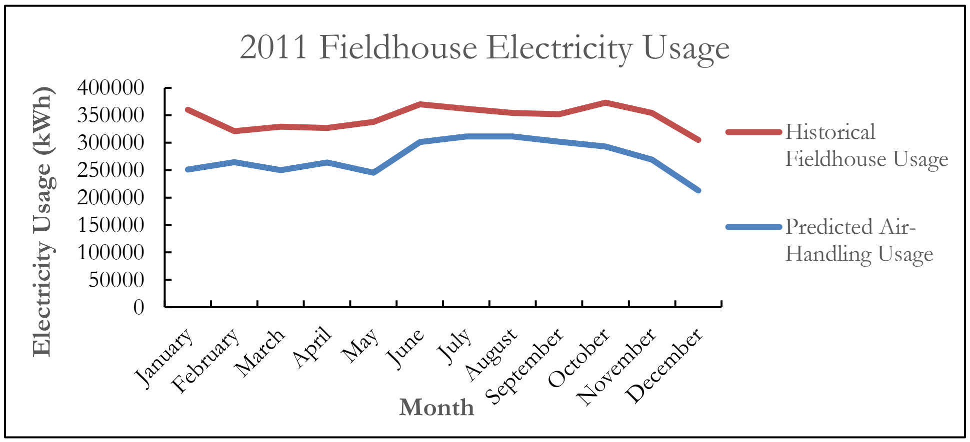

Figure 4.E.2: 2011 Backcasted Comparison

Table 4.E.3: 2012 Backcasted

Year	Month	Number of Days [days]	Number of Reduced Load (50%) Break Days [days]	Operation Type	Additional Arena Event Hours (AHU 16 & 17) [hrs]	Additional Seasonal Hours (AHU 11) [hrs]	Additional Seasonal Load (AHU 1) [kWh]	Total Additional Power Draw [kWh]	Misc. HVAC Components	Reduced Break Power Draw [kWh]	Predicted Power Draw [kWh]
2012	January	31	9	Class	16	217	0	1821	55173	42251	250633
2012	February	29	0	Class	12	203	0	1558	51613	0	273843
2012	March	31	9	Class	4	217	0	1233	55173	42251	250045
2012	April	30	4	Class	0	210	0	1004	53393	18778	263900
2012	May	31	12	Class	0	217	0	1037	55173	56335	235766
2012	June	30	0	Summer	0	0	19624	19624	53393	0	301298
2012	July	31	0	Summer	0	0	20278	20278	55173	0	311341
2012	August	31	0	Summer	0	0	20278	20278	55173	0	311341
2012	September	30	0	Class	6	0	19624	19918	53393	0	301592
2012	October	31	0	Class	10	217	0	1527	55173	0	292590
2012	November	30	3	Class	18	210	0	1885	53393	14084	269476
2012	December	31	17	Class	2	217	0	1135	55173	79808	212391
											3274216

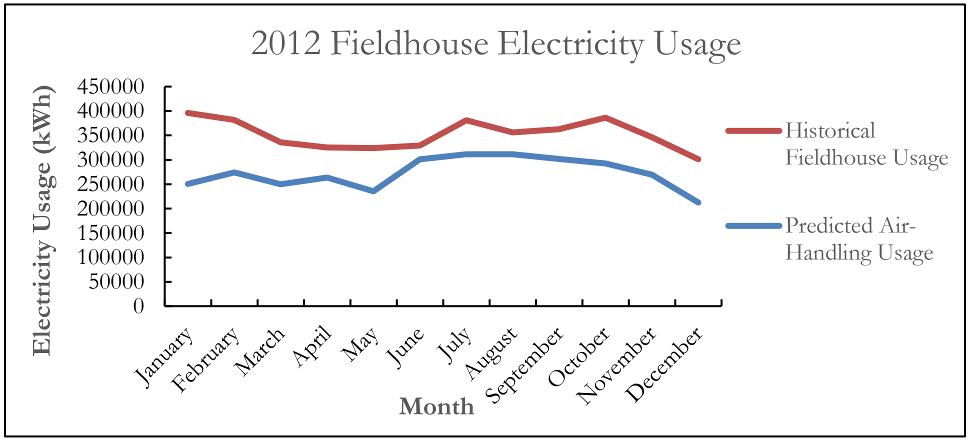

Figure 4.E.3: 2012 Backcasted Comparison

Table 4.E.4: 2013 Backcasted

Year	Month	Number of Days [days]	Number of Reduced Load (50%) Break Days [days]	Operation Type	Additional Arena Event Hours (AHU 16 & 17) [hrs]	Additional Seasonal Hours (AHU 11) [hrs]	Additional Seasonal Load (AHU 1) [kWh]	Total Additional Power Draw [kWh]	Misc. HVAC Components	Reduced Break Power Draw [kWh]	Predicted Power Draw [kWh]
2013	January	31	6	Class	18	217	0	1919	55173	28167	264814
2013	February	28	0	Class	18	196	0	1818	49833	0	264714
2013	March	31	9	Class	0	217	0	1037	55173	42251	249850
2013	April	30	4	Class	0	210	0	1004	53393	18778	263900
2013	May	31	13	Class	0	217	0	1037	55173	61029	231071
2013	June	30	0	Summer	0	0	19624	19624	53393	0	301298
2013	July	31	0	Summer	0	0	20278	20278	55173	0	311341
2013	August	31	0	Summer	0	0	20278	20278	55173	0	311341
2013	September	30	0	Class	8	0	19624	20016	53393	0	301690
2013	October	31	0	Class	14	217	0	1723	55173	0	292786
2013	November	30	3	Class	20	210	0	1983	53393	14084	269574
2013	December	31	14	Class	8	217	0	1429	55173	65724	226768
											3289148

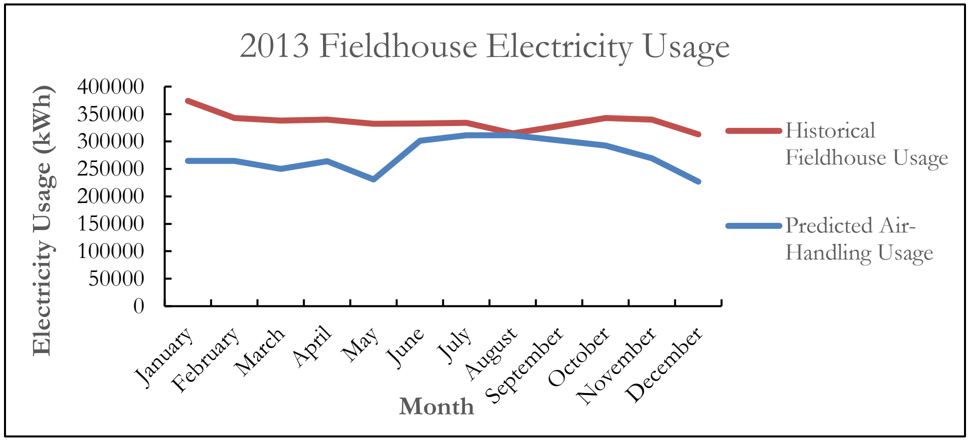

Figure 4.E.4: 2013 Backcasted Comparison

Table 4.E.5: 2014 Backcasted

Year	Month	Number of Days [days]	Number of Reduced Load (50%) Break Days [days]	Operation Type	Additional Arena Event Hours (AHU 16 & 17) [hrs]	Additional Seasonal Hours (AHU 11) [hrs]	Additional Seasonal Load (AHU 1) [kWh]	Total Additional Power Draw [kWh]	Misc. HVAC Components	Reduced Break Power Draw [kWh]	Predicted Power Draw [kWh]
2014	January	31	10	Class	10	217	0	1527	55173	46946	245645
2014	February	28	2	Class	18	196	0	1818	49833	9389	255325
2014	March	31	9	Class	0	217	0	1037	55173	42251	249850
2014	April	30	4	Class	0	210	0	1004	53393	18778	263900
2014	May	31	7	Class	0	217	0	1037	55173	32862	259239
2014	June	30	0	Summer	0	0	19624	19624	53393	0	301298
2014	July	31	0	Summer	0	0	20278	20278	55173	0	311341
2014	August	31	0	Summer	0	0	20278	20278	55173	0	311341
2014	September	30	0	Class	6	0	19624	19918	53393	0	301592
2014	October	31	0	Class	14	217	0	1723	55173	0	292786
2014	November	30	3	Class	14	210	0	1689	53393	14084	269280
2014	December	31	15	Class	6	217	0	1331	55173	70419	221976
											3283572

