Calvin College

# Redundant Data Center Design

An Exploration in Using CERF to Increase Energy Efficiency on Calvin's Campus

Engineering 333 Class, Spring 2010
Professor Matthew Heun

**Introduction**

Calvin is developing plans for a new data center to provide business continuity and quick recovery in the event of a disaster. The new data center will not replace the existing data center; rather, it will provide redundancy for the operations of the campus. Because of the energy demands of data centers, there is a worldwide push for energy efficiency. So-called "green data centers" provide the same functionality as a normal data center with reduced energy usage and reduced energy costs. Calvin, like most organizations, must weigh the long-term economic benefits of energy efficiency projects against higher initial cost. The Calvin Energy Recovery Fund (CERF) may be used to finance energy efficiency increases. The money saved on energy costs is then returned to the fund for a specified amount of time. The purpose of the fund is draw attention to the value of increasing energy efficiency campus-wide. This project is broken down into five main groups: Power, Envelope, HVAC, Instrumentation, and Finances.

The Engineering 333 Thermal Systems class is seeking to design a new data center that is 30% more energy efficient that the current data center. The class has created a unique design both conserving initial energy use and recycling waste heat.

Money from the Calvin Energy Recovery Fund will be used to implement aspects of the data center design for which an increased initial cost will lead to energy and cost savings.

**Financial**

Team Money has analyzed the financial information provided by the Envelope, Instrumentation, HVAC, and Power Teams, and the results of that analysis will be presented here. Cash flows have been divided into essentially three streams: capital expense, recurring expenses, and energy related expenses, which are also recurring. Each expenditure has also been evaluated as a potential project for the Calvin Energy Recovery Fund (CERF).

The HVAC and power systems are the primary candidates for this fund. Neither the envelope nor the instrumentation will contribute to energy savings, so they will not be considered for funding from CERF. However, tracking the energy savings is necessary for reinvesting the correct amount of money into CERF, so the instrumentation is vital to any project that receives funding from CERF.

The base cases for all four components of the new server room have been set as the standard that Calvin plans to install regardless of any funding from CERF. A final case for each component has been recommended, and those final cases have been evaluated for funding from CERF. The financial section of this report details the recommendation that Team Money has made regarding project funding from CERF.

**Envelope**

The new data center will be located in the basement of the south east corner of the Spoelhof Fieldhouse Complex. A corner of the room must be boxed in to provide the envelope for the redundant data center.

The two main purposes of the envelope are to provide security for the data center and provide a smaller space for the HVAC system to cool. The goal of the envelope design was to provide a way to transfer heat out of the room in case of HVAC failure. The goal was accomplished by designing the interior walls made of corrugated metal to provide heat transfer through the walls. Also, the design of two doors will allow for both cross ventilation and increased heat transfer by forced convection.

**HVAC**

The baseline HVAC case includes an air-cooled 20 kW Liebert unit and a condenser installed at year one and potentially an additional 20kW Liebert unit purchased at year six to account for rising cooling requirements.

Calvin College's nearby pool is heated year round, a convenient heat sink for the data center. Instead of an air-cooled unit, a water-cooled unit is recommended. This water loop can then be run through a heat exchanger with the pool's boiler loop, which will deposit the heat from the data center into the pool and decrease the data center water loop temperature enough so that a chiller will not be needed. This system will save additional money by decreasing the energy needed to heat the pool. The Liebert unit, a water pump and a heat exchanger will all have to be purchased initially. After year seven a second Liebert unit may need to be purchased to account for rising cooling requirements.

The pool loop system is highly recommended and much more efficient than the base case over the life of the data center. It will save Calvin a substantial amount of money in pool heating costs and greatly make up for the difference in initial cost.

**Power**

An Uninterruptable Power Supply (UPS) must be used to protect the servers. Both the current data center and the new data center use online systems which are a series of batteries in-between the servers and the grid The two server power consumption scenarios used by each group are shown below. UPSs act as large, stable energy storage systems designed for a short, high power release in the case of grid failure. The UPS also regulates power quality and eliminates surges and dips.

The Eaton Blade as initially selected by CIT has been confirmed by the Power Team as the best UPS option based on financial and environmental sustainability.

**Instrumentation**

The new redundant data center requires that NOC (Network Operations Center) personnel are able to monitor certain conditions within the data center to monitor the safety of the server equipment. Server equipment will fail if it gets to hot or if the surrounding environment becomes too humid, therefore the baseline instrumentation design must monitor both temperature and humidity in the data center. The system must also be capable of remotely alerting NOC personnel when there is a problem. This has been incorporated into the design by using the NetBotz 500 system. In addition to the warning system, a network of sensors will be installed to properly analyze the energy usage of the data center.

**Alternative Options**

As the need for data storage, processing speed, and system flexibility has increased over the years, various companies have seen a dramatic shift in the way they handle their computing needs. One way this could affect the new server room would be a shift to outsourcing server space to third parties. This is commonly called cloud computing. While some aspects of cloud computing appeal to CIT, this option will have no effect on the design of the redundant data center.

# Financial Appendix

Completed by: Team Money
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# Table of Contents

# 1. Introduction

Calvin Information and Technology (CIT) plans to install a second data center in the Spoelhof Fieldhouse Complex to back up the information in the current data center. It is the goal of the 2010 ENGR 333 class to design that new data center such that to the new server system is 30% more efficient than the current system. Team Money was responsible for the fiscal analysis of each project. The projects related to this new server were broken down into four different sections: the envelope (walls, floors, and doors), the Heating Ventilating and Air Conditioning (HVAC) system, the Uninterruptable Power Supply (UPS) system, and instrumentation for the project.

## 1.1 Calvin Energy Recovery Fund

Calvin College has a fund that is interested in improving energy efficiency on its campus; that fund is the Calvin Energy Recovery Fund (CERF). CERF can be used to update existing systems or for new construction as long as the project results in energy savings. Those savings then get put back into the fund for five years after the break-even date. CERF would invest in our project to provide the incremental cost increase for the more efficient equipment; the incremental savings would then be used to grow the fund so CERF is available for other projects.[2]

## 1.2 CERF Application

The server and its associated systems require a large amount of energy, and it is possible to improve to improve the system efficiency through an additional investment. The efficiency improvements can be made in the HVAC system, where the waste heat of the server can be used to displace raw energy used for heating the pool. The complexities involved in this heat transfer system add cost to the base case HVAC plan, but the cost is associated with energy (and therefore cost) savings, so this more efficient design becomes a candidate for CERF investment. It is the goal of Team Money to analyze the financial feasibility of each project and to give a recommendation to the CERF board of whether or not to invest in the incremental cost that would provide energy savings to the college.

[2] Engineering 333, Class of 2008. "Calvin Energy Efficiency Fund." Linked description of Calvin's energy fund. Calvin College, 2008. Web. 12 Feb. 2010. <http://www.calvin.edu/~mkh2/thermal-fluid_systems_desig/2008_ceef_final_report.pdf>.

# 2. Current Data Center

## 2.1 Specifications

The following table summarizes the power usage, instrumentation, and HVAC of the current data center. The data center contains the servers that provide the computational power for Calvin's entire campus. The room requires a large quantity of power both for the servers themselves and to keep the room cool. Servers create a lot of heat and that heat must be removed in order to avoid damage to the equipment. This equipment is less efficient than currently available computers and servers simply because of the rate of improvements in the area of computing.

**Table 1: Old Data Center - Specifications[3]**

| Power | |
|---|---|
| Maximum Server Power | 40.0 kW |
| Average Server Power (70 - 75% of Max.) | 30.0 kW |
| | |
| Maximum HVAC Power | 35.0 kW |
| Average HVAC Power | 24.5 kW |
| | |
| Instrumentation | |
| Instrumentation Systems | NetBotz 310, 320 (No Base / Server) |
| Connection Type | Direct - Local Network |
| System Features | Monitors Humidity, Temperature and Access |
| Alert Methods | Text Message, E-Mail, Phone Call |
| | |
| Heating, Ventilation and Air-Conditioning (HVAC) | |
| Initial Heat Load | 4 kW |
| Maximum Capacity | 40 kW |
| Air-Conditioning System | |
| Capacity | 10 ton |
| Rating | 460 V and 36.5 Amps |
| Power | 16.79 kW |
| Temperature Range | 68 - 72 F |
| Alarm Activation Temperature | 85 F |
| Damage Temperature | 90 |

[3] Sam Anema and Bob Myers, CIT

## 2.2 Efficiency

The efficiency of the current data center was determined using equation 1, and is equal to 58%. The

$$\frac{Power\ to\ Server + Power\ to\ Pool}{Power\ to\ Server + Power\ to\ HVAC + Power\ to\ UPS} \quad \text{Equation 1}$$

efficiency was calculated by dividing the usable products of the system by the input to the system. In these calculations the power supplied for HVAC and the uninterruptable power supply (UPS) is considered fuel for the servers to operate. The old data center does not supply any heat to the pool, so power to the pool in this equation is zero.

## 2.3 Room for Improvement

As emphasized in earlier sections, one of the goals of this project is to improve the efficiency of the data center by 30%. In order to achieve this goal, certain changes are made to the current systems used in the data center.

# 3. Analysis of Base Case

Computers become more and more efficient each year because of technological innovations that allow the same amount of computing to be done in a smaller space with less power. Because of this, it was quite possible that the new data center be 30% more efficient than the current data center without the efforts of our class. Our class wanted to establish the data center's efficiency if it weren't for our project and CERF. We termed the components of that design the "base case". We could then additionally compare our CERF design to this base case and ensure that the CERF design made a significant improvement. In addition, the CERF investment would only cover the additional cost of the CERF case, or the cost of the efficient improvements above what the data center would have cost anyway. Our calculations determined the cost of the base case, so that incremental cost could be firmly established.

## 3.1 Explanation

Each team, power supply, envelope, HVAC, and instrumentation, researched what Calvin had previously planned to install, determined the cost of those components, and projected the energy consumption of the base case design. Team Money then did a financial analysis of each team's base case and determined the base case efficiency. These calculations can be seen in full in the attached excel tables in at the end of this appendix. Table 2 shows the components, capital costs, and total energy costs over twenty years of each group's base case.

**Table 2: Base Case Information**

| Team | Components | Capital Cost (2010$) | Total Energy Costs over 20 yrs. (2010$) |
|---|---|---|---|
| **Power Supply (40 kW)** | Eaton Blade | $18,860 | $371,201 |
| **Envelope** | Gypsum Wall<br>1 Door | $1,755 | $0 |
| **HVAC (40 kW)** | Liebert Unit + Condenser<br>Materials<br>Refrigerant | $28,731 | $125,251 |
| **Instrumentation** | NetBotz Sensor Pod<br>NetBotz Temperature Sensor<br>Netbotz 500<br>4-20mA Sensor Pod<br>Current Transducer | $4,104 | $0 |
| **TOTAL:** | | **$53,450** | **$496,452** |

## 3.2 Efficiency

The efficiency of the base case was determined using Equation 1, and is equal to 71%. The base case does not supply power to the pool, so the only product of the system is the power the servers.

# 4. CERF Case Design

The CERF design made efficiency improvements on the base case design. The CERF design provides both server power to the new data center and warmth to the pool using the heat rejected by the data center HVAC. The envelope team upgraded their design by adding two extra doors and changing the material of the doors from gypsum to aluminum, however this upgrade is not applicable to the CERF design. The power team did not have to upgrade their design. Both the 20 kW and 40 kW base cases already maximized efficiency. The HVAC team upgraded their design by adding a heat exchanger and a water pump. The pool acts as a heat sink to cool the Liebert unit. A water pump and heat exchanger were added to the HVAC design to create this additional loop. The instrumentation team added several parts to their base case design in order to record the heat exchanged between the data center and the pool. The instrumentation is an important aspect of the CERF design because without it CERF would not know the exact measure of their savings.

## 4.1 Cost Analysis

Team Money performed the cost analysis for the CERF design for both 20 and 40 kilowatt energy use projections. The HVAC team had an increase in costs by $4,670, and the instrumentation team had a cost difference of $ 5,055 between the efficient design and the base case design. The total present value costs of the 40 and 20 kilowatt cases are $ 427,690 and $ 314,680, respectively. Team Money also performed the payback analysis for the CERF design for both cases. Surprisingly, the results show that the CERF case pays back in about three years. This is because the CERF case yields significant energy savings. In the 40 kilowatt case there would be a cost saving of $208,152 and a saving of $156,019 by the 20 kilowatt case. Also the efficiency increased by 92% for the 40 kilowatt case and 92% for the 20 kilowatt case from the base case to the CERF case in the first year. The results show that the CERF case is much more efficient and cost effective.

# 5. Future Fuel Cost Analysis

## 5.1 Resources – Energy Information Agency

The U.S. Energy Information Administration, EIA, is the statistical and analytical agency within the U.S. Department of Energy. EIA is the Nation's premier source of energy information and, by law, its data, analyses, and forecasts are independent of approval by any other officer or employee of the United States Government.

EIA conducts a comprehensive data collection program that covers the full spectrum of energy sources, end uses, and energy flows; generates short- and long-term domestic and international energy projections; and performs informative energy analyses.

## 5.2 Charts

The Energy Information Administration (EIA), part of the Department of Energy, was used to estimate the future price of electricity over the next 20 years using low, average, and high projections, shown in Figure 1.

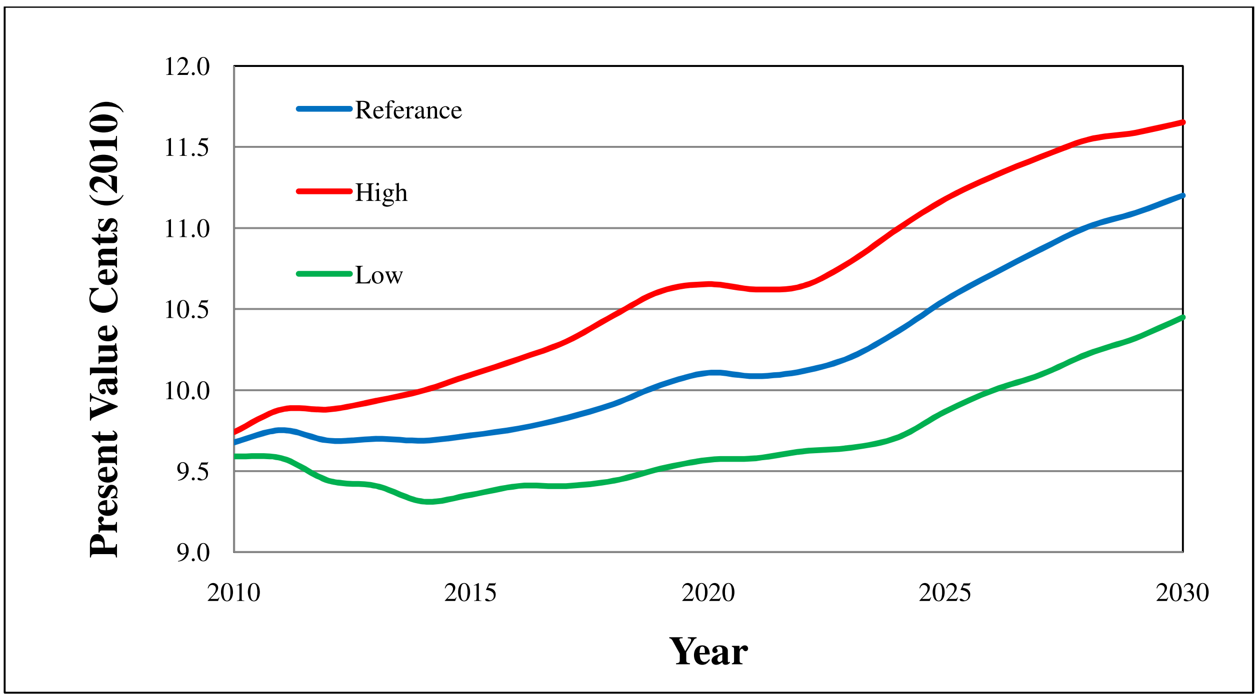



**Figure 1: Future Electricity Price Projections[4]**

The EIA was also used to determine the price of natural gas over the next 20 years. The EIA projections were adjusted to the price Calvin College currently pays for natural gas. The EIA projection and the lower Calvin College projection are shown in Figure 2.

[4] http://www.eia.doe.gov/

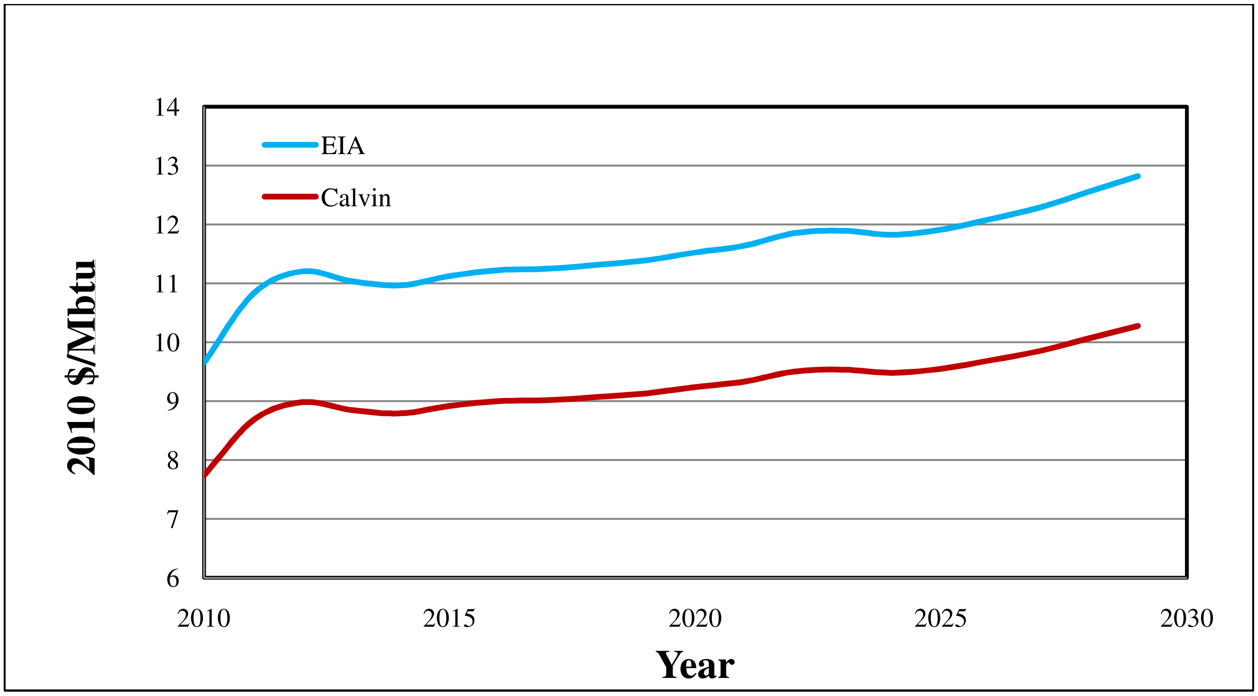



Figure 2: Future Natural Gas Price Projections[5]

# 6. CERF and Base Case Comparison

## 6.1 Comparison of Base Case and Final Design

The differences in base case and the efficient case existed in the HVAC and instrumentation designs for both the 20 and 40 kilowatt cases. In the efficient design of the HVAC team the significant changes were the addition of the heat exchanger and the water pump. This caused a jump in the total upfront costs. In the efficient design of the Instrumentation team the main changes were the addition of the equipment that will be purchased to track closely the efficiency and savings. This is necessary since the cost savings will need to be deposited back into CERF. Due to these the cost difference between the base case and CERF case will be $ 4,670 for the HVAC team and $ 5,055 for the instrumentation team. These differences can be seen in Tables 1 and 2 below. The power team had no additions to base case - they already reached the maximum efficiency in the base case. The envelope team upgrades their base case causing an increase in costs but it is not applicable to the CERF.