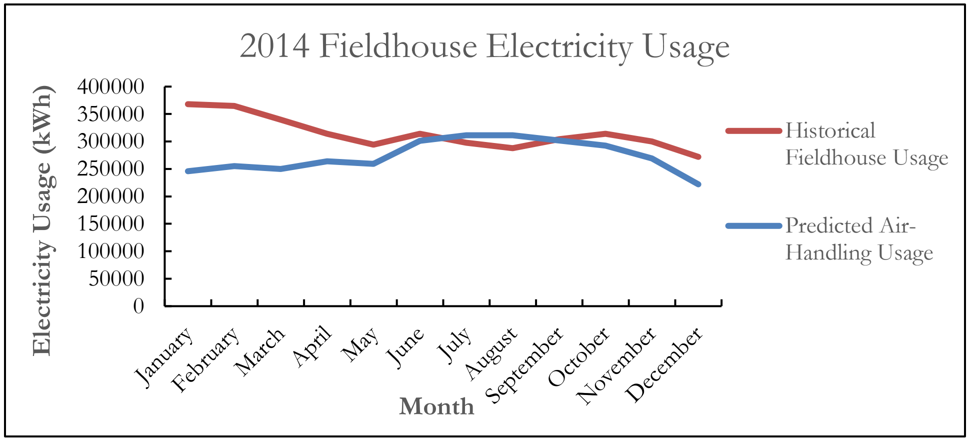

Figure 4.E.5: 2014 Backcasted Comparison

Table 4.E.6: 2015 Backcasted

Year	Month	Number of Days [days]	Number of Reduced Load (50%) Break Days [days]	Operation Type	Additional Arena Event Hours (AHU 16 & 17) [hrs]	Additional Seasonal Hours (AHU 11) [hrs]	Additional Seasonal Load (AHU 1) [kWh]	Total Additional Power Draw [kWh]	Misc. HVAC Components	Reduced Break Power Draw [kWh]	Predicted Power Draw [kWh]
2015	January	31	10	Class	16	217	0	1821	55173	46946	245938
2015	February	28	1	Class	22	196	0	2014	49833	4695	260215
2015	March	31	9	Class	8	217	0	1429	55173	42251	250241
2015	April	30	4	Class	0	210	0	1004	53393	18778	263900
2015	May	31	8	Class	0	217	0	1037	55173	37557	254544
2015	June	30	0	Summer	0	0	19624	19624	53393	0	301298
2015	July	31	0	Summer	0	0	20278	20278	55173	0	311341
2015	August	31	0	Summer	0	0	20278	20278	55173	0	311341
2015	September	30	0	Class	16	0	19624	20407	53393	0	302082
2015	October	31	0	Class	16	217	0	1821	55173	0	292884
2015	November	30	3	Class	12	210	0	1591	53393	14084	269182
2015	December	31	13	Class	12	217	0	1625	55173	61029	231659
											3294626

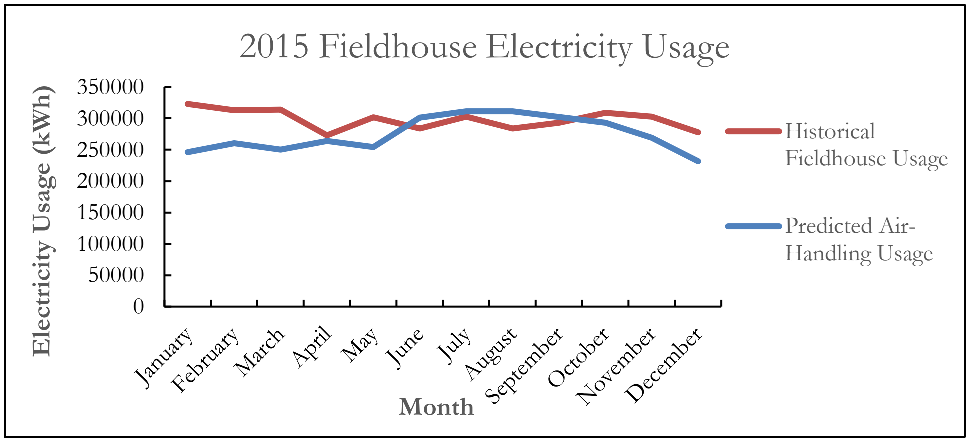

Figure 4.E.6: 2015 Backcasted Comparison

Table 4.E.7: 2016

Year	Month	Number of Days [days]	Number of Reduced Load (50%) Break Days [days]	Operation Type	Additional Arena Event Hours (AHU 16 & 17) [hrs]	Additional Seasonal Hours (AHU 11) [hrs]	Additional Seasonal Load (AHU 1) [kWh]	Total Additional Power Draw [kWh]	Misc. HVAC Components	Reduced Break Power Draw [kWh]	Predicted Power Draw [kWh]
2016	January	31	10	Class	32	217	0	2604	55173	46946	246722
2016	February	29	0	Class	14	203	0	1656	51613	0	273941
2016	March	31	9	Class	0	217	0	1037	55173	42251	249850
2016	April	30	4	Class	0	210	0	1004	53393	18778	263900
2016	May	31	10	Class	0	217	0	1037	55173	46946	245155
2016	June	30	0	Summer	0	0	19624	19624	53393	0	301298
2016	July	31	0	Summer	0	0	20278	20278	55173	0	311341
2016	August	31	0	Summer	24	0	20278	21453	55173	0	312516
2016	September	30	0	Class	32	0	19624	21191	53393	0	302865
2016	October	31	0	Class	40	217	0	2996	55173	0	294059
2016	November	30	3	Class	56	210	0	3746	53393	14084	271336
2016	December	31	11	Class	34	217	0	2702	55173	51640	242125
											3315108

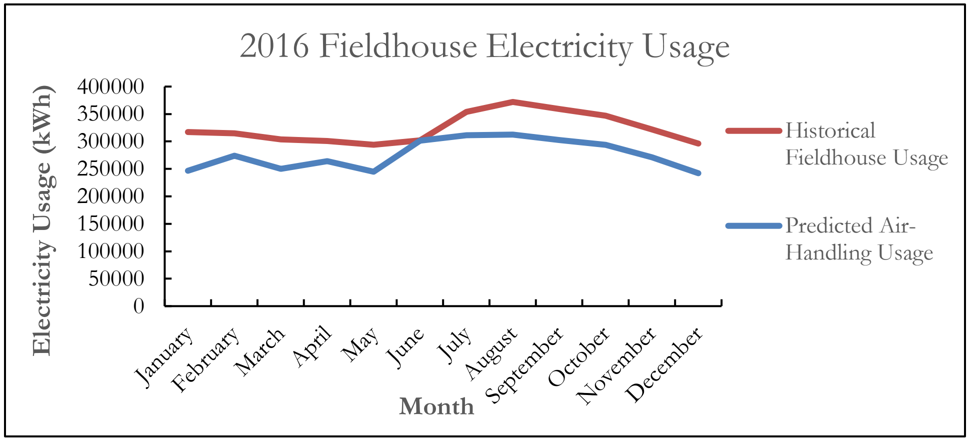

Figure 4.E.7: 2016

APPENDIX 4.F: Research Information

Most of the research for this project was done in communication with the physical plant and Calvin facilities staff. Talking to them gave great insight on how the HVAC system is run and where it is located. The first portion of research was finding out where and how many HVAC units are in the PE complex. From the Calvin staff a layout of the PE complex was given to the team in PDF format. A list of the HVAC units was sorted through and put into an excel file. Using the list of units and the fieldhouse layout, Figure 1 was made below. In Figure 1 is the highlighted rooms where units are stored on the first floor, and every floor was depicted likewise.

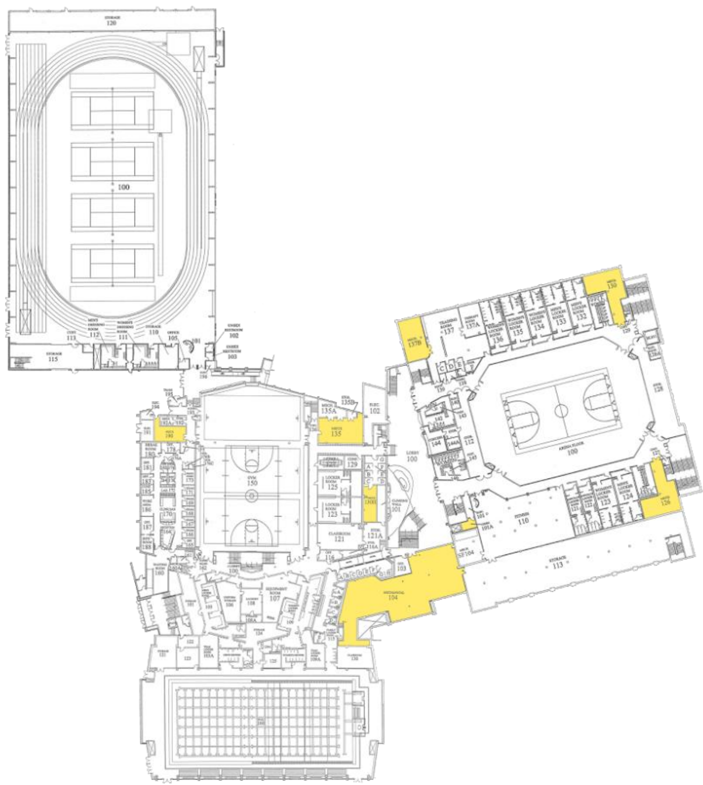

Figure 1: First Floor of the Fieldhouse

The next step of our research was determining at what percent each unit runs. The rated wattage for each unit was found on the list of units given by the Calvin staff, but not all of the units run at 100%. Not only did the team need to determine at what percent each unit runs, but also if the percent load changes based on the climate, or amount of people in the complex. To determine the percent, load each unit runs at the first estimate was that every unit runs at 40% load 17 hours a day, based on discussions with the staff. To get a better estimate most of the units have a digital read out. A camera was set up to take photos every 15 minutes over a 24-hour period at each unit with a digital air handling unit. This research and data collection killed two birds with one stone. The data gave a readout for each unit and verified how often the units are on, but it also showed that each unit stays at the same load consistently. Therefore, each readout gives a good percent load read out for every unit over the time it is on.

To determine whether or not the climate affects the load of the electricity consumption in the fieldhouse, research was done and it was concluded that the units in the fieldhouse, like the air handling units, did not rely on climate change. Calvin runs the heating and cooling of the building on a natural gas system and therefore the electricity consumption of the complex is not affected by the climate change.

The next area of research was the hours of operation. The amount of time each unit is on varies and has a large effect on the electricity consumption. To find out specifics the staff in charge of scheduling gave the team detailed information on when the air handling units are on. These are the units that make up most of the electricity consumption in the HVAC system and therefore became the team's main focus. The scheduling was complete and the percent draw was as well.

PE Complex Bottom Up Energy Model

Appendix 5

Computers, Audio/Visual, and Miscellaneous Electronics

Adam Christenson, Scott Stamper, Aaron Tucker, and
Bethany Waanders

Objective:

The goal of Team B-5's research was to determine the electrical demand of the miscellaneous devices that are either externally plugged into wall outlets (Office hardware such as computers, TVs, or appliances), exercise equipment throughout the building, and, most specifically, the AV system and jumbotrons located in the arena. Upon creating an inventory of all visible equipment throughout the complex, power draw estimates were performed.

Research:

The bulk of Team B-5's research was comprised of inventory. Several walkthroughs of the PE Complex were performed simply to gather information, writing down and taking pictures of any and all devices that could be seen. The bulk of this was comprised of desktop computers located in faculty and staff offices, and other such common office equipment, but there were several outstanding devices that might not be considered under any one category, such as vending machines, the café equipment, special lab equipment in Health Services or the Human Performance Lab, treadmills, and the like.

Calvin Information Technologies was also a vital resource to this team's research; CIT provided several lists of known devices the college provided to workspaces, model numbers, and details associated with them. This was incredibly useful to tracking desktop power usage within the complex.

Methods & Procedures:

As stated above, the basic method of the team was to simply take inventory of all devices and keep a running tally of how many of what device were present. When that was completed, CIT data and online research filled in the power consumption of those devices, and both team assumptions and scheduling data like sporting events and concerts were taken into account to provide an estimate of duty cycles for the tabulated devices.

Results:

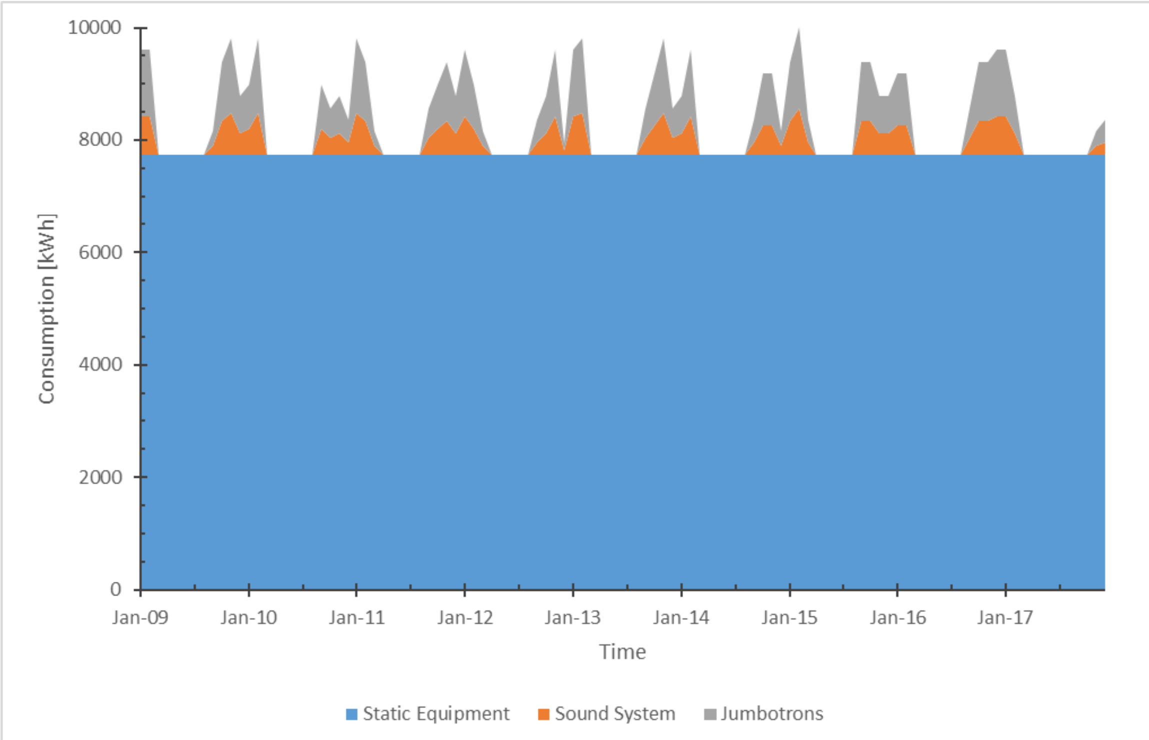

Figure 1: Energy Consumption Backcasted Model of Team 5-B

Discussion & Assessment:

Appendix 5.A, Table 5.A.1 details the entirety of all components Team 5-B took into account in its model. **Table 5.A.2** shows the game schedule since 2009 the team used to generate its backcasting model. Finally, **Figure 1** above shows the final backcasted model of energy consumption of those listed devices from 2009 to the present.

The model shown in **Figure 1** comes with several assumptions. First, the team assumed that office appliance use would remain consistent on a yearly basis. This assumption is grounded in the knowledge of a consistent work day of operation, most of those appliances being plugged in 24/7, and use during the academic year remaining consistent as the departments operate. This assumption was further backed up by the sensitivity analysis performed on the components, which may be seen in the Appendix. Therefore, as can be seen in the model, all but two components listed were held at a consistent monthly power draw of 7,734 kWh. The variation in Team 5-B's model was assumed to come entirely from the Jumbotron and AV system present in the Van Noord arena. These two components depended entirely on the sports schedule, so their usage was calculated using the home game data. It is known from the athletic department that for every hour of game play, there are three hours of practice, and, while the Jumbotrons and speakers are both in use during game hours, only the speakers are in use during practice hours; these two assumptions determined the variable consumption of these systems.

Finally, it was assumed by Team B-5 that, even if these assumptions of static power draw were incorrect, the fact that these components contributed to <2% of the overall consumption of the entire complex would essentially render any variation in the smaller systems irrelevant. Team B-5 is comfortable with the assumption that the two largest consumption systems determine the variability of its model.

Future Projections:

Should this model be refined in the future, there are a few suggestions team B-5 would make to improve its particular section.

1) CIT's inventory and Team 5-B's inventory did not necessarily line up on all accounts. Now, this could be due to professors and staff bringing in their own office equipment, such as dual monitors, extra desktops, or TVs, but there was a general sense of inconsistency between what the team was able to count and what Calvin said was there.
2) The static assumption of almost all equipment may not be correct. Computers were assumed to be on 24/7 every day of every month, however, they are routinely shut down for maintenance and installation. Also, computers in idle draw less power than active computers. It was also assumed that all desktops have remained the same since 2009; the number and efficiency of desktops was assumed to not change over time. Whether or not a count of 58 computers or 60 computers significantly contributes to the sub-model, let alone the overall model for the entire complex, though, is a conversation to be had.
3) It was nearly impossible for Team 5-B to accurately track exercise equipment use. The one device under consideration in the workout room was the treadmill, but, aside from surveying several months of use and predicting annual usage of that specific piece of exercise equipment, Team 5-B could not know what device was being used and how long it was used from card swipe data into the gym alone. Therefore, reasonable assumptions as to operating hours of all treadmills were made, and it was included under the "static equipment" usage. Further research into equipment usage in the gym may be helpful for future studies.