[5] http://www.eia.doe.gov/

Table 3: HVAC Cost Comparison

| HVAC (Lifespan 20 yrs.) | | | | | |
|---|---|---|---|---|---|
| **Base Case** | | | CERF Case | | |
| **20 kW Liebert Unit + Condenser** | $ | 24,331.00 | 20 kW Liebert Unit - Water Cooled | $ | 20,791.00 |
| **Materials** | $ | 1,200.00 | Water pump | $ | 1,500.00 |
| **Refrigerant** | $ | 200.00 | Heat exchanger for pool | $ | 1,610.00 |
| **Labor** | $ | 2,000.00 | Materials | $ | 6,500.00 |
| **Contingency** | $ | 1,000.00 | Labor | $ | 2,000.00 |
| | | | Contingency | $ | 1,000.00 |
| **Total Cost** | **$** | **28,731.00** | **Total Cost** | **$** | **33,401.00** |
| **Cost Difference** | | | **$** | | **4,670.00** |

Table 4: Instrumentation Cost Comparison

| Instrumentation (Lifespan: 30 yrs) | | | | | |
|---|---|---|---|---|---|
| **Base Case** | | | **CERF Case** | | |
| **NetBotz Sensor Pod 120** | $ | 336.00 | NetBotz 500 | $ | 2,178.00 |
| **NetBotz Temperature Sensor** | $ | 640.00 | LabVIEW Brain - cFP-2200 | $ | 1,559.00 |
| **NetBotz 500** | $ | 2,178.00 | LabVIEW Module AI-110 | $ | 529.00 |
| **4-20mA Sensor Pod** | $ | 380.00 | LabVIEW Module RTD-122 | $ | 529.00 |
| **Current Transducer** | $ | 97.00 | LabVIEW Connector Block | $ | 338.00 |
| **Labor** | $ | 100.00 | LabVIEW Back Plane | $ | 799.00 |
| **Contingency (10%)** | $ | 373.00 | Power Input | $ | 249.00 |
| | | | 4-20mA Sensor Pod | $ | 380.00 |
| | | | Current Transducer | $ | 291.00 |
| | | | Platinum RTD | $ | 126.00 |
| | | | Ultrasonic Flow Meter | $ | 1,708.00 |
| | | | Labor | $ | 300.00 |
| | | | Contingency (10%) | $ | 899.00 |
| **Total Cost** | **$** | **4,104.00** | Total Cost | **$** | **9,885.00** |
| **Cost Difference** | | | | **$** | **5,781.00** |

As this is an Energy Recovery fund, implementing the CERF case HVAC and Instrumentation would make the new server room much more efficient than both the old server room and the base case server room. Equation 1, as used before, was used to calculate the efficiencies of all server situations. A comparison between results can be seen below in Figure 3. Because the heat removed in the CERF case is added to the usable energy in the pool, that energy is counted as a usable product in the efficiency, which is why efficiencies of over 100% are achieved.

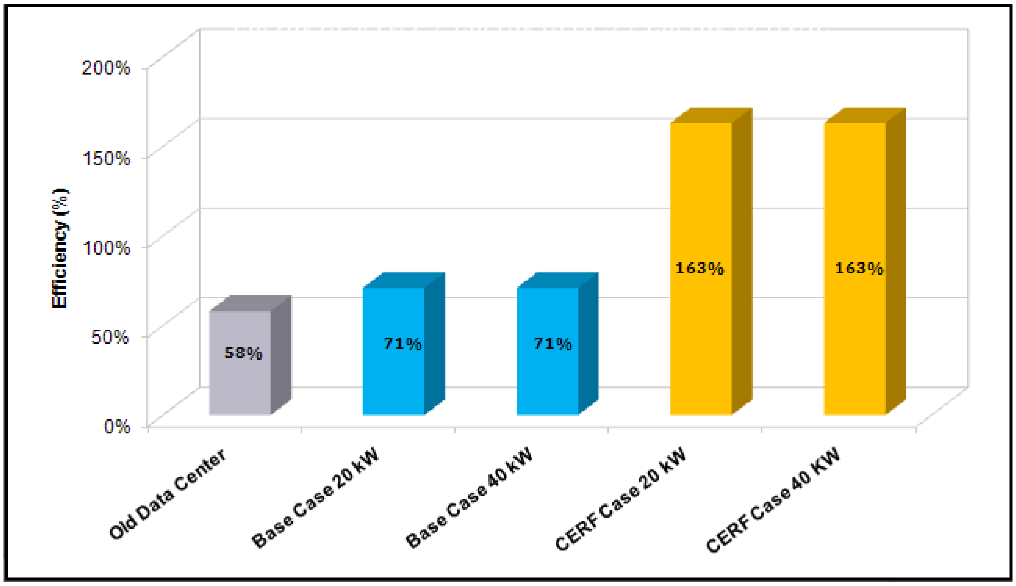



Figure 3: Efficiency Comparisons

The total 20 year cost for each component is shown in Figure 4. The total cost difference between the two scenarios is small because energy prices dominate over capital equipment costs.

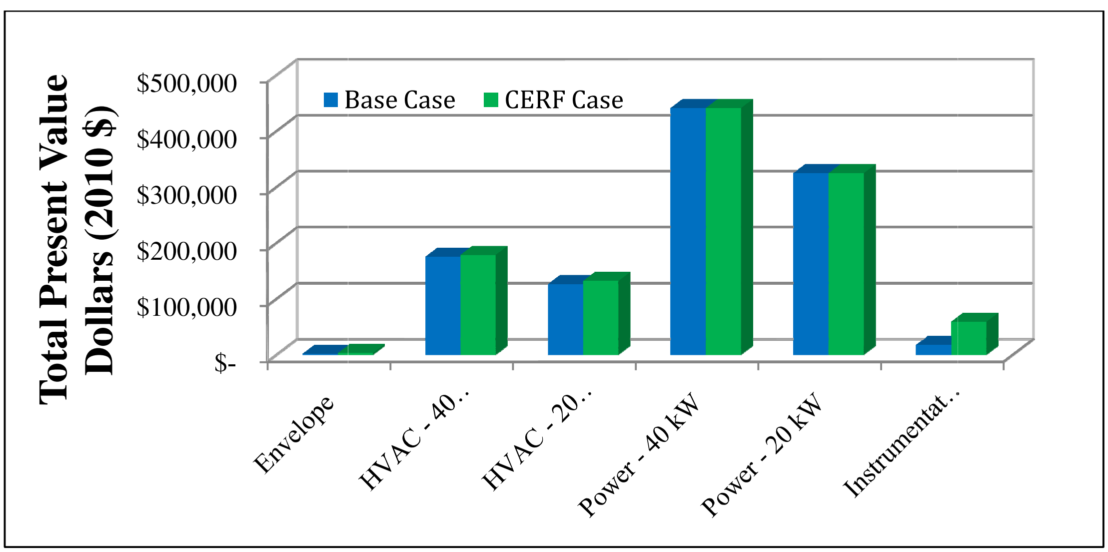



Figure 4: Cost Comparison over 20 years

## 6.2 Recommendation of Projects for CERF

As Team Money, we recommend that the HVAC and the Instrumentation designs are projects for CERF, but not the power and envelope designs. Because the upgrade by the envelope team design does not contribute to the transfer of heat from the data center to the pool, it does not play a role in energy savings. And since the power team had no changes, CERF is not needed. On the other hand, the HVAC and Instrumentation design work towards energy savings.

If the lifetime savings of the CERF design is compared to the initial investment, the choice becomes very clear. Figure 5 shows this. An initial investment of approximately $10,000 can, in 20 years, save the college between $140,000 and $190,000 (present value dollars!) depending on the energy usage of the server system.

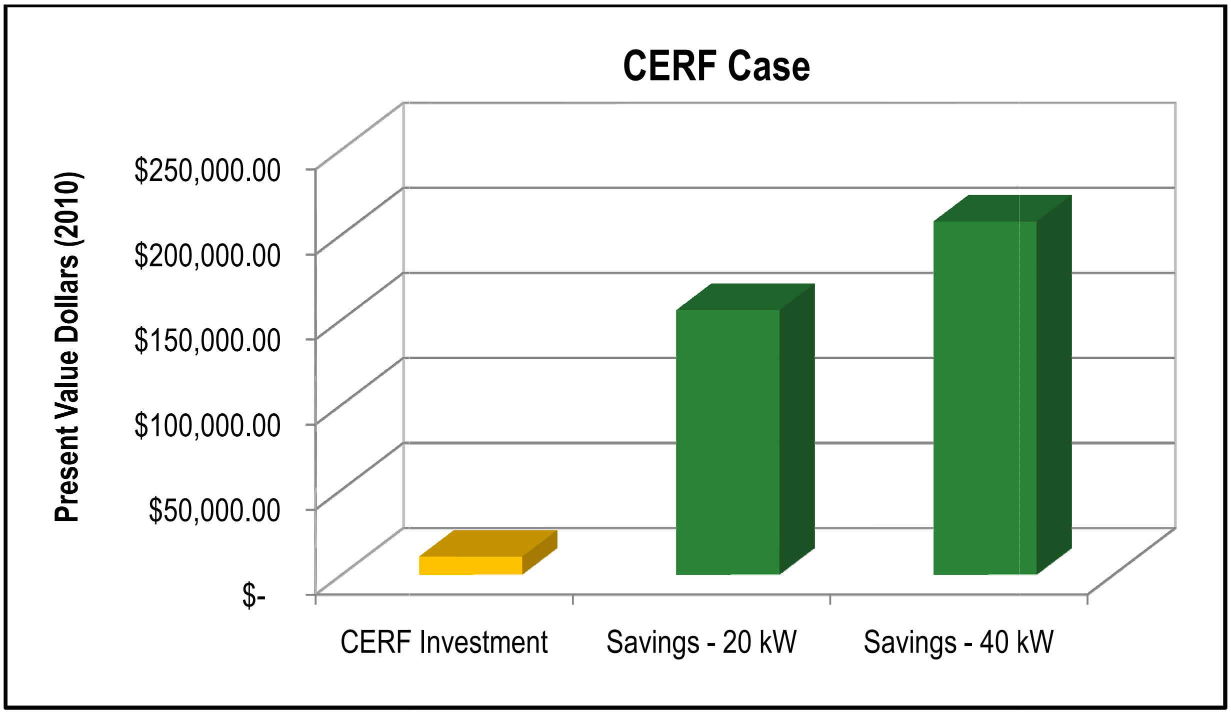



Figure 5: Investment and Project Lifetime Savings Comparison

While the college would maintain savings over the lifetime of the project, the Energy Recovery Fund will receive the savings from the project from its installment up until five years after the fund's payback period is over. The CERF balance would look approximately like what is shown below in Figure 6. The fund would approximately double through the investment into this server project.

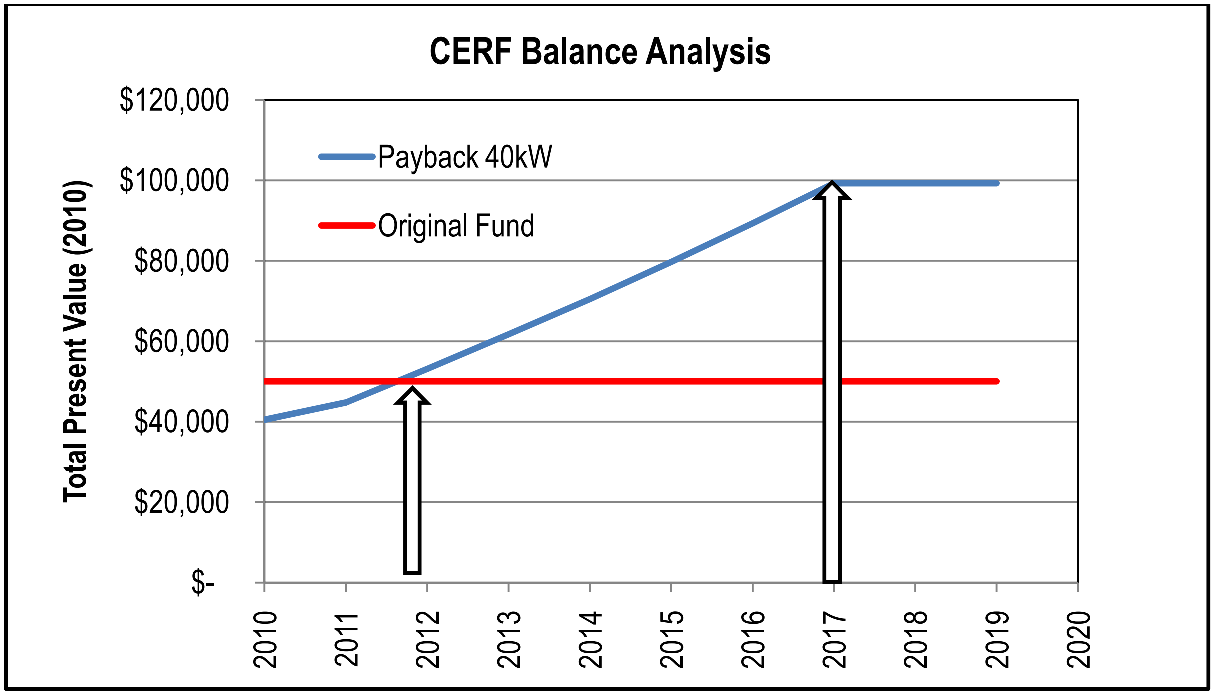



**Figure 6: Payback Analysis**

## 7. Conclusions

There are several advantages to the CERF design. The main advantage is that Calvin College will use less energy. As well, the CERF design results in cost benefits over a time period of 20 years. The CERF design is more efficient than the existing data center and the base case design. Though Calvin College could choose this efficient design regardless of the involvement of CERF, they should involve CERF as it provides an entity for focused effort and an avenue for showing results. Hence, this efficient design is the CERF design.

# 8. Full Calculations

## 8.1 Energy Price Information

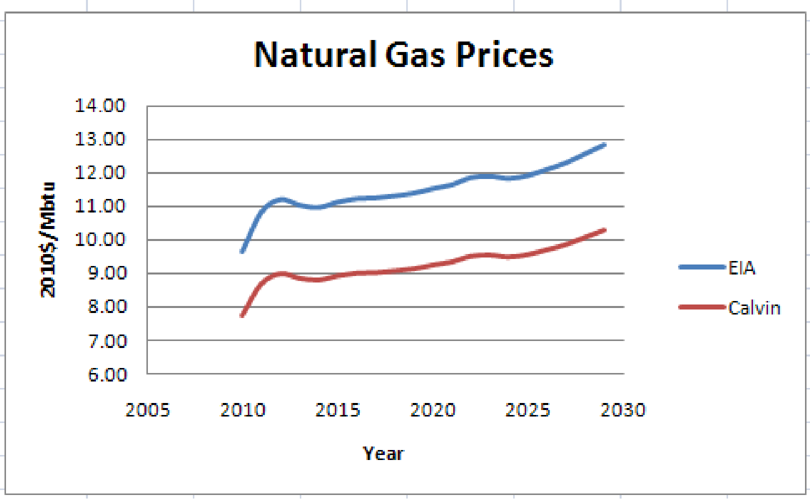
| Electricity Price in 2007 cents per kilowatthour | | | | | |
|---|---|---|---|---|---|
| Reference | % Change | High | % Change | Low | % Change |
| 9.11 | | 9.11 | | 9.11 | |
| 9.63 | 5.7080 | 9.63 | 5.7080 | 9.63 | 5.7080 |
| 9.65 | 0.2077 | 9.70 | 0.7269 | 9.61 | -0.2077 |
| 9.01 | -6.6321 | 9.07 | -6.4948 | 8.93 | -7.0760 |
| 9.08 | 0.7769 | 9.20 | 1.4333 | 8.92 | -0.1120 |
| 9.02 | -0.6608 | 9.20 | 0.0000 | 8.79 | -1.4574 |
| 9.03 | 0.1109 | 9.25 | 0.5435 | 8.76 | -0.3413 |
| 9.02 | -0.1107 | 9.31 | 0.6486 | 8.67 | -1.0274 |
| 9.05 | 0.3326 | 9.40 | 0.9667 | 8.71 | 0.4614 |
| 9.09 | 0.4420 | 9.49 | 0.9574 | 8.76 | 0.5741 |
| 9.15 | 0.6601 | 9.59 | 1.0537 | 8.76 | 0.0000 |
| 9.23 | 0.8743 | 9.74 | 1.5641 | 8.79 | 0.3425 |
| 9.34 | 1.1918 | 9.88 | 1.4374 | 8.86 | 0.7964 |
| 9.41 | 0.7495 | 9.92 | 0.4049 | 8.91 | 0.5643 |
| 9.39 | -0.2125 | 9.89 | -0.3024 | 8.92 | 0.1122 |
| 9.42 | 0.3195 | 9.91 | 0.2022 | 8.96 | 0.4484 |
| 9.50 | 0.8493 | 10.05 | 1.4127 | 8.98 | 0.2232 |
| 9.65 | 1.5789 | 10.24 | 1.8905 | 9.04 | 0.6682 |
| 9.83 | 1.8653 | 10.41 | 1.6602 | 9.19 | 1.6593 |
| 9.98 | 1.5259 | 10.54 | 1.2488 | 9.31 | 1.3058 |
| 10.12 | 1.4028 | 10.65 | 1.0436 | 9.40 | 0.9667 |
| 10.25 | 1.2846 | 10.75 | 0.9390 | 9.52 | 1.2766 |
| 10.33 | 0.7805 | 10.79 | 0.3721 | 9.61 | 0.9454 |
| 10.43 | 0.9681 | 10.85 | 0.5561 | 9.73 | 1.2487 |
| | **0.6092** | | **0.7814** | | **0.3078** |