APPENDIX 5 TABLE OF CONTENTS

APPENDIX 5.A: Sensitivity Analysis

Table 5.A.1: PE Complex Inventory Relevant to Team B-5

Area	Level	Room Number	Room Name	Item	Quantity	Notes	ID Tag
Venema	100	103	Men's Locker Room	"hand" dryers	8	covered by B6 - pool ops	-
Venema	100	109	Women's Locker Room	"hand" dryers	10	covered by B6 - pool ops	-
Venema	100	115	Family Locker Room	"hand" dryers	4	covered by B6 - pool ops	-
Venema	100	130	Classroom	-		Unkown	
Venema	100	100	Pool	Clocks	5	LED ~1'x3'	1005
Venema	100	100	Pool	Scoreboard	1	LED ~10'15'	1006
Venema	100	100	Pool	TV	1	~24" tube, used for divers	1001
Venema	100	100	Pool	Soundsystem		Unkown specs	1011
Hoogenboom	100	127	Conf	Computer	1	desktop	2000
Hoogenboom	100	127	Conf	TV	1	~32" LCD	1001
Hoogenboom	100	127	Conf	DVD/VCR	1		1002
Hoogenboom	100	121	Classroom	Fan	1	4' standing fan	1013
Hoogenboom	100	121	Classroom	Sound system	1	2 speaker ~6" drivers	1011
Hoogenboom	100	117	Offices	Computer	6	Desktop, estimated quantity	2000
Hoogenboom	100	117	Offices	Phone	6	Office phone, estimated quantity	1003
Hoogenboom	100	121A	Stor	Fridge	1	Standard	1004
Hoogenboom	100	150	Gym	Hoop motors	6	used to raise/lower hoops	1015
Hoogenboom	100	150	Gym	Scoreboard	2	Old style LED	1012
Hoogenboom	100	150	Gym	Sound system	1	10 speakers ~6-8" drivers	1011
Hoogenboom	100	130	Offices	-		Unkown	
Hoogenboom	100	129	Conf	-		Unkown	
Hoogenboom	100	125	Locker Room	-		Unkown	
Hoogenboom	100	123	Locker Room	-		Unkown	
Hoogenboom	100	116	Office	-		Unkown	
Hoogenboom	100	105	Office	-		Unkown	
Hoogenboom	100	108	Laundry	-		Unkown	
Hoogenboom	100	160-188	*Health Center*	-		Unkown	
Spoelhof	100	100	Lobby	Vending machine	2	drink and snack	1021
Spoelhof	100	100	Lobby	computer	1	desktop, climbing wall	2000
Spoelhof	100	100	Lobby	Sound system	1	2 ~6" drivers, climbing wall	1011
Spoelhof	100	100	Lobby	TV	1	LCD, ~26"	1001
Spoelhof	100	103	Office	Computer	2	desktop	2000
Spoelhof	100	103	Office	Phone	2	office phone	1003
Huizenga	100	105	Office	-		Unkown	
Huizenga	100	100	Track	Sound system	17	~8" drivers	1011
Huizenga	100	100	Track	Scoreboard	1	LED ~3'x6'	1006
Van Noord	100	114	Concess	TV	2	LCD ~26"	1001
Van Noord	100	114	Concess	Register	3	touch screen	1007
Van Noord	100	114	Concess	Fridge	1	drinks	1004
Van Noord	100	114	Concess	Fridge	1	standard	1004
Van Noord	100	114	Concess	Popcorn maker	1	Large	1008
Van Noord	100	114	Concess	Coffee maker	2	Medium	1009
Van Noord	100	114	Concess	Food warmers	2	a multi level tray + pretzel	1010
Van Noord	100	114	Concess	Phone	1	office phone	1003
Hoogenboom	300	309		Large Fan			1013
Hoogenboom	300	300		TV		40" Samsung	1001
Hoogenboom	300	305		VCR/AV			1002
			Concessions	Cash registers	4		
			Concessions	Large popcorn maker	1		
			Concessions	Drink coolers	2		1004
			Concessions	open floor cooler	1		
			Concessions	heating tray	1		
			Concessions	pretzel warmer rack	1		
			Concessions	large double coffee maker	1		
			Concessions	TV	2	samsung 36"	1001

Van Noord	300	301 or 330?		Fridge	1	Medium industrial	1004
Van Noord	300	301 or 330?		jumbotron	1		1026
Van Noord	300	301 or 330?		Rear Projector	2		1016
Van Noord	300	301 or 330?		Small Speakers	28	~6" drivers	1011
Van Noord	300	301 or 330?		Large Speakers	2	Large Stacked Speakers	1017
Van Noord	300	301 or 330?		TV	3		1001
Van Noord	300	301 or 330?		Small scoreboard	2		1012
Van Noord	300	301 or 330?		small fridge	2		1018
Van Noord	300	301 or 330?		Large AV control Rack	1	Always On	1019
Van Noord	300	301 or 330?		Small AV control Rack	1	Always On	1020
Van Noord	300	301 or 330?		Computers	3		2000
Van Noord	300	301 or 330?	NOTE: Suite lights always on--> user imput				
Hoogenboom	200	200	Lobby	Large TV	1	sharp ~60"	1014
Hoogenboom	200			Vending Machine	2		1021
Hoogenboom	200	204, 251, 280		Computer	3	Dell desktop	2000
Hoogenboom	200	204, 251, 280		VCR/DVD	3	Toshiba	1002
Hoogenboom	200	204, 251, 280		projector	3	Epson (longer duty cycle)	1022
Hoogenboom	200	22 similar offices:		Office phone	22	check 249,244 (labeled 7,8,9,11)	1003
		217,219-230, 239-243, 245-248					
Hoogenboom	200	24 similar offices:		Desktop	22	check 249,244 (labeled 7,8,9,11)	2000
		249					
Hoogenboom	200	24 similar offices:		Coffee maker	22	check 249,244 (labeled 7,8,9,11)	1009
		249					
Hoodenboom	200	239		TV	1	12" LCD (labeled 8)	1001
Hoodenboom	200	247		minifridge	1		1018
Hoodenboom	200	240,242,244,249		TV	4	15" (labeled 9 or 10)	1001
Hoodenboom	200	240,242,244,249		VCR	4	(labeled 9 or 10)	1002
Hoodenboom	200			Router	1		2002
Hoodenboom	200	215		Desktops	3		2000
Hoodenboom	200	215		Printer	2		1025
Hoodenboom	200	216, 231		Printer	2	Large Office printer like EB 130	1025
Hoodenboom	200	218		Coffee maker	3		1009
Hoodenboom	200	218		fridge	1		1004
Hoodenboom	200	218		microwave	1		1023
Hoodenboom	200	270		Desktop	1		2000
Hoodenboom	200	270		projector	1		1022
Hoodenboom	200	270		speakers	2		1011
Hoodenboom	200	270B		Tredmill	1	Uber	1027
Hoodenboom	200	270B		Computer		"Computer setup"?	
Spoelhof	200			TV	5	LE~40"	1001
Spoelhof	200			ATM	1		1024
Spoelhof	200			TV	2	40"	1001
Spoelhof	200			???		"see HH 300"	
Spoelhof	200	later		Office phone	24	GUESS	1003
Spoelhof	200	later		Desktop	24	GUESS	2000
Spoelhof	200	201		TV	4	36" LE TV	1001
Spoelhof	200	201		Fan	1	Large	1013
Spoelhof	200	201		TV	25	14"	1001
Spoelhof	200	201		Treadmills	16		1027
					363		

Table 5.A.2: Game hours and practice hours tabulated from Men's Basketball, Women's Basketball, and Volleyball schedules

Month	Games	Practice
1-Jan	21	84
1-Feb	21	84
1-Mar	0	0
1-Apr	0	0
1-May	0	0
1-Jun	0	0
1-Jul	0	0
1-Aug	0	0
1-Sep	12	48
1-Oct	24	96
1-Nov	24	96
1-Dec	27	108

APPENDIX 5.B: Sensitivity Analysis

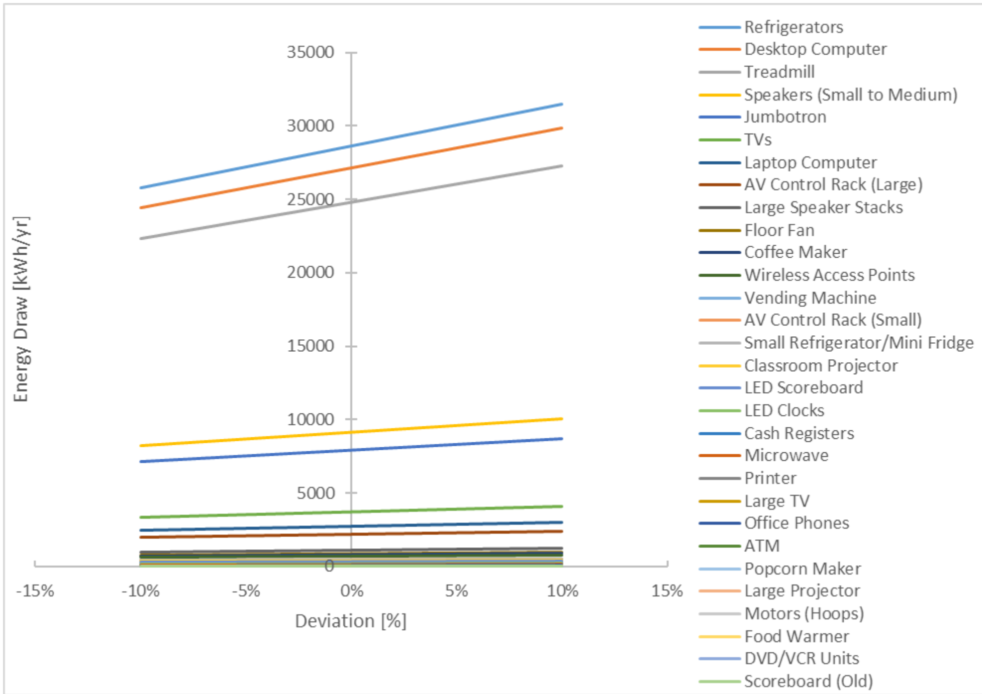

Figure 5.B.1: Sensitivity Analysis plot of all inventory components

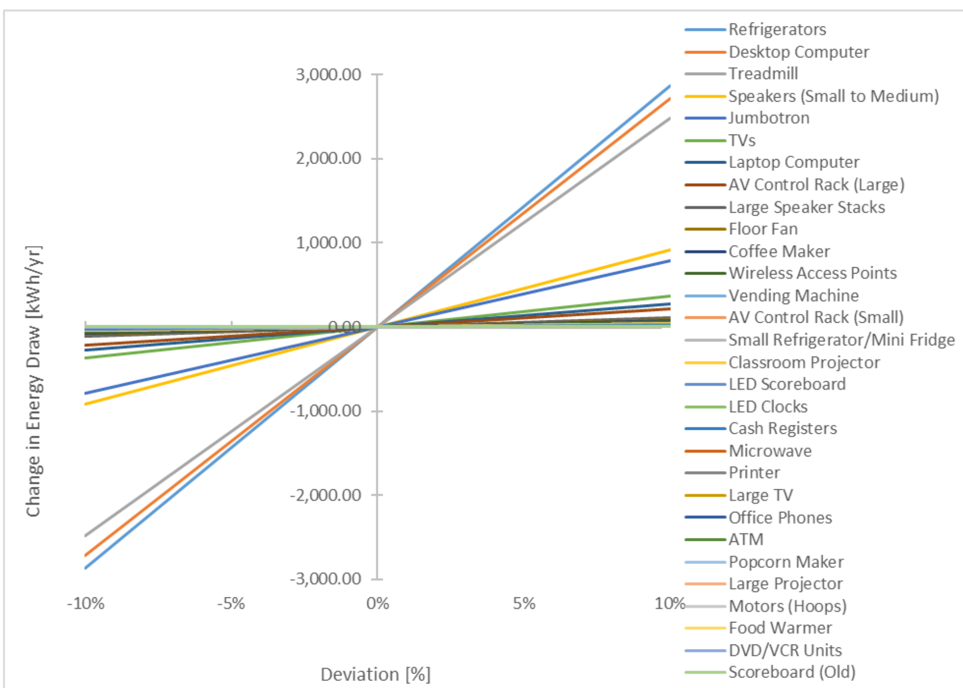

Figure 5.B.2: Sensitivity Analysis spider plot

Table 5.B.1: Tabulated Data used to generate sensitivity analysis plots

Energy Draw [kW*h/year]	-10%	-5%	5%	10%			-10%	-5%	5%	10%
28,619.14	25757.22	27188.18	30050.09	31481.05			-2,861.92	-1,430.96	1,430.95	2,861.91
27,158.98	24443.08	25801.03	28516.92	29874.87			-2,715.90	-1,357.95	1,357.94	2,715.89
24,822.72	22340.45	23581.58	26063.86	27304.99			-2,482.27	-1,241.14	1,241.14	2,482.27
9,126.00	8213.4	8669.7	9582.3	10038.6			-912.60	-456.30	456.30	912.60
7,920.00	7128	7524	8316	8712			-792.00	-396.00	396.00	792.00
3,723.41	3351.067	3537.238	3909.578	4095.749			-372.34	-186.17	186.17	372.34
2,715.90	2444.308	2580.103	2851.692	2987.487			-271.59	-135.80	135.79	271.59
2,190.24	1971.216	2080.728	2299.752	2409.264			-219.02	-109.51	109.51	219.02
1,095.12	985.608	1040.364	1149.876	1204.632			-109.51	-54.76	54.76	109.51
876.1	788.4864	832.2912	919.9008	963.7056			-87.61	-43.81	43.80	87.61
788.49	709.6378	749.0621	827.9107	867.335			-78.85	-39.43	39.42	78.85
683.35	615.0194	649.1871	717.5226	751.6904			-68.33	-34.16	34.17	68.34
455.57	410.0129	432.7914	478.3484	501.1269			-45.56	-22.78	22.78	45.56
438.05	394.2432	416.1456	459.9504	481.8528			-43.81	-21.90	21.90	43.80
438.05	394.2432	416.1456	459.9504	481.8528			-43.81	-21.90	21.90	43.80
365.04	328.536	346.788	383.292	401.544			-36.50	-18.25	18.25	36.50
330	297	313.5	346.5	363			-33.00	-16.50	16.50	33.00
219.02	197.1216	208.0728	229.9752	240.9264			-21.90	-10.95	10.96	21.91
131.41	118.273	124.8437	137.9851	144.5558			-13.14	-6.57	6.58	13.15
109.51	98.5608	104.0364	114.9876	120.4632			-10.95	-5.47	5.48	10.95
105.13	94.61837	99.87494	110.3881	115.6447			-10.51	-5.26	5.26	10.51
73.01	65.7072	69.3576	76.6584	80.3088			-7.30	-3.65	3.65	7.30
60.23	54.20844	57.22002	63.24318	66.25476			-6.02	-3.01	3.01	6.02
43.8	39.42432	41.61456	45.99504	48.18528			-4.38	-2.19	2.20	4.39
31.29	28.16023	29.72469	32.8536	34.41806			-3.13	-1.57	1.56	3.13
15	13.5	14.25	15.75	16.5			-1.50	-0.75	0.75	1.50
8.76	7.884864	8.322912	9.199008	9.637056			-0.88	-0.44	0.44	0.88
7.3	6.57072	6.93576	7.66584	8.03088			-0.73	-0.36	0.37	0.73
2.92	2.628288	2.774304	3.066336	3.212352			-0.29	-0.15	0.15	0.29
0	0	0	0	0			0.00	0.00	0.00	0.00

PE Complex Bottom Up Energy Model

Appendix 6

Pool Operations

Objective:

Present the work accomplished by the Pool Operations Group for the Bottom-up Electricity Demand Model analysis of the fieldhouse.

Research:

The team began the project by research indoor pool operations systems and taking visual inventories of the components located in the fieldhouse. The research showed that air temperature should be held at 2-4 °F above the temperature of the water in order to minimize heating costs (serescodehumidifiers.com). For this reason, the heating, cooling, dehumidifying, water pumping, and air pumping electricity usage for the entire pool area were estimated and documented by the HVAC team.

The primary purpose of the inventories was to compare the components that are in the PE complex the electrical and mechanical schematics of the fieldhouse that are held in the physical plant. These schematics proved to be a good source of information for identifying which components were initially located in the fieldhouse (when it was first built), where these components are located, and how much power these components use (P).

Methods & Procedures:

After the initial research and inventories were completed, the team sought out the physical plant prints. The main components that the group identified were broken down into four major categories: dryers, smoke dampers, vacuums & pumps, and elevators. The group found no records of these components being updated since the building was built, and thus the information on the prints was determined to be valid.