| POSITIVE % INCREASE | | | | | | |
|---|---|---|---|---|---|---|
| Electricity Price in 2010 cents per kW-h | | | | | | |
| Year | Reference | % Change | High | % Change | Low | % Change |
| 2007 | 9.78 | | 9.78 | | 9.78 | |
| 2008 | 10.34 | 5.7080 | 10.34 | 5.7080 | 10.34 | 5.7080 |
| 2009 | 10.36 | 0.2077 | 10.42 | 0.7269 | 10.32 | -0.2077 |
| 2010 | 9.68 | -6.6321 | 9.74 | -6.4948 | 9.59 | -7.0760 |
| 2011 | 9.75 | 0.7769 | 9.88 | 1.4333 | 9.58 | -0.1120 |
| 2012 | 9.69 | -0.6608 | 9.88 | 0.0000 | 9.44 | -1.4574 |
| 2013 | 9.70 | 0.1109 | 9.93 | 0.5435 | 9.41 | -0.3413 |
| 2014 | 9.69 | -0.1107 | 10.00 | 0.6486 | 9.31 | -1.0274 |
| 2015 | 9.72 | 0.3326 | 10.10 | 0.9667 | 9.35 | 0.4614 |
| 2016 | 9.76 | 0.4420 | 10.19 | 0.9574 | 9.41 | 0.5741 |
| 2017 | 9.83 | 0.6601 | 10.30 | 1.0537 | 9.41 | 0.0000 |
| 2018 | 9.91 | 0.8743 | 10.46 | 1.5641 | 9.44 | 0.3425 |
| 2019 | 10.03 | 1.1918 | 10.61 | 1.4374 | 9.52 | 0.7964 |
| 2020 | 10.11 | 0.7495 | 10.65 | 0.4049 | 9.57 | 0.5643 |
| 2021 | 10.08 | -0.2125 | 10.62 | -0.3024 | 9.58 | 0.1122 |
| 2022 | 10.12 | 0.3195 | 10.64 | 0.2022 | 9.62 | 0.4484 |
| 2023 | 10.20 | 0.8493 | 10.79 | 1.4127 | 9.64 | 0.2232 |
| 2024 | 10.36 | 1.5789 | 11.00 | 1.8905 | 9.71 | 0.6682 |
| 2025 | 10.56 | 1.8653 | 11.18 | 1.6602 | 9.87 | 1.6593 |
| 2026 | 10.72 | 1.5259 | 11.32 | 1.2488 | 10.00 | 1.3058 |
| 2027 | 10.87 | 1.4028 | 11.44 | 1.0436 | 10.10 | 0.9667 |
| 2028 | 11.01 | 1.2846 | 11.55 | 0.9390 | 10.22 | 1.2766 |
| 2029 | 11.09 | 0.7805 | 11.59 | 0.3721 | 10.32 | 0.9454 |
| 2030 | 11.20 | 0.9681 | 11.65 | 0.5561 | 10.45 | 1.2487 |
| **Average** | | **0.6092** | | **0.7814** | | **0.3078** |

| Natural Gas Prices | | | |
|---|---|---|---|
| Year | 2008$ / MBtu's | 2010$ / MBtu's | Calvin's Price per Slager |
| 2010 | 8.92 | 9.65 | 7.74 |
| 2011 | 10.01 | 10.82 | 8.68 |
| 2012 | 10.36 | 11.20 | 8.98 |
| 2013 | 10.20 | 11.04 | 8.85 |
| 2014 | 10.14 | 10.97 | 8.79 |
| 2015 | 10.28 | 11.12 | 8.92 |
| 2016 | 10.38 | 11.22 | 9.00 |
| 2017 | 10.40 | 11.25 | 9.02 |
| 2018 | 10.46 | 11.31 | 9.07 |
| 2019 | 10.53 | 11.39 | 9.13 |
| 2020 | 10.65 | 11.52 | 9.24 |
| 2021 | 10.76 | 11.64 | 9.33 |
| 2022 | 10.96 | 11.85 | 9.50 |
| 2023 | 11.00 | 11.89 | 9.54 |
| 2024 | 10.93 | 11.82 | 9.48 |
| 2025 | 11.01 | 11.91 | 9.55 |
| 2026 | 11.18 | 12.09 | 9.69 |
| 2027 | 11.36 | 12.29 | 9.85 |
| 2028 | 11.61 | 12.56 | 10.07 |
| 2029 | 11.85 | 12.82 | 10.28 |

| Convert | |
|---|---|
| MCF | Btu |
| 1 | 1034000 |

| EIA and Calvin's Price Relationship |
|---|
| 0.801901899 |



## 8.2 Base Case Calculations

| | |
|---|---|
| **Instrumentation** | |
| Project # | 1.4 |
| Lifespan (years) | 30 |

| Initial | | | |
|---|---|---|---|
| Total Unit Cost | Labor Cost | Material Costs | Contingency |
| 4214.10 | 200 | 3631 | 383.10 |

| Inflation | | Interest Rate | |
|---|---|---|---|
| Nominal | 4.0% | Nominal | 6% |
| Good Economy | 2.5% | Good Economy | 4% |
| Poor Economy | 7.0% | Poor Economy | 10% |

| Future | | | | Nominal | | Good Economy | | Poor Economy | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Labor Cost | Material Cost | Total Yearly Costs | Future | Present | Future | Present | Future | Present |
| 2010.00 | 200.00 | 4014.10 | 4214.10 | 4214.10 | 4214.10 | 4214.10 | 4214.10 | 4214.10 | 4214.10 |
| 2011.00 | 383.10 | 0.00 | 383.10 | 398.42 | 375.87 | 392.68 | 377.57 | 409.92 | 372.65 |
| 2012.00 | 383.10 | 0.00 | 383.10 | 414.36 | 368.78 | 402.49 | 372.13 | 438.61 | 362.49 |
| 2013.00 | 383.10 | 0.00 | 383.10 | 430.94 | 361.82 | 412.56 | 366.76 | 469.31 | 352.60 |
| 2014.00 | 383.10 | 0.00 | 383.10 | 448.17 | 354.99 | 422.87 | 361.47 | 502.17 | 342.99 |
| 2015.00 | 383.10 | 0.00 | 383.10 | 466.10 | 348.30 | 433.44 | 356.26 | 537.32 | 333.63 |
| 2016.00 | 383.10 | 0.00 | 383.10 | 484.74 | 341.73 | 444.28 | 351.12 | 574.93 | 324.53 |
| 2017.00 | 383.10 | 0.00 | 383.10 | 504.13 | 335.28 | 455.39 | 346.06 | 615.17 | 315.68 |
| 2018.00 | 383.10 | 0.00 | 383.10 | 524.30 | 328.95 | 466.77 | 341.06 | 658.24 | 307.07 |
| 2019.00 | 383.10 | 0.00 | 383.10 | 545.27 | 322.74 | 478.44 | 336.15 | 704.31 | 298.70 |
| 2020.00 | 383.10 | 0.00 | 383.10 | 567.08 | 316.66 | 490.40 | 331.30 | 753.62 | 290.55 |
| 2021.00 | 383.10 | 0.00 | 383.10 | 589.76 | 310.68 | 502.66 | 326.52 | 806.37 | 282.63 |
| 2022.00 | 383.10 | 0.00 | 383.10 | 613.36 | 304.82 | 515.23 | 321.81 | 862.81 | 274.92 |
| 2023.00 | 383.10 | 0.00 | 383.10 | 637.89 | 299.07 | 528.11 | 317.17 | 923.21 | 267.42 |
| 2024.00 | 383.10 | 0.00 | 383.10 | 663.41 | 293.42 | 541.31 | 312.59 | 987.84 | 260.13 |
| 2025.00 | 383.10 | 0.00 | 383.10 | 689.94 | 287.89 | 554.84 | 308.08 | 1056.98 | 253.03 |
| 2026.00 | 383.10 | 0.00 | 383.10 | 717.54 | 282.46 | 568.71 | 303.64 | 1130.97 | 246.13 |
| 2027.00 | 383.10 | 0.00 | 383.10 | 746.24 | 277.13 | 582.93 | 299.26 | 1210.14 | 239.42 |
| 2028.00 | 383.10 | 0.00 | 383.10 | 776.09 | 271.90 | 597.51 | 294.95 | 1294.85 | 232.89 |
| 2029.00 | 383.10 | 0.00 | 383.10 | 807.13 | 266.77 | 612.44 | 290.69 | 1385.49 | 226.54 |
| | | | | | | | | | |
| Total | 7478.9 | 4014 | 11493 | 15239 | $10,263.35 | 13617 | $10,528.69 | 19536 | $9,798.11 |

| | |
|---|---|
| **Envelope** | |
| Project # | 1.1 |
| Lifespan (years) | 50 |

| Upfront Costs | 2010 $ |
|---|---|
| Total Cost | 1755 |
| Labor Costs | 1000 |
| Material Costs | 755 |

| Inflation | | Interest Rate | |
|---|---|---|---|
| Nominal | 4.0% | Nominal | 6% |
| Good Economy | 2.5% | Good Economy | 4% |
| Poor Economy | 7.0% | Poor Economy | 10% |

**Power**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Battery | mass | 6 | lb | Proj # 001.2 | | | | | |
| Efficiency Fa | 1 | Details | height | 3.9 | in | Company | Eaton | | | | |
| Growth in Us | 1.051621544 | | width | 2.6 | in | Name (PN) | 12 KW Blade module - expanded in 12 kW increments | | | | |
| Growth in Us | 1.1 | | length | 6 | in | Power/Unit | 12 | kW | | | |
| | | | number per mod | 20 | | Efficiency | 0.97 | | | | |
| | | Battery Disposal Costs | | 0.35 | $/lb | | | | | | |

| Inflation | | Interest Rate | |
|---|---|---|---|
| Nominal | 4.0% | Nominal | 6% |
| Good Economy | 2.5% | Good Economy | 4% |
| Poor Economy | 7.0% | Poor Economy | 10% |

| Nominal - 40 kW | | | | | | | | | | | Nominal | | Good Economy | | Bad Economy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 3 | 1826 | 21915 | 95% | 23068 | 2232 | 18860 | | | 21092.27 | 21,092 | 21,092 | 21,092 | 21,092 | 21,092 | 21,092 |
| 2011 | 9 | 6575 | 78894 | 97% | 81334 | 7932 | | | | 7931.63 | 8,249 | 7,782 | 8,130 | 7,817 | 8,487 | 7,715 |
| 2012 | 17 | 12419 | 149022 | 97% | 153631 | 14883 | 10475 | 1936 | 42 | 27335.97 | 29,567 | 26,314 | 28,720 | 26,553 | 31,297 | 25,865 |
| 2013 | 18 | 13060 | 156715 | 97% | 161562 | 15669 | | | 0 | 15668.60 | 17,625 | 14,798 | 16,873 | 15,000 | 19,195 | 14,421 |
| 2014 | 19 | 13734 | 164805 | 97% | 169902 | 16459 | | | 0 | 16459.19 | 19,255 | 15,252 | 18,168 | 15,530 | 21,575 | 14,736 |
| 2015 | 20 | 14443 | 173312 | 97% | 178672 | 17366 | | 3872 | 84 | 21322.41 | 25,942 | 19,385 | 24,124 | 19,828 | 29,906 | 18,569 |
| 2016 | 21 | 15188 | 182259 | 97% | 187896 | 18344 | | | 0 | 18343.61 | 23,211 | 16,362 | 21,273 | 16,812 | 27,529 | 15,539 |
| 2017 | 22 | 15972 | 191667 | 97% | 197595 | 19418 | | | 0 | 19417.86 | 25,553 | 16,994 | 23,082 | 17,540 | 31,181 | 16,001 |
| 2018 | 23 | 16797 | 201561 | 97% | 207795 | 20599 | 10475 | 3872 | 84 | 35029.78 | 47,941 | 30,079 | 42,680 | 31,186 | 60,188 | 28,078 |
| 2019 | 24 | 17664 | 211966 | 97% | 218522 | 21920 | | | 0 | 21920.28 | 31,199 | 18,467 | 27,375 | 19,234 | 40,300 | 17,091 |
| 2020 | 25 | 18576 | 222908 | 97% | 229802 | 23225 | | | 0 | 23224.61 | 34,378 | 19,197 | 29,729 | 20,084 | 45,686 | 17,614 |
| 2021 | 27 | 19535 | 234415 | 97% | 241665 | 24372 | | 5808 | 126 | 30305.59 | 46,654 | 24,577 | 39,764 | 25,830 | 63,789 | 22,358 |
| 2022 | 28 | 20543 | 246516 | 97% | 254140 | 25712 | | | 0 | 25711.57 | 41,165 | 20,458 | 34,579 | 21,598 | 57,907 | 18,451 |
| 2023 | 30 | 21603 | 259242 | 97% | 267259 | 27268 | 10475 | | 0 | 37743.47 | 62,846 | 29,464 | 52,030 | 31,248 | 90,956 | 26,347 |
| 2024 | 31 | 22719 | 272624 | 97% | 281056 | 29129 | | 5808 | 126 | 35062.89 | 60,718 | 26,855 | 49,543 | 28,610 | 90,411 | 23,808 |
| 2025 | 33 | 23891 | 286697 | 97% | 295564 | 31204 | | | 0 | 31203.95 | 56,197 | 23,449 | 45,193 | 25,094 | 86,093 | 20,610 |
| 2026 | 34 | 25125 | 301497 | 97% | 310822 | 33315 | | | 0 | 33315.48 | 62,399 | 24,563 | 49,457 | 26,406 | 98,353 | 21,404 |
| 2027 | 36 | 26422 | 317061 | 97% | 326867 | 35527 | | 5808 | 126 | 41460.76 | 80,761 | 29,992 | 63,087 | 32,387 | 130,967 | 25,911 |
| 2028 | 38 | 27786 | 333428 | 97% | 343740 | 37841 | | | 0 | 37840.63 | 76,658 | 26,857 | 59,018 | 29,133 | 127,899 | 23,004 |
| 2029 | 40 | 29220 | 350640 | 97% | 361485 | 40105 | | 1936 | 42 | 42082.61 | 88,662 | 29,304 | 67,275 | 31,932 | 152,193 | 24,885 |
| | | | | | | | | | Total | 542473.1491 | 860070.43 | $441,241.26 | 721194.02 | $462,914.84 | 1235001.33 | $403,499.24 |

| High - 40 kW | | | | | | | | | | | Nominal | | Good Economy | | Bad Economy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 3 | 1826 | 21915 | 0.95 | 23068.4 | 2247.1 | 18860 | | | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 |
| 2011 | 9 | 6575 | 78894 | 0.97 | 81334.0 | 8036.5 | | | | 8036.45 | 8357.91 | 7884.82 | 8237.36 | 7920.54 | 8599.00 | 7817.28 |
| 2012 | 17 | 12419 | 149022 | 0.97 | 153630.9 | 15180.0 | 10475 | 1936 | 42 | 27632.96 | 29887.81 | 26600.05 | 29031.88 | 26841.61 | 31636.98 | 26146.27 |
| 2013 | 18 | 13060 | 156715 | 0.97 | 161561.6 | 16050.3 | | | 0 | 16050.34 | 18054.45 | 15158.86 | 17284.46 | 15365.82 | 19662.35 | 14772.62 |
| 2014 | 19 | 13734 | 164805 | 0.97 | 169901.7 | 16988.4 | | | 0 | 16988.36 | 19873.98 | 15742.06 | 18751.98 | 16029.27 | 22268.28 | 15209.53 |
| 2015 | 20 | 14443 | 173312 | 0.97 | 178672.2 | 18038.0 | | 3872 | 84 | 21994.03 | 26759.11 | 19995.96 | 24884.23 | 20453.02 | 30847.77 | 19154.04 |
| 2016 | 21 | 15188 | 182259 | 0.97 | 187895.6 | 19150.8 | | | 0 | 19150.81 | 24231.88 | 17082.52 | 22209.06 | 17552.15 | 28740.20 | 16223.09 |
| 2017 | 22 | 15972 | 191667 | 0.97 | 197595.0 | 20351.6 | | | 0 | 20351.62 | 26781.34 | 17811.12 | 24191.68 | 18383.69 | 32680.25 | 16770.14 |
| 2018 | 23 | 16797 | 201561 | 0.97 | 207795.2 | 21737.0 | 10475 | 3872 | 84 | 36167.96 | 49498.35 | 31055.87 | 44067.14 | 32199.43 | 62143.28 | 28990.30 |
| 2019 | 24 | 17664 | 211966 | 0.97 | 218521.9 | 23187.6 | | | 0 | 23187.62 | 33003.22 | 19534.55 | 28958.16 | 20345.62 | 42629.50 | 18079.07 |
| 2020 | 25 | 18576 | 222908 | 0.97 | 229802.3 | 24483.3 | | | 0 | 24483.33 | 36241.30 | 20236.95 | 31340.73 | 21172.67 | 48162.41 | 18568.69 |
| 2021 | 27 | 19535 | 234415 | 0.97 | 241665.1 | 25669.3 | | 5808 | 126 | 31603.33 | 48651.87 | 25629.20 | 41466.30 | 26935.72 | 66520.33 | 23314.97 |
| 2022 | 28 | 20543 | 246516 | 0.97 | 254140.2 | 27049.0 | | | 0 | 27049.01 | 43306.33 | 21521.92 | 36377.91 | 22721.53 | 60919.55 | 19410.85 |
| 2023 | 30 | 21603 | 259242 | 0.97 | 267259.3 | 28847.2 | 10475 | | 0 | 39322.17 | 65474.30 | 30696.91 | 54206.05 | 32554.75 | 94760.34 | 27448.69 |
| 2024 | 31 | 22719 | 272624 | 0.97 | 281055.7 | 30909.8 | | 5808 | 126 | 36843.83 | 63801.59 | 28219.50 | 52059.36 | 30062.99 | 95003.07 | 25017.28 |
| 2025 | 33 | 23891 | 286697 | 0.97 | 295564.2 | 33045.1 | | | 0 | 33045.08 | 59512.33 | 24832.41 | 47859.13 | 26574.48 | 91172.42 | 21825.95 |
| 2026 | 34 | 25125 | 301497 | 0.97 | 310821.7 | 35184.9 | | | 0 | 35184.89 | 65900.64 | 25941.54 | 52232.17 | 27887.18 | 103871.56 | 22605.48 |
| 2027 | 36 | 26422 | 317061 | 0.97 | 326866.8 | 37387.3 | | 5808 | 126 | 43321.35 | 84385.68 | 31337.84 | 65918.55 | 33840.82 | 136844.13 | 27073.88 |
| 2028 | 38 | 27786 | 333428 | 0.97 | 343740.1 | 39686.5 | | | 0 | 39686.52 | 80397.60 | 28166.80 | 61897.42 | 30554.31 | 134137.74 | 24125.85 |
| 2029 | 40 | 29220 | 350640 | 0.97 | 361484.5 | 41890.5 | | 1936 | 42 | 43868.49 | 92424.29 | 30547.43 | 70130.37 | 33286.85 | 158651.61 | 25940.81 |
| | | | | | | | | | Total | 565075.2765 | 897651.11 | $459,103.46 | 752211.09 | $481,789.58 | 1290357.89 | $419,601.91 |