The energy usage [kwh/op-h] for each of these components was calculated (Equation 1). The load percent (L) of 40% remained constant for all components (per Dan Slager). The operating hours (h_{op}) for sporting events, classes, and camps were estimated from official team and Calvin College Schedules. The hours of usage per operating hour ($h_{u/op}$) show an estimate of how long each component is used for every hour an event takes place in the pool. For example, for each hour of pool activity, the pool vacuums and Jockey Pumps will need to run twice as long to keep the pool clean. A full table showing these calculations can be found in Appendix 6.A.

$$\frac{Usage}{Operating\ Hour} = LP\,h_{u/op} \qquad \text{Equation 1}$$

A sensitivity analysis was performed by varying the load percent of these components ±15% (Appendix 6.B). As the team anticipated, the components that have a greater electricity usage are more sensitive to changes in the load percent. Because of the relatively low kwh produced by these components compared to the overall usage, in the best interest of the overall project, the group decided to not spend time improving these estimates. Instead, Group 6 spent their time acquiring schedules from various organizations on campus and organizing that data (Appendix 6.E), assisting Group 4 (HVAC) by analyzing compressors and condensers, and looking at the actual energy usage to see if any trends from year to year could be found (Appendix 6.F).

A decrease in efficiency of 1.11% (f_{eff}) from year to year was calculated by group B-1, and this value was used to back cast from year to year (n) (Equation 2). The usage estimates remained constant from year to year for these components.

$$\frac{Usage}{Month} = LP\,h_{\frac{u}{op}} h_{op}(1 - nf_{eff}) \qquad \text{Equation 2}$$

Results:

The results for year 2016 are shown below (Figure 1 and Table 1). The main factor of for the difference in electricity usage from month to month is the amount of operating hours in the pool. June is when most camps are held in the aquatic center, and October, November, and February are big months for the swim team to have practices and meets.

Tables for other previous years (2010-2015) Appendix 6.C, and figures showing the electricity used in those years can be found in Appendix 6.D of this report. Because the components get slightly less efficient each year they are not replaced and more components are added to the complex and not documented, the energy usage will slightly increase each year.

Table 1: 2016 Pool Operations Energy Usage

Month	kWh / Month	Event [hr]	Classes [hr]	Camp [hr]	Other [hr]	Total [hr]
January	**3702.55**	70	10.8	0	0	80.8
February	**5687.64**	91	33.12	0	0	124.12
March	**2434.15**	20	33.12	0	0	53.12
April	**2434.15**	20	33.12	0	0	53.12
May	**3979.33**	20	24.84	42	0	86.84
June	**7049.52**	20	3.84	130	0	153.84
July	**4781.24**	20	3.84	80.5	0	104.34
August	**2467.15**	20	3.84	30	0	53.84
September	**2434.15**	20	33.12	0	0	53.12
October	**5000.28**	76	33.12	0	0	109.12
November	**5641.81**	90	33.12	0	0	123.12
December	**3612.74**	54	24.84	0	0	78.84
Total	**49224.72**	**521**	**270.72**	**282.5**	**0**	**1074.22**

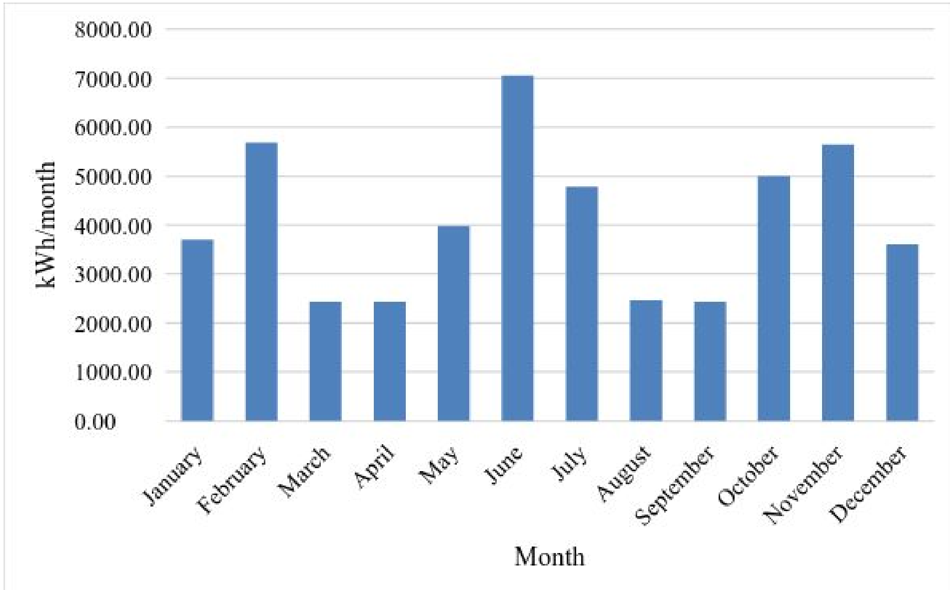

Figure 1: 2016 Pool Operations Energy Usage

APPENDIX 6 TABLE OF CONTENTS

APPENDIX 6.A: Energy Usage

UNIT	ROOM	LOAD	Power [W]	$h_{u/op}$ [hr/oph]	kWh / yr	kWh/ op-h	PANEL
Elevator	C001	40%	10387.69	2	3033.20	8.31	HVDP-J
PEQ-16 (1/2 HP)	C001	40%	1176.00	1	171.70	0.47	RP-J
Suit Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer E109	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer E108	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer E107	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer E104	E118	40%	2300.00	1	335.80	0.92	RP-K1
N.E. Pool Vacuum	E118	40%	3000.00	2	876.00	2.40	RP-K1
Suit Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Suit Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K1
S.E. Pool Vacuum	E118	40%	3000.00	2	876.00	2.40	RP-K1
Suit Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Suit Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2

Dryer	E118	40%	2300.00	1	335.80	0.92	RP-K2
Smoke Dampers	E118	40%	240.00	0.01	0.35	0.00	RP-K3
Smoke Dampers	E141	40%	240.00	0.01	0.35	0.00	RP-K3
Smoke Dampers	E212	40%	840.00	0.01	1.23	0.00	RP-K4
Smoke Dampers	E212	40%	960.00	0.01	1.40	0.00	RP-K4
Smoke Dampers	E212	40%	840.00	0.01	1.23	0.00	RP-K4
Smoke Dampers	E212	40%	840.00	0.01	1.23	0.00	RP-K4
VAVS	E212	40%	960.00	1	140.16	0.38	RP-K4
PP-3A, PP-3B	C001	40%	4733.00	1	691.02	1.89	EHVP-3
PP-4A, PP-4B	C001	40%	2118.00	1	309.23	0.85	EHVP-3
PP-5A PP-5B	C001	40%	6851.00	1	1000.25	2.74	EHVP-3
Jockey Pump	C001	40%	3045.00	1.25	555.71	1.52	EHVP-3

APPENDIX 6.B: Sensitivity Analysis

Table B-1: Sensitivity Analysis of Various Pool Operations Components to Changes in L

Sensitivity (ΔL)	Dryers [kWh/yr]	Smoke Dampers [kWh/yr]	Vacuums & Pumps [kWh/yr]	Elevator kWh/yr]
-15%	7,706.61	4.91	3,781.11	4,465.61
-10%	8,159.94	5.20	4,003.53	4,728.30
-5%	8,613.27	5.49	4,225.95	4,990.98
0%	9,066.60	5.78	4,448.36	5,253.66
5%	9,519.93	6.07	4,670.78	5,516.35
10%	9,973.26	6.36	4,893.20	5,779.03
15%	10,426.59	6.65	5,115.62	6,041.71

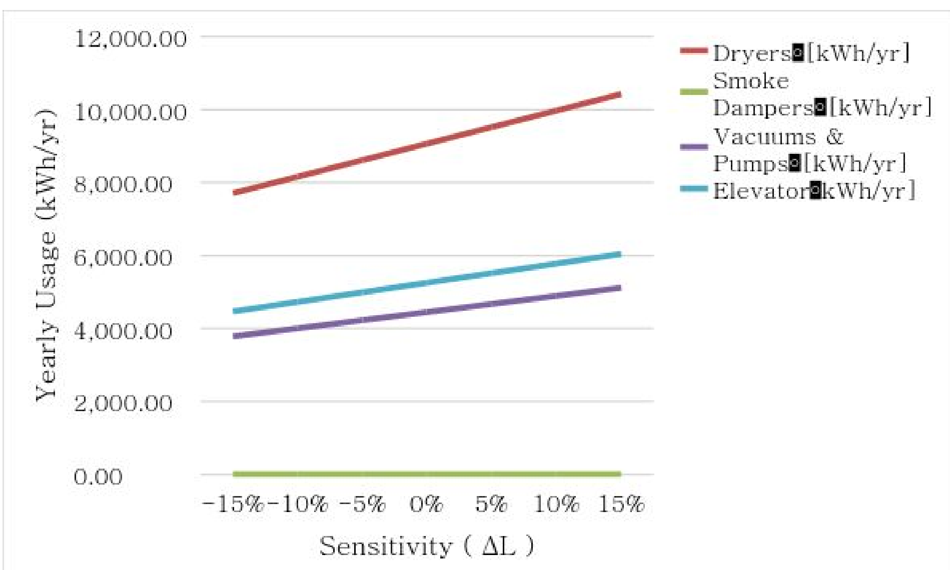

Figure B-1: Sensitivity Analysis of Various Pool Operations Components to Changes in L