| Low - 40 kW | | | | | | | | | | | Nominal | | Good Economy | | Bad Economy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value - | Present Value 2010$ | Future Value - | Present Value 2010$ | Future Value - | Present Value 2010$ |
| 2010 | 3 | 1826 | 21915.0 | 0.95 | 23068.4 | 2212.5 | 18860 | | | 21072.5 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 |
| 2011 | 9 | 6575 | 78894.0 | 0.97 | 81334.0 | 7791.9 | | | | 7791.9 | 8103.54 | 7644.85 | 7986.66 | 7679.48 | 8337.29 | 7579.36 |
| 2012 | 17 | 12419 | 149022.0 | 0.97 | 153630.9 | 14503.5 | 10475 | 1936 | 42 | 26956.5 | 29156.11 | 25948.84 | 28321.14 | 26184.48 | 30862.46 | 25506.16 |
| 2013 | 18 | 13060 | 156714.7 | 0.97 | 161561.6 | 15200.1 | | | 0 | 15200.1 | 17098.05 | 14355.85 | 16368.85 | 14551.85 | 18620.78 | 13990.07 |
| 2014 | 19 | 13734 | 164804.6 | 0.97 | 169901.7 | 15820.5 | | | 0 | 15820.5 | 18507.78 | 14659.90 | 17462.90 | 14927.36 | 20737.49 | 14163.98 |
| 2015 | 20 | 14443 | 173312.1 | 0.97 | 178672.2 | 16714.0 | | 3872 | 84 | 20670.0 | 25148.17 | 18792.18 | 23386.17 | 19221.73 | 28990.70 | 18000.94 |
| 2016 | 21 | 15188 | 182258.7 | 0.97 | 187895.6 | 17677.7 | | | 0 | 17677.7 | 22367.89 | 15768.48 | 20500.67 | 16201.98 | 26529.41 | 14975.16 |
| 2017 | 22 | 15972 | 191667.2 | 0.97 | 197595.0 | 18590.2 | | | 0 | 18590.2 | 24463.45 | 16269.59 | 22097.92 | 16792.61 | 29851.82 | 15318.71 |
| 2018 | 23 | 16797 | 201561.3 | 0.97 | 207795.2 | 19616.8 | 10475 | 3872 | 84 | 34047.8 | 46596.80 | 29235.41 | 41483.97 | 30311.93 | 58500.50 | 27290.91 |
| 2019 | 24 | 17664 | 211966.2 | 0.97 | 218521.9 | 20793.8 | | | 0 | 20793.8 | 29596.00 | 17517.83 | 25968.55 | 18245.16 | 38228.48 | 16212.61 |
| 2020 | 25 | 18576 | 222908.3 | 0.97 | 229802.3 | 21990.6 | | | 0 | 21990.6 | 32551.41 | 18176.54 | 28149.79 | 19016.99 | 43258.77 | 16678.13 |
| 2021 | 27 | 19535 | 234415.1 | 0.97 | 241665.1 | 23151.7 | | 5808 | 126 | 29085.7 | 44776.11 | 23587.50 | 38162.97 | 24789.94 | 61221.11 | 21457.63 |
| 2022 | 28 | 20543 | 246516.0 | 0.97 | 254140.2 | 24456.0 | | | 0 | 24456.0 | 39154.87 | 19458.77 | 32890.62 | 20543.38 | 55079.63 | 17550.07 |
| 2023 | 30 | 21603 | 259241.6 | 0.97 | 267259.3 | 25775.9 | 10475 | | 0 | 36250.9 | 60360.38 | 28299.30 | 49972.24 | 30012.03 | 87359.00 | 25304.79 |
| 2024 | 31 | 22719 | 272624.0 | 0.97 | 281055.7 | 27287.6 | | 5808 | 126 | 33221.6 | 57529.03 | 25445.15 | 46941.23 | 27107.39 | 85662.98 | 22557.74 |
| 2025 | 33 | 23891 | 286697.3 | 0.97 | 295564.2 | 29172.4 | | | 0 | 29172.4 | 52537.78 | 21922.18 | 42250.28 | 23460.08 | 80487.47 | 19268.06 |
| 2026 | 34 | 25125 | 301497.0 | 0.97 | 310821.7 | 31078.9 | | | 0 | 31078.9 | 58210.15 | 22914.21 | 46136.76 | 24632.79 | 91749.92 | 19967.46 |
| 2027 | 36 | 26422 | 317060.8 | 0.97 | 326866.8 | 32999.2 | | 5808 | 126 | 38933.2 | 75837.93 | 28163.51 | 59241.41 | 30412.95 | 122982.66 | 24331.46 |
| 2028 | 38 | 27786 | 333427.9 | 0.97 | 343740.1 | 35145.6 | | | 0 | 35145.6 | 71198.62 | 24944.00 | 54815.21 | 27058.33 | 118789.89 | 21365.41 |
| 2029 | 40 | 29220 | 350640.0 | 0.97 | 361484.5 | 37309.3 | | 1936 | 42 | 39287.3 | 82772.47 | 27357.38 | 62806.69 | 29810.72 | 142083.69 | 23231.82 |
| | | | | | | | | | Total | 517242.9588 | 817038.99 | $421,533.89 | 686016.48 | $442,033.63 | 1170406.51 | $385,822.91 |

| Nominal - 20 kW | | | | | | | | | | | Nominal | | High | | Low | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 95% | 23068.42 | 2232.27 | 18860 | | | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 |
| 2011 | 9 | 6574.5 | 78894 | 97% | 81334.02 | 7931.63 | | | | 7931.63 | 8248.89 | 7781.98 | 8129.92 | 7817.23 | 8486.84 | 7715.31 |
| 2012 | 17 | 12418.5 | 149022 | 97% | 153630.93 | 14882.97 | 10475 | 1936 | 42 | 27335.97 | 29566.58 | 26314.15 | 28719.85 | 26553.11 | 31296.95 | 25865.25 |
| 2013 | 18 | 13060 | 156715 | 97% | 161561.59 | 15668.60 | | 1936 | 42 | 17646.60 | 19850.02 | 16666.46 | 19003.46 | 16894.00 | 21617.84 | 16241.80 |
| 2014 | 19 | 13734 | 164805 | 97% | 169901.65 | 16459.19 | | | 0 | 16459.19 | 19254.92 | 15251.70 | 18167.86 | 15529.97 | 21574.64 | 14735.77 |
| 2015 | 20 | 14443 | 173312 | 97% | 178672.24 | 17366.41 | | 1936 | 42 | 19344.41 | 23535.43 | 17587.04 | 21886.42 | 17989.04 | 27131.53 | 16846.55 |
| 2016 | 20 | 14610 | 175320 | 97% | 180742.27 | 17645.25 | | 1936 | 42 | 19623.25 | 24829.68 | 17503.94 | 22756.96 | 17985.15 | 29449.21 | 16623.31 |
| 2017 | 20 | 14610 | 175320 | 97% | 180742.27 | 17761.72 | | | 0 | 17761.72 | 23373.22 | 15544.52 | 21113.11 | 16044.23 | 28521.45 | 14636.01 |
| 2018 | 20 | 14610 | 175320 | 97% | 180742.27 | 17917.02 | | 1936 | 42 | 19895.02 | 27227.70 | 17083.00 | 24240.15 | 17712.04 | 34183.34 | 15946.78 |
| 2019 | 20 | 14610 | 175320 | 97% | 180742.27 | 18130.55 | | 1936 | 42 | 20108.55 | 28620.73 | 16940.57 | 25112.82 | 17643.93 | 36968.74 | 15678.36 |
| 2020 | 20 | 14610 | 175320 | 97% | 180742.27 | 18266.43 | | | 0 | 18266.43 | 27038.78 | 15098.31 | 23382.57 | 15796.43 | 35932.83 | 13853.66 |
| 2021 | 20 | 14610 | 175320 | 97% | 180742.27 | 18227.60 | | 1936 | 42 | 20205.60 | 31105.60 | 16386.04 | 26511.50 | 17221.37 | 42529.81 | 14906.44 |
| 2022 | 20 | 14610 | 175320 | 97% | 180742.27 | 18285.84 | | 1936 | 42 | 20263.84 | 32443.06 | 16123.21 | 27252.61 | 17021.90 | 45638.05 | 14541.69 |
| 2023 | 20 | 14610 | 175320 | 97% | 180742.27 | 18441.13 | | | 0 | 18441.13 | 30705.84 | 14396.10 | 25421.31 | 15267.38 | 44440.27 | 12872.76 |
| 2024 | 20 | 14610 | 175320 | 97% | 180742.27 | 18732.31 | | 1936 | 42 | 20710.31 | 35863.56 | 15862.48 | 29263.13 | 16898.73 | 53402.24 | 14062.48 |
| 2025 | 20 | 14610 | 175320 | 97% | 180742.27 | 19081.72 | | 1936 | 42 | 21059.72 | 37927.37 | 15825.76 | 30500.75 | 16935.99 | 58104.43 | 13909.74 |
| 2026 | 20 | 14610 | 175320 | 97% | 180742.27 | 19372.90 | | | 0 | 19372.90 | 36285.07 | 14283.48 | 28759.17 | 15354.76 | 57191.96 | 12446.64 |
| 2027 | 20 | 14610 | 175320 | 97% | 180742.27 | 19644.66 | | 1936 | 42 | 21622.66 | 42118.79 | 15641.42 | 32901.43 | 16890.72 | 68301.99 | 13513.18 |
| 2028 | 20 | 14610 | 175320 | 97% | 180742.27 | 19897.01 | | 1936 | 42 | 21875.01 | 44314.76 | 15525.40 | 34117.55 | 16841.38 | 73936.06 | 13298.05 |
| 2029 | 20 | 14610 | 175320 | 97% | 180742.27 | 20052.31 | | | 0 | 20052.31 | 42247.19 | 13963.24 | 32056.62 | 15215.43 | 72519.72 | 11857.55 |
| | | | | | | | | | Total | 389068.5092 | 585649.46 | $324,871.09 | 500389.47 | $338,705.06 | 812320.17 | $300,643.60 |

| High - 20 kW | | | | | | | | | | | Nominal | | High | | Low | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 0.95 | 23068.42 | 2247.14 | 18860 | | | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 |
| 2011 | 9 | 6574.5 | 78894 | 0.97 | 81334.02 | 8036.45 | | | | 8036.45 | 8357.91 | 7884.82 | 8237.36 | 7920.54 | 8599.00 | 7817.28 |
| 2012 | 17 | 12418.5 | 149022 | 0.97 | 153630.93 | 15179.96 | 10475 | 1936 | 42 | 27632.96 | 29887.81 | 26600.05 | 29031.88 | 26841.61 | 31636.98 | 26146.27 |
| 2013 | 18 | 13060 | 156715 | 0.97 | 161561.59 | 16050.34 | | 1936 | 42 | 18028.34 | 20279.43 | 17027.00 | 19414.55 | 17259.46 | 22085.49 | 16593.15 |
| 2014 | 19 | 13734 | 164805 | 0.97 | 169901.65 | 16988.36 | | | 0 | 16988.36 | 19873.98 | 15742.06 | 18751.98 | 16029.27 | 22268.28 | 15209.53 |
| 2015 | 20 | 14443 | 173312 | 0.97 | 178672.24 | 18038.03 | | 1936 | 42 | 20016.03 | 24352.57 | 18197.65 | 22646.31 | 18613.61 | 28073.52 | 17431.45 |
| 2016 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18421.72 | | 1936 | 42 | 20399.72 | 25812.16 | 18196.55 | 23657.42 | 18696.81 | 30614.48 | 17281.08 |
| 2017 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18615.84 | | | 0 | 18615.84 | 24497.17 | 16292.02 | 22128.38 | 16815.75 | 29892.97 | 15339.82 |
| 2018 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18907.01 | | 1936 | 42 | 20885.01 | 28582.58 | 17933.07 | 25446.36 | 18593.41 | 35884.34 | 16740.31 |
| 2019 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19178.78 | | 1936 | 42 | 21156.78 | 30112.69 | 17823.66 | 26421.92 | 18563.69 | 38895.88 | 16495.65 |
| 2020 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19256.43 | | | 0 | 19256.43 | 28504.21 | 15916.60 | 24649.85 | 16652.56 | 37880.30 | 14604.50 |
| 2021 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19198.19 | | 1936 | 42 | 21176.19 | 32599.77 | 17173.15 | 27785.00 | 18048.60 | 44572.75 | 15622.48 |
| 2022 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19237.01 | | 1936 | 42 | 21215.01 | 33965.92 | 16880.02 | 28531.84 | 17820.90 | 47780.28 | 15224.27 |
| 2023 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19508.78 | | | 0 | 19508.78 | 32483.55 | 15229.56 | 26893.07 | 16151.28 | 47013.13 | 13618.03 |
| 2024 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19877.60 | | 1936 | 42 | 21855.60 | 37846.83 | 16739.69 | 30881.39 | 17833.23 | 56355.41 | 14840.14 |
| 2025 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20207.60 | | 1936 | 42 | 22185.60 | 39955.01 | 16671.83 | 32131.36 | 17841.41 | 61210.77 | 14653.37 |
| 2026 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20459.95 | | | 0 | 20459.95 | 38321.11 | 15084.96 | 30372.91 | 16216.35 | 60401.13 | 13145.05 |
| 2027 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20673.48 | | 1936 | 42 | 22651.48 | 44122.83 | 16385.65 | 34466.91 | 17694.39 | 71551.84 | 14156.15 |
| 2028 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20867.60 | | 1936 | 42 | 22845.60 | 46280.99 | 16214.26 | 35631.34 | 17588.63 | 77216.58 | 13888.08 |
| 2029 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20945.25 | | | 0 | 20945.25 | 44128.47 | 14585.03 | 33484.12 | 15892.98 | 75749.06 | 12385.58 |
| | | | | | | | | | Total | 404966.5307 | 611072.15 | $337,684.77 | 521671.08 | $352,181.61 | 848789.33 | $312,299.31 |

| Low - 20 kW | | | | | | | | | | | Nominal | | High | | Low | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 0.95 | 23068.42 | 2212.45 | 18860 | | | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 |
| 2011 | 9 | 6574.5 | 78894 | 0.97 | 81334.02 | 7791.86 | | | | 7791.86 | 8103.54 | 7644.85 | 7986.66 | 7679.48 | 8337.29 | 7579.36 |
| 2012 | 17 | 12418.5 | 149022 | 0.97 | 153630.93 | 14503.47 | 10475 | 1936 | 42 | 26956.47 | 29156.11 | 25948.84 | 28321.14 | 26184.48 | 30862.46 | 25506.16 |
| 2013 | 18 | 13060 | 156715 | 0.97 | 161561.59 | 15200.10 | | 1936 | 42 | 17178.10 | 19323.03 | 16223.99 | 18498.94 | 16445.49 | 21043.91 | 15810.60 |
| 2014 | 19 | 13734 | 164805 | 0.97 | 169901.65 | 15820.53 | | | 0 | 15820.53 | 18507.78 | 14659.90 | 17462.90 | 14927.36 | 20737.49 | 14163.98 |
| 2015 | 20 | 14443 | 173312 | 0.97 | 178672.24 | 16713.97 | | 1936 | 42 | 18691.97 | 22741.63 | 16993.87 | 21148.24 | 17382.31 | 26216.45 | 16278.35 |
| 2016 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17004.67 | | 1936 | 42 | 18982.67 | 24019.13 | 16932.54 | 22014.07 | 17398.04 | 28487.86 | 16080.66 |
| 2017 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17004.67 | | | 0 | 17004.67 | 22376.98 | 14881.97 | 20213.20 | 15360.37 | 27305.78 | 14012.18 |
| 2018 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17062.90 | | 1936 | 42 | 19040.90 | 26058.79 | 16349.61 | 23199.49 | 16951.64 | 32715.81 | 15262.17 |
| 2019 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17198.78 | | 1936 | 42 | 19176.78 | 27294.54 | 16155.60 | 23949.17 | 16826.37 | 35255.73 | 14951.87 |
| 2020 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17295.84 | | | 0 | 17295.84 | 25602.07 | 14296.06 | 22140.14 | 14957.09 | 34023.54 | 13117.55 |
| 2021 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17315.25 | | 1936 | 42 | 19293.25 | 29701.08 | 15646.16 | 25314.42 | 16443.77 | 40609.44 | 14233.36 |
| 2022 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17392.90 | | 1936 | 42 | 19370.90 | 31013.44 | 15412.73 | 26051.71 | 16271.82 | 43626.98 | 13900.90 |
| 2023 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17431.72 | | | 0 | 17431.72 | 29025.10 | 13608.10 | 24029.82 | 14431.69 | 42007.75 | 12168.15 |
| 2024 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17548.19 | | 1936 | 42 | 19526.19 | 33813.05 | 14955.55 | 27590.00 | 15932.54 | 50348.96 | 13258.45 |
| 2025 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17839.37 | | 1936 | 42 | 19817.37 | 35689.96 | 14892.18 | 28701.46 | 15936.90 | 54676.75 | 13089.18 |
| 2026 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18072.31 | | | 0 | 18072.31 | 33849.10 | 13324.57 | 26828.45 | 14323.93 | 53352.42 | 11611.04 |
| 2027 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18247.02 | | 1936 | 42 | 20225.02 | 39396.32 | 14630.39 | 30774.75 | 15798.94 | 63887.09 | 12639.72 |
| 2028 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18479.96 | | 1936 | 42 | 20457.96 | 41444.07 | 14519.67 | 31907.43 | 15750.41 | 69146.51 | 12436.61 |
| 2029 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18654.66 | | | 0 | 18654.66 | 39302.56 | 12990.01 | 29822.28 | 14154.92 | 67465.10 | 11031.08 |
| | | | | | | | | | Total | 371861.6285 | 557490.74 | $311,139.02 | 477026.74 | $324,230.00 | 771179.79 | $288,203.84 |

**HVAC**

Project # 1.3

Lifespan (years) 20

Note: Need to Upgrade to meet capacity after 6 years

| Initial | | | |
|---|---|---|---|
| Total Cost | Labor Cost | Material Costs | Contingency |
| 28731 | 2000 | 25731 | 1000 |

| Inflation | | Interest Rate | |
|---|---|---|---|
| Nominal | 4.0% | Nominal | 6% |
| Good Economy | 2.5% | Good Economy | 4% |
| Poor Economy | 7.0% | Poor Economy | 10% |

| Future : 40 kW | | | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.677 | 795.33 | 28731 | 29526.33 | 29526.33 | 29526.33 | 29526.33 | 29526.33 | 29526.33 | 29526.33 |
| 2011 | 29108 | 9.75 | 2838.59 | | 2838.59 | 2952.13 | 2785.03 | 2909.55 | 2797.65 | 3037.29 | 2761.17 |
| 2012 | 53905 | 9.69 | 5222.04 | | 5222.04 | 5648.15 | 5026.84 | 5486.40 | 5072.49 | 5978.71 | 4941.08 |
| 2013 | 56483 | 9.70 | 5477.85 | | 5477.85 | 6161.83 | 5173.59 | 5899.04 | 5244.23 | 6710.60 | 5041.77 |
| 2014 | 59176 | 9.69 | 5732.66 | | 5732.66 | 6706.41 | 5312.10 | 6327.79 | 5409.02 | 7514.35 | 5132.40 |
| 2015 | 61996 | 9.72 | 6025.83 | 24331 | 30356.83 | 36933.72 | 27599.02 | 34345.96 | 28229.88 | 42577.02 | 26436.98 |
| 2016 | 64940 | 9.76 | 6339.87 | | 6339.87 | 8021.96 | 5655.17 | 7352.31 | 5810.64 | 9514.44 | 5370.65 |
| 2017 | 68016 | 9.83 | 6684.00 | | 6684.00 | 8795.69 | 5849.64 | 7945.18 | 6037.68 | 10733.04 | 5507.75 |
| 2018 | 71231 | 9.91 | 7061.14 | | 7061.14 | 9663.66 | 6063.10 | 8603.32 | 6286.36 | 12132.36 | 5659.83 |
| 2019 | 74587 | 10.03 | 7481.94 | | 7481.94 | 10649.14 | 6303.21 | 9343.92 | 6564.91 | 13755.24 | 5833.57 |
| 2020 | 78092 | 10.11 | 7892.24 | | 7892.24 | 11682.45 | 6523.42 | 10102.74 | 6825.05 | 15525.24 | 5985.65 |
| 2021 | 81751 | 10.08 | 8244.47 | | 8244.47 | 12691.99 | 6685.98 | 10817.46 | 7026.82 | 17353.40 | 6082.26 |
| 2022 | 85567 | 10.12 | 8656.88 | | 8656.88 | 13859.95 | 6887.97 | 11642.54 | 7271.90 | 19496.96 | 6212.33 |
| 2023 | 89553 | 10.20 | 9137.09 | | 9137.09 | 15213.93 | 7132.88 | 12595.58 | 7564.58 | 22018.98 | 6378.11 |
| 2024 | 93708 | 10.36 | 9711.99 | | 9711.99 | 16818.03 | 7438.63 | 13722.79 | 7924.57 | 25042.70 | 6594.53 |
| 2025 | 98039 | 10.56 | 10350.39 | | 10350.39 | 18640.47 | 7778.02 | 14990.45 | 8323.66 | 28557.05 | 6836.33 |
| 2026 | 102557 | 10.72 | 10992.59 | | 10992.59 | 20588.92 | 8104.75 | 16318.57 | 8712.62 | 32451.93 | 7062.49 |
| 2027 | 107264 | 10.87 | 11658.40 | | 11658.40 | 22709.39 | 8433.46 | 17739.63 | 9107.05 | 36826.72 | 7285.97 |
| 2028 | 112167 | 11.01 | 12347.90 | | 12347.90 | 25014.59 | 8763.71 | 19258.52 | 9506.55 | 41735.08 | 7506.42 |
| 2029 | 117273 | 11.09 | 13010.76 | | 13010.76 | 27411.71 | 9059.93 | 20799.65 | 9872.40 | 47053.77 | 7693.67 |
| | | | | Total Cost Over 20 yrs: | $237,455 | $309,690 | $176,103 | $265,728 | $183,114 | $427,541 | $163,849 |

| Future : 40 kW | | | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.741 | 800.63 | 28731 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 |
| 2011 | 29108 | 9.88 | 2876.10 | | 2876.10 | 2991.15 | 2821.84 | 2948.01 | 2834.62 | 3077.43 | 2797.66 |
| 2012 | 53905 | 9.88 | 5326.25 | | 5326.25 | 5760.87 | 5127.15 | 5595.89 | 5173.71 | 6098.02 | 5039.68 |
| 2013 | 56483 | 9.93 | 5611.30 | | 5611.30 | 6311.95 | 5299.64 | 6042.76 | 5371.99 | 6874.09 | 5164.60 |
| 2014 | 59176 | 10.00 | 5916.97 | | 5916.97 | 6922.02 | 5482.89 | 6531.23 | 5582.92 | 7755.94 | 5297.41 |
| 2015 | 61996 | 10.10 | 6258.87 | 24331 | 30589.87 | 37217.25 | 27810.90 | 34609.63 | 28446.59 | 42903.87 | 26639.93 |
| 2016 | 64940 | 10.19 | 6618.85 | | 6618.85 | 8374.96 | 5904.02 | 7675.84 | 6066.33 | 9933.11 | 5606.98 |
| 2017 | 68016 | 10.30 | 7005.42 | | 7005.42 | 9218.65 | 6130.93 | 8327.24 | 6328.02 | 11249.17 | 5772.60 |
| 2018 | 71231 | 10.46 | 7451.30 | | 7451.30 | 10197.62 | 6398.12 | 9078.69 | 6633.71 | 12802.73 | 5972.57 |
| 2019 | 74587 | 10.61 | 7914.52 | | 7914.52 | 11264.82 | 6667.63 | 9884.15 | 6944.47 | 14550.51 | 6170.84 |
| 2020 | 78092 | 10.65 | 8319.98 | | 8319.98 | 12315.61 | 6876.97 | 10650.28 | 7194.95 | 16366.67 | 6310.06 |
| 2021 | 81751 | 10.62 | 8683.48 | | 8683.48 | 13367.81 | 7042.00 | 11393.47 | 7400.98 | 18277.43 | 6406.13 |
| 2022 | 85567 | 10.64 | 9107.19 | | 9107.19 | 14580.90 | 7246.26 | 12248.15 | 7650.16 | 20511.13 | 6535.48 |
| 2023 | 89553 | 10.79 | 9666.08 | | 9666.08 | 16094.74 | 7545.84 | 13324.80 | 8002.53 | 23293.76 | 6747.37 |
| 2024 | 93708 | 11.00 | 10305.78 | | 10305.78 | 17846.28 | 7893.43 | 14561.80 | 8409.08 | 26573.81 | 6997.71 |
| 2025 | 98039 | 11.18 | 10961.09 | | 10961.09 | 19740.31 | 8236.94 | 15874.93 | 8814.79 | 30242.00 | 7239.70 |
| 2026 | 102557 | 11.32 | 11609.41 | | 11609.41 | 21744.21 | 8559.53 | 17234.24 | 9201.50 | 34272.88 | 7458.78 |
| 2027 | 107264 | 11.44 | 12268.96 | | 12268.96 | 23898.72 | 8875.13 | 18668.68 | 9584.00 | 38755.39 | 7667.55 |
| 2028 | 112167 | 11.55 | 12950.24 | | 12950.24 | 26234.81 | 9191.20 | 20197.96 | 9970.28 | 43770.94 | 7872.59 |
| 2029 | 117273 | 11.59 | 13590.13 | | 13590.13 | 28632.36 | 9463.37 | 21725.87 | 10312.02 | 49149.10 | 8036.27 |
| | | | | Total Cost Over 20 yrs: | $245,036 | $322,247 | $182,105 | $276,105 | $189,454 | $445,990 | $169,266 |

| Future : 40 kW | | | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.591 | 788.27 | 28731 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 |
| 2011 | 29108 | 9.58 | 2788.57 | | 2788.57 | 2900.11 | 2735.96 | 2858.28 | 2748.35 | 2983.77 | 2712.52 |
| 2012 | 53905 | 9.44 | 5088.88 | | 5088.88 | 5504.13 | 4898.66 | 5346.50 | 4943.14 | 5826.26 | 4815.09 |
| 2013 | 56483 | 9.41 | 5314.06 | | 5314.06 | 5977.59 | 5018.90 | 5722.66 | 5087.42 | 6509.95 | 4891.02 |
| 2014 | 59176 | 9.31 | 5510.22 | | 5510.22 | 6446.18 | 5105.98 | 6082.25 | 5199.13 | 7222.78 | 4933.25 |
| 2015 | 61996 | 9.35 | 5799.44 | 24331 | 30130.44 | 36658.29 | 27393.21 | 34089.83 | 28019.35 | 42259.50 | 26239.83 |
| 2016 | 64940 | 9.41 | 6109.71 | | 6109.71 | 7730.73 | 5449.86 | 7085.39 | 5599.69 | 9169.03 | 5175.68 |
| 2017 | 68016 | 9.41 | 6399.11 | | 6399.11 | 8420.79 | 5600.31 | 7606.53 | 5780.34 | 10275.57 | 5272.99 |
| 2018 | 71231 | 9.44 | 6724.53 | | 6724.53 | 9202.99 | 5774.07 | 8193.19 | 5986.68 | 11554.00 | 5390.03 |
| 2019 | 74587 | 9.52 | 7097.43 | | 7097.43 | 10101.86 | 5979.27 | 8863.72 | 6227.53 | 13048.34 | 5533.77 |
| 2020 | 78092 | 9.57 | 7472.89 | | 7472.89 | 11061.70 | 6176.80 | 9565.93 | 6462.40 | 14700.30 | 5667.60 |
| 2021 | 81751 | 9.58 | 7831.81 | | 7831.81 | 12056.71 | 6351.33 | 10276.01 | 6675.10 | 16484.80 | 5777.82 |
| 2022 | 85567 | 9.62 | 8234.15 | | 8234.15 | 13183.13 | 6551.61 | 11074.01 | 6916.80 | 18544.88 | 5908.97 |
| 2023 | 89553 | 9.64 | 8636.96 | | 8636.96 | 14381.17 | 6742.45 | 11906.14 | 7150.52 | 20813.73 | 6029.00 |
| 2024 | 93708 | 9.71 | 9098.07 | | 9098.07 | 15754.92 | 6968.42 | 12855.34 | 7423.64 | 23459.69 | 6177.67 |
| 2025 | 98039 | 9.87 | 9676.51 | | 9676.51 | 17426.84 | 7271.61 | 14014.47 | 7781.74 | 26697.79 | 6391.24 |
| 2026 | 102557 | 10.00 | 10254.61 | | 10254.61 | 19206.70 | 7560.65 | 15223.03 | 8127.70 | 30273.30 | 6588.35 |
| 2027 | 107264 | 10.10 | 10828.94 | | 10828.94 | 21093.71 | 7833.45 | 16477.52 | 8459.12 | 34206.63 | 6767.60 |
| 2028 | 112167 | 10.22 | 11468.49 | | 11468.49 | 23233.06 | 8139.56 | 17886.93 | 8829.49 | 38762.73 | 6971.82 |
| 2029 | 117273 | 10.32 | 12103.91 | | 12103.91 | 25501.11 | 8428.45 | 19349.92 | 9184.29 | 43774.13 | 7157.42 |
| | | | | Total Cost Over 20 yrs: | $229,020 | $295,361 | $169,500 | $253,997 | $176,122 | $406,086 | $157,921 |

| Future : 20kW | | | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.677 | 795.33 | 28731 | 29526.33 | 29526.33 | 29526.33 | 29526.33 | 29526.33 | 29526.33 | 29526.33 |
| 2011 | 29108 | 9.75 | 2838.59 | | 2838.59 | 2952.13 | 2785.03 | 2909.55 | 2797.65 | 3037.29 | 2761.17 |
| 2012 | 53905 | 9.69 | 5222.04 | | 5222.04 | 5648.15 | 5026.84 | 5486.40 | 5072.49 | 5978.71 | 4941.08 |
| 2013 | 56483 | 9.70 | 5477.85 | | 5477.85 | 6161.83 | 5173.59 | 5899.04 | 5244.23 | 6710.60 | 5041.77 |
| 2014 | 59176 | 9.69 | 5732.66 | | 5732.66 | 6706.41 | 5312.10 | 6327.79 | 5409.02 | 7514.35 | 5132.40 |
| 2015 | 61996 | 9.72 | 6025.83 | | 6025.83 | 7331.34 | 5478.40 | 6817.67 | 5603.63 | 8451.53 | 5247.74 |
| 2016 | 64940 | 9.76 | 6339.87 | | 6339.87 | 8021.96 | 5655.17 | 7352.31 | 5810.64 | 9514.44 | 5370.65 |
| 2017 | 64940 | 9.83 | 6381.72 | | 6381.72 | 8397.91 | 5585.09 | 7585.86 | 5764.63 | 10247.65 | 5258.66 |
| 2018 | 64940 | 9.91 | 6437.52 | | 6437.52 | 8810.18 | 5527.62 | 7843.49 | 5731.16 | 11060.85 | 5159.97 |
| 2019 | 64940 | 10.03 | 6514.24 | | 6514.24 | 9271.79 | 5487.96 | 8135.39 | 5715.82 | 11976.16 | 5079.06 |
| 2020 | 64940 | 10.11 | 6563.06 | | 6563.06 | 9714.93 | 5424.77 | 8401.27 | 5675.60 | 12910.53 | 4977.57 |
| 2021 | 64940 | 10.08 | 6549.11 | | 6549.11 | 10082.05 | 5311.10 | 8593.00 | 5581.85 | 13784.90 | 4831.52 |
| 2022 | 64940 | 10.12 | 6570.03 | | 6570.03 | 10518.83 | 5227.54 | 8835.96 | 5518.92 | 14796.97 | 4714.77 |
| 2023 | 64940 | 10.20 | 6625.83 | | 6625.83 | 11032.49 | 5172.46 | 9133.78 | 5485.51 | 15967.22 | 4625.13 |
| 2024 | 64940 | 10.36 | 6730.45 | | 6730.45 | 11654.96 | 5155.00 | 9509.94 | 5491.76 | 17354.69 | 4570.03 |
| 2025 | 64940 | 10.56 | 6855.99 | | 6855.99 | 12347.25 | 5152.08 | 9929.52 | 5513.51 | 18915.89 | 4528.31 |
| 2026 | 64940 | 10.72 | 6960.61 | | 6960.61 | 13037.09 | 5132.00 | 10333.06 | 5516.91 | 20548.85 | 4472.03 |
| 2027 | 64940 | 10.87 | 7058.25 | | 7058.25 | 13748.77 | 5105.80 | 10739.96 | 5513.61 | 22295.71 | 4411.09 |
| 2028 | 64940 | 11.01 | 7148.92 | | 7148.92 | 14482.40 | 5073.82 | 11149.88 | 5503.89 | 24162.87 | 4345.90 |
| 2029 | 64940 | 11.09 | 7204.72 | | 7204.72 | 15179.25 | 5016.94 | 11517.82 | 5466.85 | 26056.06 | 4260.37 |
| | | | | Total Cost Over 20 yrs: | $177,495 | 214626.04 | 127329.62 | 186028.01 | 131943.96 | 290811.57 | 119255.57 |

| Future : 20kW | | | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.741 | 800.63 | 28731 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 |
| 2011 | 29108 | 9.88 | 2876.10 | | 2876.10 | 2991.15 | 2821.84 | 2948.01 | 2834.62 | 3077.43 | 2797.66 |
| 2012 | 53905 | 9.88 | 5326.25 | | 5326.25 | 5760.87 | 5127.15 | 5595.89 | 5173.71 | 6098.02 | 5039.68 |
| 2013 | 56483 | 9.93 | 5611.30 | | 5611.30 | 6311.95 | 5299.64 | 6042.76 | 5371.99 | 6874.09 | 5164.60 |
| 2014 | 59176 | 10.00 | 5916.97 | | 5916.97 | 6922.02 | 5482.89 | 6531.23 | 5582.92 | 7755.94 | 5297.41 |
| 2015 | 61996 | 10.10 | 6258.87 | | 6258.87 | 7614.87 | 5690.27 | 7081.33 | 5820.34 | 8778.39 | 5450.69 |
| 2016 | 64940 | 10.19 | 6618.85 | | 6618.85 | 8374.96 | 5904.02 | 7675.84 | 6066.33 | 9933.11 | 5606.98 |
| 2017 | 64940 | 10.30 | 6688.60 | | 6688.60 | 8801.74 | 5853.66 | 7950.64 | 6041.83 | 10740.43 | 5511.54 |
| 2018 | 64940 | 10.46 | 6793.22 | | 6793.22 | 9296.99 | 5833.04 | 8276.88 | 6047.83 | 11672.01 | 5445.08 |
| 2019 | 64940 | 10.61 | 6890.86 | | 6890.86 | 9807.84 | 5805.25 | 8605.74 | 6046.28 | 12668.57 | 5372.71 |
| 2020 | 64940 | 10.65 | 6918.76 | | 6918.76 | 10241.45 | 5718.77 | 8856.60 | 5983.20 | 13610.25 | 5247.34 |
| 2021 | 64940 | 10.62 | 6897.84 | | 6897.84 | 10618.90 | 5593.90 | 9050.56 | 5879.07 | 14518.92 | 5088.79 |
| 2022 | 64940 | 10.64 | 6911.78 | | 6911.78 | 11065.99 | 5499.46 | 9295.58 | 5805.99 | 15566.66 | 4960.02 |
| 2023 | 64940 | 10.79 | 7009.43 | | 7009.43 | 11671.21 | 5471.92 | 9662.57 | 5803.09 | 16891.64 | 4892.91 |
| 2024 | 64940 | 11.00 | 7141.95 | | 7141.95 | 12367.54 | 5470.17 | 10091.38 | 5827.52 | 18415.75 | 4849.44 |
| 2025 | 64940 | 11.18 | 7260.51 | | 7260.51 | 13075.77 | 5456.06 | 10515.39 | 5838.82 | 20031.98 | 4795.50 |
| 2026 | 64940 | 11.32 | 7351.18 | | 7351.18 | 13768.63 | 5419.97 | 10912.87 | 5826.47 | 21701.89 | 4722.96 |
| 2027 | 64940 | 11.44 | 7427.90 | | 7427.90 | 14468.81 | 5373.20 | 11302.43 | 5802.37 | 23463.37 | 4642.10 |
| 2028 | 64940 | 11.55 | 7497.65 | | 7497.65 | 15188.86 | 5321.32 | 11693.77 | 5772.37 | 25341.54 | 4557.90 |
| 2029 | 64940 | 11.59 | 7525.55 | | 7525.55 | 15855.19 | 5240.35 | 12030.72 | 5710.29 | 27216.34 | 4450.09 |
| | | | | Total Cost Over 20 yrs: | $183,186 | 223736.38 | 131914.52 | 193651.82 | 136766.69 | 303887.97 | 123425.05 |

| Future : 20kW | | | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.591 | 788.27 | 28731 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 |
| 2011 | 29108 | 9.58 | 2788.57 | | 2788.57 | 2900.11 | 2735.96 | 2858.28 | 2748.35 | 2983.77 | 2712.52 |
| 2012 | 53905 | 9.44 | 5088.88 | | 5088.88 | 5504.13 | 4898.66 | 5346.50 | 4943.14 | 5826.26 | 4815.09 |
| 2013 | 56483 | 9.41 | 5314.06 | | 5314.06 | 5977.59 | 5018.90 | 5722.66 | 5087.42 | 6509.95 | 4891.02 |
| 2014 | 59176 | 9.31 | 5510.22 | | 5510.22 | 6446.18 | 5105.98 | 6082.25 | 5199.13 | 7222.78 | 4933.25 |
| 2015 | 61996 | 9.35 | 5799.44 | | 5799.44 | 7055.91 | 5272.58 | 6561.53 | 5393.10 | 8134.02 | 5050.58 |
| 2016 | 64940 | 9.41 | 6109.71 | | 6109.71 | 7730.73 | 5449.86 | 7085.39 | 5599.69 | 9169.03 | 5175.68 |
| 2017 | 64940 | 9.41 | 6109.71 | | 6109.71 | 8039.96 | 5347.03 | 7262.53 | 5518.92 | 9810.86 | 5034.52 |
| 2018 | 64940 | 9.44 | 6130.63 | | 6130.63 | 8390.20 | 5264.11 | 7469.58 | 5457.95 | 10533.57 | 4913.99 |
| 2019 | 64940 | 9.52 | 6179.46 | | 6179.46 | 8795.29 | 5205.92 | 7717.29 | 5422.07 | 11360.68 | 4818.04 |
| 2020 | 64940 | 9.57 | 6214.33 | | 6214.33 | 9198.73 | 5136.52 | 7954.87 | 5374.02 | 12224.53 | 4713.08 |
| 2021 | 64940 | 9.58 | 6221.30 | | 6221.30 | 9577.41 | 5045.26 | 8162.89 | 5302.46 | 13094.92 | 4589.69 |
| 2022 | 64940 | 9.62 | 6249.20 | | 6249.20 | 10005.17 | 4972.26 | 8404.48 | 5249.41 | 14074.40 | 4484.54 |
| 2023 | 64940 | 9.64 | 6263.15 | | 6263.15 | 10428.61 | 4889.34 | 8633.82 | 5185.25 | 15093.22 | 4371.97 |
| 2024 | 64940 | 9.71 | 6305.00 | | 6305.00 | 10918.22 | 4829.14 | 8908.80 | 5144.61 | 16257.65 | 4281.15 |
| 2025 | 64940 | 9.87 | 6409.62 | | 6409.62 | 11543.36 | 4816.64 | 9283.04 | 5154.54 | 17684.34 | 4233.49 |
| 2026 | 64940 | 10.00 | 6493.31 | | 6493.31 | 12161.85 | 4787.47 | 9639.36 | 5146.53 | 19169.32 | 4171.80 |
| 2027 | 64940 | 10.10 | 6556.08 | | 6556.08 | 12770.60 | 4742.55 | 9975.86 | 5121.34 | 20709.45 | 4097.25 |
| 2028 | 64940 | 10.22 | 6639.78 | | 6639.78 | 13450.97 | 4712.46 | 10355.79 | 5111.91 | 22442.00 | 4036.39 |
| 2029 | 64940 | 10.32 | 6702.55 | | 6702.55 | 14121.26 | 4667.26 | 10715.03 | 5085.81 | 24239.95 | 3963.43 |
| | | | | Total Cost Over 20 yrs: | $171,335 | 204535.55 | 122417.17 | 177659.22 | 126764.93 | 276059.96 | 114806.75 |