APPENDIX 6.C: Backcasting Tables

Table C-1: 2015 Pool Operations Energy Usage

Month	kWh / Month	Event [hr]	Classes [hr]	Camp [hr]	Other [hr]	Total [hr]
January	**3661.46**	70	10.8	0	0	80.8
February	**5624.50**	91	33.12	0	0	124.12
March	**2407.14**	20	33.12	0	0	53.12
April	**2407.14**	20	33.12	0	0	53.12
May	**3935.16**	20	24.84	42	0	86.84
June	**6971.27**	20	3.84	130	0	153.84
July	**4728.17**	20	3.84	80.5	0	104.34
August	**2439.76**	20	3.84	30	0	53.84
September	**2407.14**	20	33.12	0	0	53.12
October	**4944.78**	76	33.12	0	0	109.12
November	**5579.19**	90	33.12	0	0	123.12
December	**3572.64**	54	24.84	0	0	78.84
Total	**48678.33**	**521**	**270.72**	**282.5**	**0**	**1074.22**

Table C-2: 2015 Pool Operations Energy Usage

Month	kWh / Month	Event [hr]	Classes [hr]	Camp [hr]	Other [hr]	Total [hr]
January	**3620.36**	70	10.8	0	0	80.8
February	**5561.37**	91	33.12	0	0	124.12
March	**2380.12**	20	33.12	0	0	53.12
April	**2380.12**	20	33.12	0	0	53.12
May	**3890.99**	20	24.84	42	0	86.84
June	**6893.02**	20	3.84	130	0	153.84
July	**4675.10**	20	3.84	80.5	0	104.34
August	**2412.38**	20	3.84	30	0	53.84
September	**2380.12**	20	33.12	0	0	53.12
October	**4889.27**	76	33.12	0	0	109.12
November	**5516.56**	90	33.12	0	0	123.12
December	**3532.54**	54	24.84	0	0	78.84
Total	**48131.93**	**521**	**270.72**	**282.5**	**0**	**1074.22**

Table C-3: 2013 Pool Operations Energy Usage

Month	kWh / Month	Event [hr]	Classes [hr]	Camp [hr]	Other [hr]	Total [hr]
January	**3579.26**	70	10.8	0	0	80.8
February	**5498.24**	91	33.12	0	0	124.12
March	**2353.10**	20	33.12	0	0	53.12
April	**2353.10**	20	33.12	0	0	53.12
May	**3846.82**	20	24.84	42	0	86.84
June	**6814.77**	20	3.84	130	0	153.84
July	**4622.03**	20	3.84	80.5	0	104.34
August	**2384.99**	20	3.84	30	0	53.84
September	**2353.10**	20	33.12	0	0	53.12
October	**4833.77**	76	33.12	0	0	109.12
November	**5453.94**	90	33.12	0	0	123.12
December	**3492.44**	54	24.84	0	0	78.84
Total	**47585.54**	**521**	**270.72**	**282.5**	**0**	**1074.22**

Table C-4: 2012 Pool Operations Energy Usage

Month	kWh / Month	Event [hr]	Classes [hr]	Camp [hr]	Other [hr]	Total [hr]
January	**3538.16**	70	10.8	0	0	80.8
February	**5435.11**	91	33.12	0	0	124.12
March	**2326.08**	20	33.12	0	0	53.12
April	**2326.08**	20	33.12	0	0	53.12
May	**3802.65**	20	24.84	42	0	86.84
June	**6736.52**	20	3.84	130	0	153.84
July	**4568.96**	20	3.84	80.5	0	104.34
August	**2357.61**	20	3.84	30	0	53.84
September	**2326.08**	20	33.12	0	0	53.12
October	**4778.27**	76	33.12	0	0	109.12
November	**5391.32**	90	33.12	0	0	123.12
December	**3452.33**	54	24.84	0	0	78.84
Total	**47039.15**	**521**	**270.72**	**282.5**	**0**	**1074.22**

Table C-5: 2011 Pool Operations Energy Usage

Month	kWh / Month	Event [hr]	Classes [hr]	Camp [hr]	Other [hr]	Total [hr]
January	**3497.06**	70	10.8	0	0	80.8
February	**5371.97**	91	33.12	0	0	124.12
March	**2299.06**	20	33.12	0	0	53.12
April	**2299.06**	20	33.12	0	0	53.12
May	**3758.48**	20	24.84	42	0	86.84
June	**6658.27**	20	3.84	130	0	153.84
July	**4515.88**	20	3.84	80.5	0	104.34
August	**2330.22**	20	3.84	30	0	53.84
September	**2299.06**	20	33.12	0	0	53.12
October	**4722.77**	76	33.12	0	0	109.12
November	**5328.69**	90	33.12	0	0	123.12
December	**3412.23**	54	24.84	0	0	78.84
Total	**46492.75**	**521**	**270.72**	**282.5**	**0**	**1074.22**

Table C-6: 2010 Pool Operations Energy Usage

Month	kWh / Month	Event [hr]	Classes [hr]	Camp [hr]	Other [hr]	Total [hr]
January	**0.00**					
February	**0.00**					
March	**0.00**					
April	**0.00**					
May	**0.00**					
June	**0.00**					
July	**4462.81**	20	3.84	80.5	0	104.34
August	**2302.84**	20	3.84	30	0	53.84
September	**2272.04**	20	33.12	0	0	53.12
October	**4667.26**	76	33.12	0	0	109.12
November	**5266.07**	90	33.12	0	0	123.12
December	**3372.13**	54	24.84	0	0	78.84
Total	**22343.15**	**280**	**131.88**	**110.5**	**0**	**522.38**