| Energy Costs to Heat Pool: 40 kW | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy Offset | Nat'l Gas Price | Cost to Heat the | Nominal | | Good Economy | | Poor Economy | |
| Year | (Btu/hr) | 2010$/million btu | Pool (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 11008 | 7.74 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 |
| 2011 | 39629 | 9.69 | 3838.78 | 3992.33 | 3766.35 | 3934.75 | 3783.42 | 4107.50 | 3734.09 |
| 2012 | 74855 | 10.37 | 7762.13 | 8395.52 | 7471.99 | 8155.09 | 7539.84 | 8886.87 | 7344.52 |
| 2013 | 78597 | 10.28 | 8077.93 | 9086.58 | 7629.27 | 8699.05 | 7733.43 | 9895.82 | 7434.87 |
| 2014 | 82527 | 10.20 | 8415.15 | 9844.54 | 7797.79 | 9288.75 | 7940.06 | 11030.55 | 7534.01 |
| 2015 | 86654 | 10.46 | 9063.55 | 11027.20 | 8240.16 | 10254.58 | 8428.51 | 12712.10 | 7893.21 |
| 2016 | 90986 | 10.57 | 9619.23 | 12171.39 | 8580.35 | 11155.35 | 8816.24 | 14435.87 | 8148.67 |
| 2017 | 95536 | 10.56 | 10090.80 | 13278.81 | 8831.17 | 11994.79 | 9115.06 | 16203.63 | 8315.02 |
| 2018 | 100313 | 10.63 | 10658.86 | 14587.39 | 9152.31 | 12986.79 | 9489.32 | 18313.91 | 8543.58 |
| 2019 | 105328 | 10.71 | 11277.68 | 16051.65 | 9500.95 | 14084.27 | 9895.42 | 20733.55 | 8793.05 |
| 2020 | 110594 | 10.87 | 12022.82 | 17796.72 | 9937.59 | 15390.23 | 10397.09 | 23650.71 | 9118.37 |
| 2021 | 116124 | 11.01 | 12784.71 | 19681.48 | 10367.96 | 16774.65 | 10896.49 | 26909.93 | 9431.77 |
| 2022 | 121931 | 11.30 | 13780.13 | 22062.44 | 10964.36 | 18532.75 | 11575.50 | 31035.50 | 9888.87 |
| 2023 | 128027 | 11.38 | 14566.99 | 24255.12 | 11371.74 | 20080.76 | 12059.99 | 35104.20 | 10168.44 |
| 2024 | 134428 | 11.30 | 15191.56 | 26306.86 | 11635.55 | 21465.27 | 12395.66 | 39171.94 | 10315.20 |
| 2025 | 141150 | 11.38 | 16068.73 | 28938.88 | 12075.18 | 23272.31 | 12922.29 | 44334.14 | 10613.24 |
| 2026 | 148207 | 11.60 | 17191.50 | 32199.36 | 12675.16 | 25520.88 | 13625.81 | 50752.12 | 11045.14 |
| 2027 | 155618 | 11.82 | 18400.80 | 35842.93 | 13310.79 | 27998.99 | 14373.93 | 58124.73 | 11499.67 |
| 2028 | 163399 | 12.19 | 19911.80 | 40337.65 | 14132.05 | 31055.61 | 15329.92 | 67300.53 | 12104.59 |
| 2029 | 171568 | 12.54 | 21507.37 | 45312.79 | 14976.47 | 34382.76 | 16319.52 | 77782.00 | 12717.98 |
| | | Total Savings Over 20 yrs: | $241,083 | 392021.64 | 193269.19 | 325879.68 | 203489.52 | 571337.60 | 175496.30 |

| Energy Costs to Heat Pool: 20 kW | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy Offset | Nat'l Gas Price | Cost to Heat the | Nominal | | Good Economy | | Poor Economy | |
| Year | (kWh/yr) | 2010$/million btu | Pool (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 11008 | 7.740 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 |
| 2011 | 39629 | 9.69 | 3838.78 | 3992.33 | 3766.35 | 3934.75 | 3783.42 | 4107.50 | 3734.09 |
| 2012 | 74855 | 10.37 | 7762.13 | 8395.52 | 7471.99 | 8155.09 | 7539.84 | 8886.87 | 7344.52 |
| 2013 | 78597 | 10.28 | 8077.93 | 9086.58 | 7629.27 | 8699.05 | 7733.43 | 9895.82 | 7434.87 |
| 2014 | 82527 | 10.20 | 8415.15 | 9844.54 | 7797.79 | 9288.75 | 7940.06 | 11030.55 | 7534.01 |
| 2015 | 86654 | 10.46 | 9063.55 | 11027.20 | 8240.16 | 10254.58 | 8428.51 | 12712.10 | 7893.21 |
| 2016 | 90986 | 10.57 | 9619.23 | 12171.39 | 8580.35 | 11155.35 | 8816.24 | 14435.87 | 8148.67 |
| 2017 | 90986 | 10.56 | 9610.22 | 12646.39 | 8410.57 | 11423.53 | 8680.94 | 15431.91 | 7919.01 |
| 2018 | 90986 | 10.63 | 9667.81 | 13231.07 | 8301.34 | 11779.29 | 8607.01 | 16611.10 | 7749.20 |
| 2019 | 90986 | 10.71 | 9742.05 | 13865.98 | 8207.25 | 12166.49 | 8548.01 | 17910.36 | 7595.74 |
| 2020 | 90986 | 10.87 | 9891.21 | 14641.41 | 8175.69 | 12661.59 | 8553.71 | 19457.51 | 7501.71 |
| 2021 | 90986 | 11.01 | 10017.14 | 15420.92 | 8123.55 | 13143.35 | 8537.67 | 21084.59 | 7390.02 |
| 2022 | 90986 | 11.30 | 10282.86 | 16463.19 | 8181.70 | 13829.30 | 8637.74 | 23158.97 | 7379.16 |
| 2023 | 90986 | 11.38 | 10352.45 | 17237.58 | 8081.65 | 14270.96 | 8570.77 | 24947.79 | 7226.49 |
| 2024 | 90986 | 11.30 | 10282.22 | 17805.49 | 7875.38 | 14528.51 | 8389.85 | 26513.07 | 6981.72 |
| 2025 | 90986 | 11.38 | 10357.98 | 18654.15 | 7783.72 | 15001.45 | 8329.77 | 28578.01 | 6841.35 |
| 2026 | 90986 | 11.60 | 10554.06 | 19767.56 | 7781.43 | 15667.56 | 8365.04 | 31157.32 | 6780.74 |
| 2027 | 90986 | 11.82 | 10758.49 | 20956.48 | 7782.49 | 16370.32 | 8404.08 | 33984.09 | 6723.57 |
| 2028 | 90986 | 12.19 | 11087.55 | 22461.35 | 7869.19 | 17292.80 | 8536.21 | 37475.18 | 6740.24 |
| 2029 | 90986 | 12.54 | 11405.80 | 24030.29 | 11405.80 | 18233.88 | 11405.80 | 41249.38 | 11405.80 |
| | | Total Savings Over 20 yrs: | $181,639 | 282551.42 | 152317.69 | 238708.63 | 158660.14 | 399479.98 | 141176.14 |

## 8.3 CERF Case Calculations

| | | |
|---|---|---|
| **Envelope** | | |
| Project # | 1.1 | |
| Lifespan (years) | 50 | |

| Upfront Costs | 2010 $ |
|---|---|
| Total Cost | 3158 |
| Labor Costs | 1000 |
| Material Costs | 2158 |

| Efficient Case | | |
|---|---|---|
| Aluminum Wall | $ | 1,693.00 |
| 3 Doors | $ | 465.00 |
| Labor | $ | 1,000.00 |
| $3,158.00 | | |

| | |
|---|---|
| **Instrumentation** | |
| Project # | 1.4 |
| Lifespan (years) | 30 |

| Inflation | | Interest Rate | |
|---|---|---|---|
| Nominal | 4% | Nominal | 6.0% |
| Good Economy | 3% | Good Economy | 4.0% |
| Poor Economy | 7% | Poor Economy | 10.0% |

| Initial | | | |
|---|---|---|---|
| Total Capital Cost | Labor Cost | Material Costs | Contingency |
| 9774.84 | 200.00 | 8686.22 | 888.62 |

| Future | | | | Nominal | | Good Economy | | Poor Economy | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Labor Cost | Material Cost | Total Yearly Costs | Future | Present | Future | Present | Future | Present |
| 2010 | 200.00 | 9574.84 | 9774.842 | 9774.84 | 9774.84 | 9774.84 | 9774.84 | 9774.84 | 9774.84 |
| 2011 | 888.62 | 0.00 | 888.62 | 924.17 | 871.86 | 910.84 | 875.81 | 950.83 | 864.39 |
| 2012 | 888.62 | 0.00 | 888.62 | 961.13 | 855.41 | 933.61 | 863.17 | 1017.38 | 840.81 |
| 2013 | 888.62 | 0.00 | 888.62 | 999.58 | 839.27 | 956.95 | 850.72 | 1088.60 | 817.88 |
| 2014 | 888.62 | 0.00 | 888.62 | 1039.56 | 823.43 | 980.87 | 838.45 | 1164.80 | 795.58 |
| 2015 | 888.62 | 0.00 | 888.62 | 1081.14 | 807.89 | 1005.39 | 826.36 | 1246.34 | 773.88 |
| 2016 | 888.62 | 0.00 | 888.62 | 1124.39 | 792.65 | 1030.53 | 814.44 | 1333.58 | 752.77 |
| 2017 | 888.62 | 0.00 | 888.62 | 1169.37 | 777.70 | 1056.29 | 802.70 | 1426.93 | 732.24 |
| 2018 | 888.62 | 0.00 | 888.62 | 1216.14 | 763.02 | 1082.70 | 791.12 | 1526.82 | 712.27 |
| 2019 | 888.62 | 0.00 | 888.62 | 1264.79 | 748.63 | 1109.77 | 779.71 | 1633.70 | 692.85 |
| 2020 | 888.62 | 0.00 | 888.62 | 1315.38 | 734.50 | 1137.51 | 768.46 | 1748.05 | 673.95 |
| 2021 | 888.62 | 0.00 | 888.62 | 1367.99 | 720.64 | 1165.95 | 757.38 | 1870.42 | 655.57 |
| 2022 | 888.62 | 0.00 | 888.62 | 1422.71 | 707.04 | 1195.10 | 746.45 | 2001.35 | 637.69 |
| 2023 | 888.62 | 0.00 | 888.62 | 1479.62 | 693.70 | 1224.98 | 735.69 | 2141.44 | 620.30 |
| 2024 | 888.62 | 0.00 | 888.62 | 1538.81 | 680.62 | 1255.60 | 725.08 | 2291.34 | 603.38 |
| 2025 | 888.62 | 0.00 | 888.62 | 1600.36 | 667.77 | 1286.99 | 714.62 | 2451.74 | 586.93 |
| 2026 | 888.62 | 0.00 | 888.62 | 1664.37 | 655.17 | 1319.16 | 704.31 | 2623.36 | 570.92 |
| 2027 | 888.62 | 0.00 | 888.62 | 1730.95 | 642.81 | 1352.14 | 694.15 | 2806.99 | 555.35 |
| 2028 | 888.62 | 0.00 | 888.62 | 1800.19 | 630.68 | 1385.95 | 684.14 | 3003.48 | 540.20 |
| 2029 | 888.62 | 0.00 | 888.62 | 1872.19 | 618.78 | 1420.60 | 674.27 | 3213.73 | 525.47 |
| | | | | | | | | | |
| Totals | 17083.82 | 9574.84 | 26658.66 | 35347.68 | $23,806.42 | 31585.76 | $24,421.89 | 45315.72 | $22,727.27 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Power | | Battery Details: | mass | 6 | lb | Proj #001.2 | | Interest Rate | | Inflation | |
| Efficiency | 1 | | height | 3.9 | in | Company | Eaton | Nominal | 6.0% | Nominal | 4.0% |
| Growth in | 1.051621544 | | width | 2.6 | in | Name (PN) | 12 KW Blade module - expanded in 12 kW increr | Good Economy | 4.0% | Good Economy | 2.5% |
| Growth in | 1.1 | | length | 6 | in | Power/Unit | 12 kW | Poor Economy | 10.0% | Poor Economy | 7.0% |
| | | | number per module | 20 | | Efficiency | 0.97 | | | | |
| | | | Battery Disposal Costs | 0.35 | $/lb | | | | | | |

| Nominal - 40 kW | | | | | | | | | | | Nominal | | Good Economy | | Bad Economy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 95% | 23068.4211 | 2232.271127 | 18860 | | | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 |
| 2011 | 9 | 6574.5 | 78894 | 97% | 81334.0206 | 7931.628624 | | | | 7931.63 | 8248.89 | 7781.98 | 8129.92 | 7817.23 | 8486.84 | 7715.31 |
| 2012 | 17 | 12418.5 | 149022 | 97% | 153630.928 | 14882.96541 | 10475 | 1936 | 42 | 27335.97 | 29566.58 | 26314.15 | 28719.85 | 26553.11 | 31296.95 | 25865.25 |
| 2013 | 17.87756625 | 13059.5621 | 156714.75 | 97% | 161561.594 | 15668.59878 | | | 0 | 15668.60 | 17625.04 | 14798.33 | 16873.37 | 15000.36 | 19194.71 | 14421.27 |
| 2014 | 18.80043382 | 13733.7169 | 164804.6 | 97% | 169901.652 | 16459.1886 | | | 0 | 16459.19 | 19254.92 | 15251.70 | 18167.86 | 15529.97 | 21574.64 | 14735.77 |
| 2015 | 19.77094125 | 14442.6726 | 173312.07 | 97% | 178672.238 | 17366.40553 | | 3872 | 84 | 21322.41 | 25941.97 | 19385.35 | 24124.34 | 19828.45 | 29905.78 | 18569.13 |
| 2016 | 20.79154776 | 15188.2256 | 182258.71 | 97% | 187895.575 | 18343.60613 | | | 0 | 18343.61 | 23210.51 | 16362.50 | 21272.96 | 16812.33 | 27528.81 | 15539.29 |
| 2017 | 21.86483956 | 15972.2653 | 191667.18 | 97% | 197595.035 | 19417.86165 | | | 0 | 19417.86 | 25552.58 | 16993.93 | 23081.74 | 17540.22 | 31180.84 | 16000.70 |
| 2018 | 22.99353634 | 16796.7783 | 201561.34 | 97% | 207795.195 | 20598.77928 | 10475 | 3872 | 84 | 35029.78 | 47940.67 | 30078.57 | 42680.38 | 31186.14 | 60187.68 | 28078.00 |
| 2019 | 24.18049819 | 17663.8539 | 211966.25 | 97% | 218521.904 | 21920.28185 | | | 0 | 21920.28 | 31199.40 | 18466.87 | 27375.43 | 19233.61 | 40299.54 | 17090.94 |
| 2020 | 25.42873284 | 18575.6893 | 222908.27 | 97% | 229802.342 | 23224.60604 | | | 0 | 23224.61 | 34378.09 | 19196.55 | 29729.46 | 20084.16 | 45686.32 | 17614.05 |
| 2021 | 26.74140329 | 19534.5951 | 234415.14 | 97% | 241665.094 | 24371.58641 | | 5808 | 126 | 30305.59 | 46654.06 | 24576.78 | 39763.56 | 25829.65 | 63788.77 | 22357.58 |
| 2022 | 28.12183582 | 20543.0011 | 246516.01 | 97% | 254140.219 | 25711.56931 | | | 0 | 25711.57 | 41165.05 | 20457.77 | 34579.20 | 21598.07 | 57907.38 | 18451.08 |
| 2023 | 29.57352841 | 21603.4625 | 259241.55 | 97% | 267259.33 | 27268.46943 | 10475 | | 0 | 37743.47 | 62845.65 | 29464.49 | 52029.79 | 31247.74 | 90955.91 | 26346.69 |
| 2024 | 31.1001596 | 22718.6666 | 272624 | 97% | 281055.669 | 29128.89061 | | 5808 | 126 | 35062.89 | 60717.58 | 26855.45 | 49542.95 | 28609.82 | 90410.86 | 23808.01 |
| 2025 | 32.70559786 | 23891.4392 | 286697.27 | 97% | 295564.197 | 31203.95362 | | | 0 | 31203.95 | 56196.56 | 23448.86 | 45192.63 | 25093.86 | 86092.69 | 20609.91 |
| 2026 | 34.39391132 | 25124.7522 | 301497.03 | 97% | 310821.677 | 33315.48361 | | | 0 | 33315.48 | 62399.28 | 24563.24 | 49457.02 | 26405.51 | 98352.76 | 21404.43 |
| 2027 | 36.16937813 | 26421.7307 | 317060.77 | 97% | 326866.772 | 35526.75719 | | 5808 | 126 | 41460.76 | 80761.43 | 29991.92 | 63087.45 | 32387.41 | 130966.87 | 25911.10 |
| 2028 | 38.03649728 | 27785.6613 | 333427.94 | 97% | 343740.139 | 37840.63324 | | | 0 | 37840.63 | 76658.18 | 26856.72 | 59018.47 | 29133.18 | 127898.78 | 23003.72 |
| 2029 | 40 | 29220 | 350640 | 97% | 361484.536 | 40104.61267 | | 1936 | 42 | 42082.61 | 88661.72 | 29303.85 | 67275.38 | 31931.75 | 152192.93 | 24884.76 |
| | | | | | | | | | Total | 542473.1491 | 860070.43 | $441,241.26 | 721194.02 | $462,914.84 | 1235001.3 | $403,499.24 |

| High - 40 kW | | | | | | | | | | | Nominal | | Good Economy | | Bad Economy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 0.95 | 23068.4211 | 2247.136418 | 18860 | | | 21107.13642 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 |
| 2011 | 9 | 6574.5 | 78894 | 0.97 | 81334.0206 | 8036.451909 | | | | 8036.451909 | 8357.91 | 7884.82 | 8237.36 | 7920.54 | 8599.00 | 7817.28 |
| 2012 | 17 | 12418.5 | 149022 | 0.97 | 153630.928 | 15179.96472 | 10475 | 1936 | 42 | 27632.96472 | 29887.81 | 26600.05 | 29031.88 | 26841.61 | 31636.98 | 26146.27 |
| 2013 | 17.87756625 | 13059.5621 | 156714.75 | 0.97 | 161561.594 | 16050.33651 | | | 0 | 16050.33651 | 18054.45 | 15158.86 | 17284.46 | 15365.82 | 19662.35 | 14772.62 |
| 2014 | 18.80043382 | 13733.7169 | 164804.6 | 0.97 | 169901.652 | 16988.36429 | | | 0 | 16988.36429 | 19873.98 | 15742.06 | 18751.98 | 16029.27 | 22268.28 | 15209.53 |
| 2015 | 19.77094125 | 14442.6726 | 173312.07 | 0.97 | 178672.238 | 18038.03447 | | 3872 | 84 | 21994.03447 | 26759.11 | 19995.96 | 24884.23 | 20453.02 | 30847.77 | 19154.04 |
| 2016 | 20.79154776 | 15188.2256 | 182258.71 | 0.97 | 187895.575 | 19150.80552 | | | 0 | 19150.80552 | 24231.88 | 17082.52 | 22209.06 | 17552.15 | 28740.20 | 16223.09 |
| 2017 | 21.86483956 | 15972.2653 | 191667.18 | 0.97 | 197595.035 | 20351.61674 | | | 0 | 20351.61674 | 26781.34 | 17811.12 | 24191.68 | 18383.69 | 32680.25 | 16770.14 |
| 2018 | 22.99353634 | 16796.7783 | 201561.34 | 0.97 | 207795.195 | 21736.95668 | 10475 | 3872 | 84 | 36167.95668 | 49498.35 | 31055.87 | 44067.14 | 32199.43 | 62143.28 | 28990.30 |
| 2019 | 24.18049819 | 17663.8539 | 211966.25 | 0.97 | 218521.904 | 23187.62148 | | | 0 | 23187.62148 | 33003.22 | 19534.55 | 28958.16 | 20345.62 | 42629.50 | 18079.07 |
| 2020 | 25.42873284 | 18575.6893 | 222908.27 | 0.97 | 229802.342 | 24483.32539 | | | 0 | 24483.32539 | 36241.30 | 20236.95 | 31340.73 | 21172.67 | 48162.41 | 18568.69 |
| 2021 | 26.74140329 | 19534.5951 | 234415.14 | 0.97 | 241665.094 | 25669.32796 | | 5808 | 126 | 31603.32796 | 48651.87 | 25629.20 | 41466.30 | 26935.72 | 66520.33 | 23314.97 |
| 2022 | 28.12183582 | 20543.0011 | 246516.01 | 0.97 | 254140.219 | 27049.00762 | | | 0 | 27049.00762 | 43306.33 | 21521.92 | 36377.91 | 22721.53 | 60919.55 | 19410.85 |
| 2023 | 29.57352841 | 21603.4625 | 259241.55 | 0.97 | 267259.33 | 28847.17029 | 10475 | | 0 | 39322.17029 | 65474.30 | 30696.91 | 54206.05 | 32554.75 | 94760.34 | 27448.69 |
| 2024 | 31.1001596 | 22718.6666 | 272624 | 0.97 | 281055.669 | 30909.82796 | | 5808 | 126 | 36843.82796 | 63801.59 | 28219.50 | 52059.36 | 30062.99 | 95003.07 | 25017.28 |
| 2025 | 32.70559786 | 23891.4392 | 286697.27 | 0.97 | 295564.197 | 33045.08212 | | | 0 | 33045.08212 | 59512.33 | 24832.41 | 47859.13 | 26574.48 | 91172.42 | 21825.95 |
| 2026 | 34.39391132 | 25124.7522 | 301497.03 | 0.97 | 310821.677 | 35184.88951 | | | 0 | 35184.88951 | 65900.64 | 25941.54 | 52232.17 | 27887.18 | 103871.56 | 22605.48 |
| 2027 | 36.16937813 | 26421.7307 | 317060.77 | 0.97 | 326866.772 | 37387.34823 | | 5808 | 126 | 43321.34823 | 84385.68 | 31337.84 | 65918.55 | 33840.82 | 136844.13 | 27073.88 |
| 2028 | 38.03649728 | 27785.6613 | 333427.94 | 0.97 | 343740.139 | 39686.51779 | | | 0 | 39686.51779 | 80397.60 | 28166.80 | 61897.42 | 30554.31 | 134137.74 | 24125.85 |
| 2029 | 40 | 29220 | 350640 | 0.97 | 361484.536 | 41890.49087 | | 1936 | 42 | 43868.49087 | 92424.29 | 30547.43 | 70130.37 | 33286.85 | 158651.61 | 25940.81 |
| | | | | | | | | | Total | 565075.2765 | 897651.11 | 459103.46 | 752211.09 | 481789.58 | 1290357.9 | 419601.91 |

| Low - 40 kW | | | | | | | | | | | Nominal | | Good Economy | | Bad Economy | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value - | Present Value 2010$ | Future Value - | Present Value 2010$ | Future Value - | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 0.95 | 23068.4211 | 2212.45074 | 18860 | | | 21072.45074 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 |
| 2011 | 9 | 6574.5 | 78894 | 0.97 | 81334.0206 | 7791.864242 | | | | 7791.864242 | 8103.54 | 7644.85 | 7986.66 | 7679.48 | 8337.29 | 7579.36 |
| 2012 | 17 | 12418.5 | 149022 | 0.97 | 153630.928 | 14503.46629 | 10475 | 1936 | 42 | 26956.46629 | 29156.11 | 25948.84 | 28321.14 | 26184.48 | 30862.46 | 25506.16 |
| 2013 | 17.87756625 | 13059.5621 | 156714.75 | 0.97 | 161561.594 | 15200.10247 | | | 0 | 15200.10247 | 17098.05 | 14355.85 | 16368.85 | 14551.85 | 18620.78 | 13990.07 |
| 2014 | 18.80043382 | 13733.7169 | 164804.6 | 0.97 | 169901.652 | 15820.52829 | | | 0 | 15820.52829 | 18507.78 | 14659.90 | 17462.90 | 14927.36 | 20737.49 | 14163.98 |
| 2015 | 19.77094125 | 14442.6726 | 173312.07 | 0.97 | 178672.238 | 16713.96598 | | 3872 | 84 | 20669.96598 | 25148.17 | 18792.18 | 23386.17 | 19221.73 | 28990.70 | 18000.94 |
| 2016 | 20.79154776 | 15188.2256 | 182258.71 | 0.97 | 187895.575 | 17677.66664 | | | 0 | 17677.66664 | 22367.89 | 15768.48 | 20500.67 | 16201.98 | 26529.41 | 14975.16 |
| 2017 | 21.86483956 | 15972.2653 | 191667.18 | 0.97 | 197595.035 | 18590.21508 | | | 0 | 18590.21508 | 24463.45 | 16269.59 | 22097.92 | 16792.61 | 29851.82 | 15318.71 |
| 2018 | 22.99353634 | 16796.7783 | 201561.34 | 0.97 | 207795.195 | 19616.8223 | 10475 | 3872 | 84 | 34047.8223 | 46596.80 | 29235.41 | 41483.97 | 30311.93 | 58500.50 | 27290.91 |
| 2019 | 24.18049819 | 17663.8539 | 211966.25 | 0.97 | 218521.904 | 20793.75773 | | | 0 | 20793.75773 | 29596.00 | 17517.83 | 25968.55 | 18245.16 | 38228.48 | 16212.61 |
| 2020 | 25.42873284 | 18575.6893 | 222908.27 | 0.97 | 229802.342 | 21990.56747 | | | 0 | 21990.56747 | 32551.41 | 18176.54 | 28149.79 | 19016.99 | 43258.77 | 16678.13 |
| 2021 | 26.74140329 | 19534.5951 | 234415.14 | 0.97 | 241665.094 | 23151.70934 | | 5808 | 126 | 29085.70934 | 44776.11 | 23587.50 | 38162.97 | 24789.94 | 61221.11 | 21457.63 |
| 2022 | 28.12183582 | 20543.0011 | 246516.01 | 0.97 | 254140.219 | 24456.01497 | | | 0 | 24456.01497 | 39154.87 | 19458.77 | 32890.62 | 20543.38 | 55079.63 | 17550.07 |
| 2023 | 29.57352841 | 21603.4625 | 259241.55 | 0.97 | 267259.33 | 25775.87952 | 10475 | | 0 | 36250.87952 | 60360.38 | 28299.30 | 49972.24 | 30012.03 | 87359.00 | 25304.79 |
| 2024 | 31.1001596 | 22718.6666 | 272624 | 0.97 | 281055.669 | 27287.5825 | | 5808 | 126 | 33221.5825 | 57529.03 | 25445.15 | 46941.23 | 27107.39 | 85662.98 | 22557.74 |
| 2025 | 32.70559786 | 23891.4392 | 286697.27 | 0.97 | 295564.197 | 29172.36356 | | | 0 | 29172.36356 | 52537.78 | 21922.18 | 42250.28 | 23460.08 | 80487.47 | 19268.06 |
| 2026 | 34.39391132 | 25124.7522 | 301497.03 | 0.97 | 310821.677 | 31078.87299 | | | 0 | 31078.87299 | 58210.15 | 22914.21 | 46136.76 | 24632.79 | 91749.92 | 19967.46 |
| 2027 | 36.16937813 | 26421.7307 | 317060.77 | 0.97 | 326866.772 | 32999.16182 | | 5808 | 126 | 38933.16182 | 75837.93 | 28163.51 | 59241.41 | 30412.95 | 122982.66 | 24331.46 |
| 2028 | 38.03649728 | 27785.6613 | 333427.94 | 0.97 | 343740.139 | 35145.6418 | | | 0 | 35145.6418 | 71198.62 | 24944.00 | 54815.21 | 27058.33 | 118789.89 | 21365.41 |
| 2029 | 40 | 29220 | 350640 | 0.97 | 361484.536 | 37309.32505 | | 1936 | 42 | 39287.32505 | 82772.47 | 27357.38 | 62806.69 | 29810.72 | 142083.69 | 23231.82 |
| | | | | | | | | | Total | 517242.9588 | 817038.99 | 421533.89 | 686016.48 | 442033.63 | 1170406.5 | 385822.91 |

**Power**

| Nominal - 20 kW | | | | | | | | | | | Nominal | | High | | Low | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 95% | 23068.421 | 2232.271127 | 18860 | | | 21092.27113 | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 | 21092.27 |
| 2011 | 9 | 6574.5 | 78894 | 97% | 81334.021 | 7931.628624 | | | | 7931.628624 | 8248.89 | 7781.98 | 8129.92 | 7817.23 | 8486.84 | 7715.31 |
| 2012 | 17 | 12418.5 | 149022 | 97% | 153630.93 | 14882.96541 | 10475 | 1936 | 42 | 27335.96541 | 29566.58 | 26314.15 | 28719.85 | 26553.11 | 31296.95 | 25865.25 |
| 2013 | 17.87756625 | 13059.56214 | 156714.75 | 97% | 161561.59 | 15668.59878 | | 1936 | 42 | 17646.59878 | 19850.02 | 16666.46 | 19003.46 | 16894.00 | 21617.84 | 16241.80 |
| 2014 | 18.80043382 | 13733.71691 | 164804.6 | 97% | 169901.65 | 16459.1886 | | | 0 | 16459.1886 | 19254.92 | 15251.70 | 18167.86 | 15529.97 | 21574.64 | 14735.77 |
| 2015 | 19.77094125 | 14442.67258 | 173312.07 | 97% | 178672.24 | 17366.40553 | | 1936 | 42 | 19344.40553 | 23535.43 | 17587.04 | 21886.42 | 17989.04 | 27131.53 | 16846.55 |
| 2016 | 20 | 14610 | 175320 | 97% | 180742.27 | 17645.25311 | | 1936 | 42 | 19623.25311 | 24829.68 | 17503.94 | 22756.96 | 17985.15 | 29449.21 | 16623.31 |
| 2017 | 20 | 14610 | 175320 | 97% | 180742.27 | 17761.72342 | | | 0 | 17761.72342 | 23373.22 | 15544.52 | 21113.11 | 16044.23 | 28521.45 | 14636.01 |
| 2018 | 20 | 14610 | 175320 | 97% | 180742.27 | 17917.01718 | | 1936 | 42 | 19895.01718 | 27227.70 | 17083.00 | 24240.15 | 17712.04 | 34183.34 | 15946.78 |
| 2019 | 20 | 14610 | 175320 | 97% | 180742.27 | 18130.54609 | | 1936 | 42 | 20108.54609 | 28620.73 | 16940.57 | 25112.82 | 17643.93 | 36968.74 | 15678.36 |
| 2020 | 20 | 14610 | 175320 | 97% | 180742.27 | 18266.42813 | | | 0 | 18266.42813 | 27038.78 | 15098.31 | 23382.57 | 15796.43 | 35932.83 | 13853.66 |
| 2021 | 20 | 14610 | 175320 | 97% | 180742.27 | 18227.60469 | | 1936 | 42 | 20205.60469 | 31105.60 | 16386.04 | 26511.50 | 17221.37 | 42529.81 | 14906.44 |
| 2022 | 20 | 14610 | 175320 | 97% | 180742.27 | 18285.83985 | | 1936 | 42 | 20263.83985 | 32443.06 | 16123.21 | 27252.61 | 17021.90 | 45638.05 | 14541.69 |
| 2023 | 20 | 14610 | 175320 | 97% | 180742.27 | 18441.13361 | | | 0 | 18441.13361 | 30705.84 | 14396.10 | 25421.31 | 15267.38 | 44440.27 | 12872.76 |
| 2024 | 20 | 14610 | 175320 | 97% | 180742.27 | 18732.3094 | | 1936 | 42 | 20710.3094 | 35863.56 | 15862.48 | 29263.13 | 16898.73 | 53402.24 | 14062.48 |
| 2025 | 20 | 14610 | 175320 | 97% | 180742.27 | 19081.72035 | | 1936 | 42 | 21059.72035 | 37927.37 | 15825.76 | 30500.75 | 16935.99 | 58104.43 | 13909.74 |
| 2026 | 20 | 14610 | 175320 | 97% | 180742.27 | 19372.89615 | | | 0 | 19372.89615 | 36285.07 | 14283.48 | 28759.17 | 15354.76 | 57191.96 | 12446.64 |
| 2027 | 20 | 14610 | 175320 | 97% | 180742.27 | 19644.66022 | | 1936 | 42 | 21622.66022 | 42118.79 | 15641.42 | 32901.43 | 16890.72 | 68301.99 | 13513.18 |
| 2028 | 20 | 14610 | 175320 | 97% | 180742.27 | 19897.01258 | | 1936 | 42 | 21875.01258 | 44314.76 | 15525.40 | 34117.55 | 16841.38 | 73936.06 | 13298.05 |
| 2029 | 20 | 14610 | 175320 | 97% | 180742.27 | 20052.30633 | | | 0 | 20052.30633 | 42247.19 | 13963.24 | 32056.62 | 15215.43 | 72519.72 | 11857.55 |
| | | | | | | | | | Total | 389068.5092 | 585649.46 | 324871.09 | 500389.47 | 338705.06 | 812320.17 | 300643.60 |

| High - 20 kW | | | | | | | | | | | Nominal | | High | | Low | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 0.95 | 23068.421 | 2247.136418 | 18860 | | | 21107.13642 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 | 21107.14 |
| 2011 | 9 | 6574.5 | 78894 | 0.97 | 81334.021 | 8036.451909 | | | | 8036.451909 | 8357.91 | 7884.82 | 8237.36 | 7920.54 | 8599.00 | 7817.28 |
| 2012 | 17 | 12418.5 | 149022 | 0.97 | 153630.93 | 15179.96472 | 10475 | 1936 | 42 | 27632.96472 | 29887.81 | 26600.05 | 29031.88 | 26841.61 | 31636.98 | 26146.27 |
| 2013 | 17.87756625 | 13059.56214 | 156714.75 | 0.97 | 161561.59 | 16050.33651 | | 1936 | 42 | 18028.33651 | 20279.43 | 17027.00 | 19414.55 | 17259.46 | 22085.49 | 16593.15 |
| 2014 | 18.80043382 | 13733.71691 | 164804.6 | 0.97 | 169901.65 | 16988.36429 | | | 0 | 16988.36429 | 19873.98 | 15742.06 | 18751.98 | 16029.27 | 22268.28 | 15209.53 |
| 2015 | 19.77094125 | 14442.67258 | 173312.07 | 0.97 | 178672.24 | 18038.03447 | | 1936 | 42 | 20016.03447 | 24352.57 | 18197.65 | 22646.31 | 18613.61 | 28073.52 | 17431.45 |
| 2016 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18421.72189 | | 1936 | 42 | 20399.72189 | 25812.16 | 18196.55 | 23657.42 | 18696.81 | 30614.48 | 17281.08 |
| 2017 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18615.83908 | | | 0 | 18615.83908 | 24497.17 | 16292.02 | 22128.38 | 16815.75 | 29892.97 | 15339.82 |
| 2018 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18907.01488 | | 1936 | 42 | 20885.01488 | 28582.58 | 17933.07 | 25446.36 | 18593.41 | 35884.34 | 16740.31 |
| 2019 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19178.77895 | | 1936 | 42 | 21156.77895 | 30112.69 | 17823.66 | 26421.92 | 18563.69 | 38895.88 | 16495.65 |
| 2020 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19256.42583 | | | 0 | 19256.42583 | 28504.21 | 15916.60 | 24649.85 | 16652.56 | 37880.30 | 14604.50 |
| 2021 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19198.19067 | | 1936 | 42 | 21176.19067 | 32599.77 | 17173.15 | 27785.00 | 18048.60 | 44572.75 | 15622.48 |
| 2022 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19237.01411 | | 1936 | 42 | 21215.01411 | 33965.92 | 16880.02 | 28531.84 | 17820.90 | 47780.28 | 15224.27 |
| 2023 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19508.77819 | | | 0 | 19508.77819 | 32483.55 | 15229.56 | 26893.07 | 16151.28 | 47013.13 | 13618.03 |
| 2024 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 19877.60086 | | 1936 | 42 | 21855.60086 | 37846.83 | 16739.69 | 30881.39 | 17833.23 | 56355.41 | 14840.14 |
| 2025 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20207.60009 | | 1936 | 42 | 22185.60009 | 39955.01 | 16671.83 | 32131.36 | 17841.41 | 61210.77 | 14653.37 |
| 2026 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20459.95245 | | | 0 | 20459.95245 | 38321.11 | 15084.96 | 30372.91 | 16216.35 | 60401.13 | 13145.05 |
| 2027 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20673.48136 | | 1936 | 42 | 22651.48136 | 44122.83 | 16385.65 | 34466.91 | 17694.39 | 71551.84 | 14156.15 |
| 2028 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20867.59856 | | 1936 | 42 | 22845.59856 | 46280.99 | 16214.26 | 35631.34 | 17588.63 | 77216.58 | 13888.08 |
| 2029 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 20945.24544 | | | 0 | 20945.24544 | 44128.47 | 14585.03 | 33484.12 | 15892.98 | 75749.06 | 12385.58 |
| | | | | | | | | | Total | 404966.5307 | 611072.15 | 337684.77 | 521671.08 | 352181.61 | 848789.33 | 312299.31 |