APPENDIX 6.D: Backcasting Figures

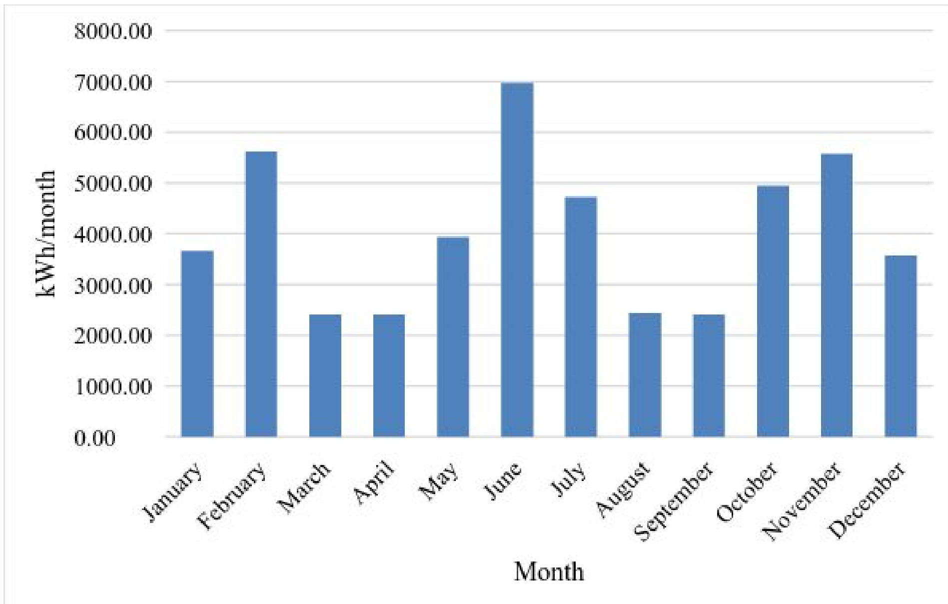

Figure D-1: 2015 Pool Operations Energy Usage

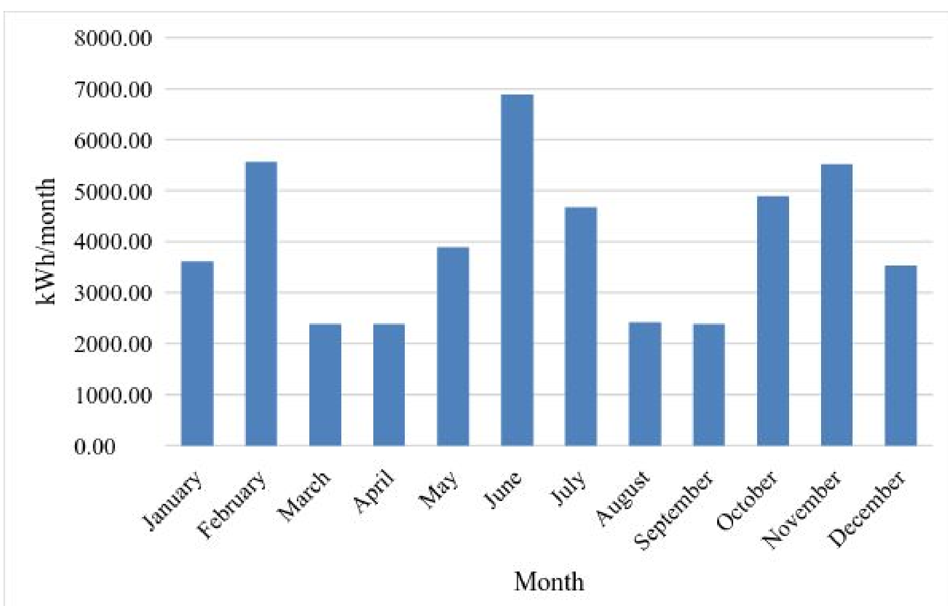

Figure D-2: 2014 Pool Operations Energy Usage

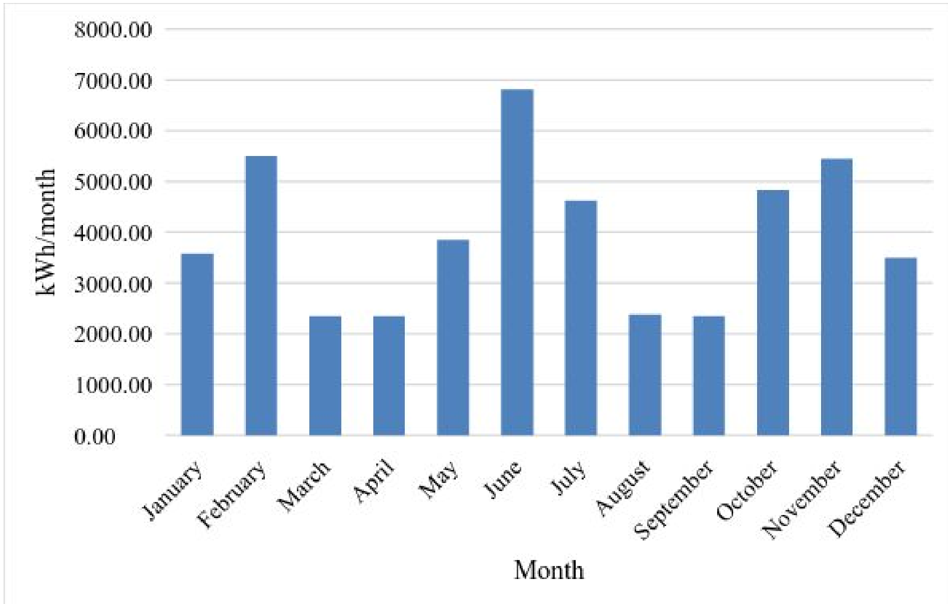

Figure D-3: 2013 Pool Operations Energy Usage

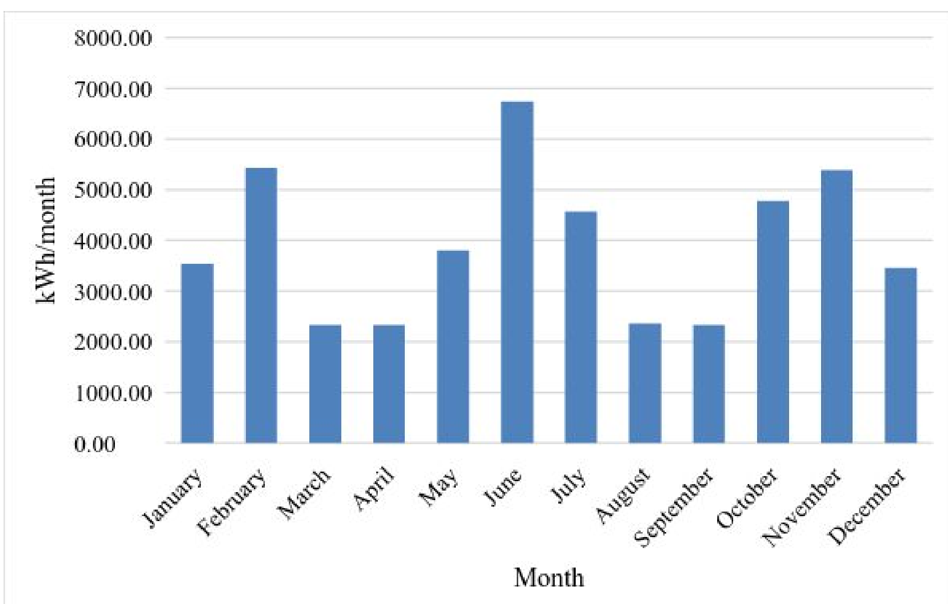

Figure D-4: 2012 Pool Operations Energy Usage

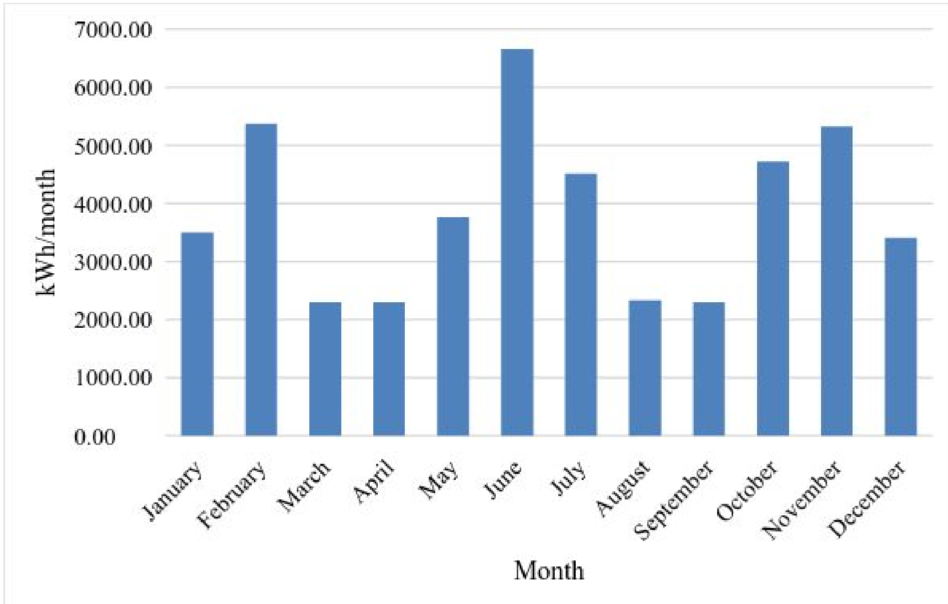

Figure D-5: 2011 Pool Operations Energy Usage

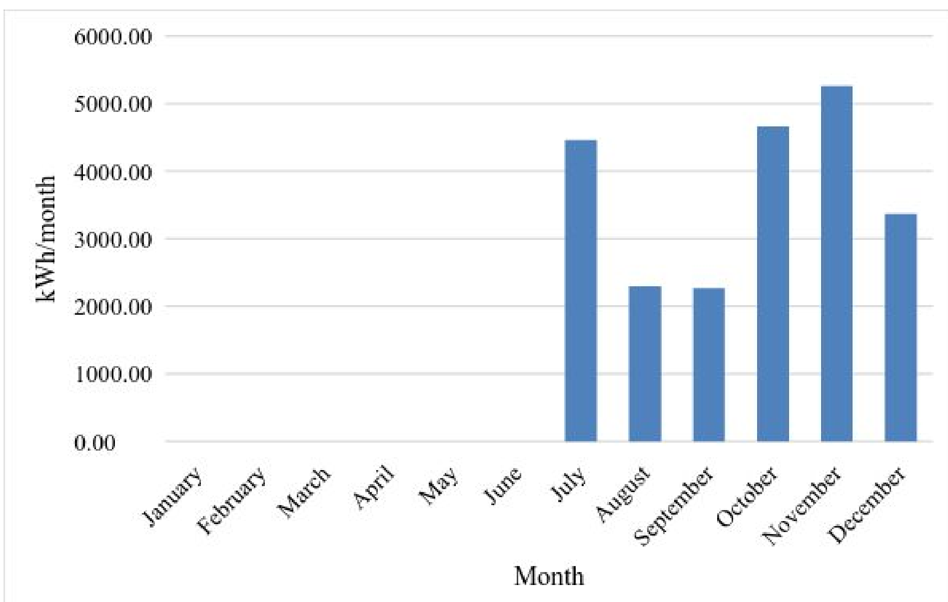

Figure D-6: 2010 Pool Operations Energy Usage