| Low - 20 kW | | | | | | | | | | | Nominal | | High | | Low | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Electrical Consumption (W) | kWh/Month | kWh/Year | Efficiency | Actual Power kWh/year | Actual Power Costs (2010 $/yr) | Current $ Unit Cost | Battery Cost | Environmental Costs | Total Costs 2010 $ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ | Future Value | Present Value 2010$ |
| 2010 | 2.5 | 1826.25 | 21915 | 0.95 | 23068.421 | 2212.45074 | 18860 | | | 21072.45074 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 | 21072.45 |
| 2011 | 9 | 6574.5 | 78894 | 0.97 | 81334.021 | 7791.864242 | | | | 7791.864242 | 8103.54 | 7644.85 | 7986.66 | 7679.48 | 8337.29 | 7579.36 |
| 2012 | 17 | 12418.5 | 149022 | 0.97 | 153630.93 | 14503.46629 | 10475 | 1936 | 42 | 26956.46629 | 29156.11 | 25948.84 | 28321.14 | 26184.48 | 30862.46 | 25506.16 |
| 2013 | 17.87756625 | 13059.56214 | 156714.75 | 0.97 | 161561.59 | 15200.10247 | | 1936 | 42 | 17178.10247 | 19323.03 | 16223.99 | 18498.94 | 16445.49 | 21043.91 | 15810.60 |
| 2014 | 18.80043382 | 13733.71691 | 164804.6 | 0.97 | 169901.65 | 15820.52829 | | | 0 | 15820.52829 | 18507.78 | 14659.90 | 17462.90 | 14927.36 | 20737.49 | 14163.98 |
| 2015 | 19.77094125 | 14442.67258 | 173312.07 | 0.97 | 178672.24 | 16713.96598 | | 1936 | 42 | 18691.96598 | 22741.63 | 16993.87 | 21148.24 | 17382.31 | 26216.45 | 16278.35 |
| 2016 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17004.66636 | | 1936 | 42 | 18982.66636 | 24019.13 | 16932.54 | 22014.07 | 17398.04 | 28487.86 | 16080.66 |
| 2017 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17004.66636 | | | 0 | 17004.66636 | 22376.98 | 14881.97 | 20213.20 | 15360.37 | 27305.78 | 14012.18 |
| 2018 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17062.90152 | | 1936 | 42 | 19040.90152 | 26058.79 | 16349.61 | 23199.49 | 16951.64 | 32715.81 | 15262.17 |
| 2019 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17198.78355 | | 1936 | 42 | 19176.78355 | 27294.54 | 16155.60 | 23949.17 | 16826.37 | 35255.73 | 14951.87 |
| 2020 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17295.84215 | | | 0 | 17295.84215 | 25602.07 | 14296.06 | 22140.14 | 14957.09 | 34023.54 | 13117.55 |
| 2021 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17315.25387 | | 1936 | 42 | 19293.25387 | 29701.08 | 15646.16 | 25314.42 | 16443.77 | 40609.44 | 14233.36 |
| 2022 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17392.90075 | | 1936 | 42 | 19370.90075 | 31013.44 | 15412.73 | 26051.71 | 16271.82 | 43626.98 | 13900.90 |
| 2023 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17431.72419 | | | 0 | 17431.72419 | 29025.10 | 13608.10 | 24029.82 | 14431.69 | 42007.75 | 12168.15 |
| 2024 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17548.19451 | | 1936 | 42 | 19526.19451 | 33813.05 | 14955.55 | 27590.00 | 15932.54 | 50348.96 | 13258.45 |
| 2025 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 17839.3703 | | 1936 | 42 | 19817.3703 | 35689.96 | 14892.18 | 28701.46 | 15936.90 | 54676.75 | 13089.18 |
| 2026 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18072.31094 | | | 0 | 18072.31094 | 33849.10 | 13324.57 | 26828.45 | 14323.93 | 53352.42 | 11611.04 |
| 2027 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18247.01641 | | 1936 | 42 | 20225.01641 | 39396.32 | 14630.39 | 30774.75 | 15798.94 | 63887.09 | 12639.72 |
| 2028 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18479.95705 | | 1936 | 42 | 20457.95705 | 41444.07 | 14519.67 | 31907.43 | 15750.41 | 69146.51 | 12436.61 |
| 2029 | 20 | 14610 | 175320 | 0.97 | 180742.27 | 18654.66252 | | | 0 | 18654.66252 | 39302.56 | 12990.01 | 29822.28 | 14154.92 | 67465.10 | 11031.08 |
| | | | | | | | | | Total | 371861.6285 | 557490.74 | 311139.02 | 477026.74 | 324230.00 | 771179.79 | 288203.84 |

**HVAC**

Project # 1.3 — Note: For 40 kW Need to Upgrade to meet capacity after 6 years

Lifespan (years) 20

| Initial | | | |
|---|---|---|---|
| Total Cost | Labor Cost | Material Costs | Contingency |
| 33401 | 2000 | 30401 | 1000 |

| Interest Rate | | Inflation | |
|---|---|---|---|
| Nominal | 6.0% | Nominal | 4% |
| Good Economy | 4.0% | Good Economy | 3% |
| Poor Economy | 10.0% | Poor Economy | 7% |

| Future : 40 kW | | | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.677 | 795.33 | 33401 | 34196.33 | 34196.33 | 34196.33 | 34196.33 | 34196.33 | 34196.33 | 34196.33 |
| 2011 | 29108 | 9.75 | 2838.59 | | 2838.59 | 2952.13 | 2785.03 | 2909.55 | 2797.65 | 3037.29 | 2761.17 |
| 2012 | 53905 | 9.69 | 5222.04 | | 5222.04 | 5648.15 | 5026.84 | 5486.40 | 5072.49 | 5978.71 | 4941.08 |
| 2013 | 56483 | 9.70 | 5477.85 | | 5477.85 | 6161.83 | 5173.59 | 5899.04 | 5244.23 | 6710.60 | 5041.77 |
| 2014 | 59176 | 9.69 | 5732.66 | | 5732.66 | 6706.41 | 5312.10 | 6327.79 | 5409.02 | 7514.35 | 5132.40 |
| 2015 | 61996 | 9.72 | 6025.83 | | 6025.83 | 7331.34 | 5478.40 | 6817.67 | 5603.63 | 8451.53 | 5247.74 |
| 2016 | 64940 | 9.76 | 6339.87 | 0 | 6339.87 | 8021.96 | 5655.17 | 7352.31 | 5810.64 | 9514.44 | 5370.65 |
| 2017 | 68016 | 9.83 | 6684.00 | | 6684.00 | 8795.69 | 5849.64 | 7945.18 | 6037.68 | 10733.04 | 5507.75 |
| 2018 | 71231 | 9.91 | 7061.14 | | 7061.14 | 9663.66 | 6063.10 | 8603.32 | 6286.36 | 12132.36 | 5659.83 |
| 2019 | 74587 | 10.03 | 7481.94 | | 7481.94 | 10649.14 | 6303.21 | 9343.92 | 6564.91 | 13755.24 | 5833.57 |
| 2020 | 78092 | 10.11 | 7892.24 | | 7892.24 | 11682.45 | 6523.42 | 10102.74 | 6825.05 | 15525.24 | 5985.65 |
| 2021 | 81751 | 10.08 | 8244.47 | | 8244.47 | 12691.99 | 6685.98 | 10817.46 | 7026.82 | 17353.40 | 6082.26 |
| 2022 | 85567 | 10.12 | 8656.88 | | 8656.88 | 13859.95 | 6887.97 | 11642.54 | 7271.90 | 19496.96 | 6212.33 |
| 2023 | 89553 | 10.20 | 9137.09 | | 9137.09 | 15213.93 | 7132.88 | 12595.58 | 7564.58 | 22018.98 | 6378.11 |
| 2024 | 93708 | 10.36 | 9711.99 | | 9711.99 | 16818.03 | 7438.63 | 13722.79 | 7924.57 | 25042.70 | 6594.53 |
| 2025 | 98039 | 10.56 | 10350.39 | | 10350.39 | 18640.47 | 7778.02 | 14990.45 | 8323.66 | 28557.05 | 6836.33 |
| 2026 | 102557 | 10.72 | 10992.59 | | 10992.59 | 20588.92 | 8104.75 | 16318.57 | 8712.62 | 32451.93 | 7062.49 |
| 2027 | 107264 | 10.87 | 11658.40 | | 11658.40 | 22709.39 | 8433.46 | 17739.63 | 9107.05 | 36826.72 | 7285.97 |
| 2028 | 112167 | 11.01 | 12347.90 | | 12347.90 | 25014.59 | 8763.71 | 19258.52 | 9506.55 | 41735.08 | 7506.42 |
| 2029 | 117273 | 11.09 | 13010.76 | | 13010.76 | 27411.71 | 9059.93 | 20799.65 | 9872.40 | 47053.77 | 7693.67 |
| | | | | Total Cost Over 20 yrs: | 222,463.97 | 284,758.05 | 158,652.14 | 242,869.43 | 165,158.11 | 398,085.71 | 147,330.05 |

| Future : 40 kW | | | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.591 | 788.27 | 33401 | 34189.27 | 34189.27 | 34189.27 | 34189.27 | 34189.27 | 34189.27 | 34189.27 |
| 2011 | 29108 | 9.58 | 2788.57 | | 2788.57 | 2900.11 | 2735.96 | 2858.28 | 2748.35 | 2983.77 | 2712.52 |
| 2012 | 53905 | 9.44 | 5088.88 | | 5088.88 | 5504.13 | 4898.66 | 5346.50 | 4943.14 | 5826.26 | 4815.09 |
| 2013 | 56483 | 9.41 | 5314.06 | | 5314.06 | 5977.59 | 5018.90 | 5722.66 | 5087.42 | 6509.95 | 4891.02 |
| 2014 | 59176 | 9.31 | 5510.22 | | 5510.22 | 6446.18 | 5105.98 | 6082.25 | 5199.13 | 7222.78 | 4933.25 |
| 2015 | 61996 | 9.35 | 5799.44 | | 5799.44 | 7055.91 | 5272.58 | 6561.53 | 5393.10 | 8134.02 | 5050.58 |
| 2016 | 64940 | 9.41 | 6109.71 | 0 | 6109.71 | 7730.73 | 5449.86 | 7085.39 | 5599.69 | 9169.03 | 5175.68 |
| 2017 | 68016 | 9.41 | 6399.11 | | 6399.11 | 8420.79 | 5600.31 | 7606.53 | 5780.34 | 10275.57 | 5272.99 |
| 2018 | 71231 | 9.44 | 6724.53 | | 6724.53 | 9202.99 | 5774.07 | 8193.19 | 5986.68 | 11554.00 | 5390.03 |
| 2019 | 74587 | 9.52 | 7097.43 | | 7097.43 | 10101.86 | 5979.27 | 8863.72 | 6227.53 | 13048.34 | 5533.77 |
| 2020 | 78092 | 9.57 | 7472.89 | | 7472.89 | 11061.70 | 6176.80 | 9565.93 | 6462.40 | 14700.30 | 5667.60 |
| 2021 | 81751 | 9.58 | 7831.81 | | 7831.81 | 12056.71 | 6351.33 | 10276.01 | 6675.10 | 16484.80 | 5777.82 |
| 2022 | 85567 | 9.62 | 8234.15 | | 8234.15 | 13183.13 | 6551.61 | 11074.01 | 6916.80 | 18544.88 | 5908.97 |
| 2023 | 89553 | 9.64 | 8636.96 | | 8636.96 | 14381.17 | 6742.45 | 11906.14 | 7150.52 | 20813.73 | 6029.00 |
| 2024 | 93708 | 9.71 | 9098.07 | | 9098.07 | 15754.92 | 6968.42 | 12855.34 | 7423.64 | 23459.69 | 6177.67 |
| 2025 | 98039 | 9.87 | 9676.51 | | 9676.51 | 17426.84 | 7271.61 | 14014.47 | 7781.74 | 26697.79 | 6391.24 |
| 2026 | 102557 | 10.00 | 10254.61 | | 10254.61 | 19206.70 | 7560.65 | 15223.03 | 8127.70 | 30273.30 | 6588.35 |
| 2027 | 107264 | 10.10 | 10828.94 | | 10828.94 | 21093.71 | 7833.45 | 16477.52 | 8459.12 | 34206.63 | 6767.60 |
| 2028 | 112167 | 10.22 | 11468.49 | | 11468.49 | 23233.06 | 8139.56 | 17886.93 | 8829.49 | 38762.73 | 6971.82 |
| 2029 | 117273 | 10.32 | 12103.91 | | 12103.91 | 25501.11 | 8428.45 | 19349.92 | 9184.29 | 43774.13 | 7157.42 |
| | | | | Total Cost Over 20 yrs: | $214,029 | $270,428.62 | $152,049.18 | $231,138.64 | $158,165.46 | $376,630.95 | $141,401.69 |

| Future : 40 kW | | | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.741 | 800.63 | 33401 | 34201.63 | 34201.63 | 34201.63 | 34201.63 | 34201.63 | 34201.63 | 34201.63 |
| 2011 | 29108 | 9.88 | 2876.10 | | 2876.10 | 2991.15 | 2821.84 | 2948.01 | 2834.62 | 3077.43 | 2797.66 |
| 2012 | 53905 | 9.88 | 5326.25 | | 5326.25 | 5760.87 | 5127.15 | 5595.89 | 5173.71 | 6098.02 | 5039.68 |
| 2013 | 56483 | 9.93 | 5611.30 | | 5611.30 | 6311.95 | 5299.64 | 6042.76 | 5371.99 | 6874.09 | 5164.60 |
| 2014 | 59176 | 10.00 | 5916.97 | | 5916.97 | 6922.02 | 5482.89 | 6531.23 | 5582.92 | 7755.94 | 5297.41 |
| 2015 | 61996 | 10.10 | 6258.87 | | 6258.87 | 7614.87 | 5690.27 | 7081.33 | 5820.34 | 8778.39 | 5450.69 |
| 2016 | 64940 | 10.19 | 6618.85 | 0 | 6618.85 | 8374.96 | 5904.02 | 7675.84 | 6066.33 | 9933.11 | 5606.98 |
| 2017 | 68016 | 10.30 | 7005.42 | | 7005.42 | 9218.65 | 6130.93 | 8327.24 | 6328.02 | 11249.17 | 5772.60 |
| 2018 | 71231 | 10.46 | 7451.30 | | 7451.30 | 10197.62 | 6398.12 | 9078.69 | 6633.71 | 12802.73 | 5972.57 |
| 2019 | 74587 | 10.61 | 7914.52 | | 7914.52 | 11264.82 | 6667.63 | 9884.15 | 6944.47 | 14550.51 | 6170.84 |
| 2020 | 78092 | 10.65 | 8319.98 | | 8319.98 | 12315.61 | 6876.97 | 10650.28 | 7194.95 | 16366.67 | 6310.06 |
| 2021 | 81751 | 10.62 | 8683.48 | | 8683.48 | 13367.81 | 7042.00 | 11393.47 | 7400.98 | 18277.43 | 6406.13 |
| 2022 | 85567 | 10.64 | 9107.19 | | 9107.19 | 14580.90 | 7246.26 | 12248.15 | 7650.16 | 20511.13 | 6535.48 |
| 2023 | 89553 | 10.79 | 9666.08 | | 9666.08 | 16094.74 | 7545.84 | 13324.80 | 8002.53 | 23293.76 | 6747.37 |
| 2024 | 93708 | 11.00 | 10305.78 | | 10305.78 | 17846.28 | 7893.43 | 14561.80 | 8409.08 | 26573.81 | 6997.71 |
| 2025 | 98039 | 11.18 | 10961.09 | | 10961.09 | 19740.31 | 8236.94 | 15874.93 | 8814.79 | 30242.00 | 7239.70 |
| 2026 | 102557 | 11.32 | 11609.41 | | 11609.41 | 21744.21 | 8559.53 | 17234.24 | 9201.50 | 34272.88 | 7458.78 |
| 2027 | 107264 | 11.44 | 12268.96 | | 12268.96 | 23898.72 | 8875.13 | 18668.68 | 9584.00 | 38755.39 | 7667.55 |
| 2028 | 112167 | 11.55 | 12950.24 | | 12950.24 | 26234.81 | 9191.20 | 20197.96 | 9970.28 | 43770.94 | 7872.59 |
| 2029 | 117273 | 11.59 | 13590.13 | | 13590.13 | 28632.36 | 9463.37 | 21725.87 | 10312.02 | 49149.10 | 8036.27 |
| | | | | Total Cost Over 20 yrs: | $230,045 | $297,314.30 | $164,654.78 | $253,246.95 | $171,498.03 | $416,534.13 | $152,746.30 |

| Future : 20kW | | | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Nominal | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.677 | 795.33 | 33401 | 34196.33 | 34196.33 | 34196.33 | 34196.33 | 34196.33 | 34196.33 | 34196.33 |
| 2011 | 29108 | 9.75 | 2838.59 | | 2838.59 | 2952.13 | 2785.03 | 2909.55 | 2797.65 | 3037.29 | 2761.17 |
| 2012 | 53905 | 9.69 | 5222.04 | | 5222.04 | 5648.15 | 5026.84 | 5486.40 | 5072.49 | 5978.71 | 4941.08 |
| 2013 | 56483 | 9.70 | 5477.85 | | 5477.85 | 6161.83 | 5173.59 | 5899.04 | 5244.23 | 6710.60 | 5041.77 |
| 2014 | 59176 | 9.69 | 5732.66 | | 5732.66 | 6706.41 | 5312.10 | 6327.79 | 5409.02 | 7514.35 | 5132.40 |
| 2015 | 61996 | 9.72 | 6025.83 | | 6025.83 | 7331.34 | 5478.40 | 6817.67 | 5603.63 | 8451.53 | 5247.74 |
| 2016 | 64940 | 9.76 | 6339.87 | | 6339.87 | 8021.96 | 5655.17 | 7352.31 | 5810.64 | 9514.44 | 5370.65 |
| 2017 | 64940 | 9.83 | 6381.72 | | 6381.72 | 8397.91 | 5585.09 | 7585.86 | 5764.63 | 10247.65 | 5258.66 |
| 2018 | 64940 | 9.91 | 6437.52 | | 6437.52 | 8810.18 | 5527.62 | 7843.49 | 5731.16 | 11060.85 | 5159.97 |
| 2019 | 64940 | 10.03 | 6514.24 | | 6514.24 | 9271.79 | 5487.96 | 8135.39 | 5715.82 | 11976.16 | 5079.06 |
| 2020 | 64940 | 10.11 | 6563.06 | | 6563.06 | 9714.93 | 5424.77 | 8401.27 | 5675.60 | 12910.53 | 4977.57 |
| 2021 | 64940 | 10.08 | 6549.11 | | 6549.11 | 10082.05 | 5311.10 | 8593.00 | 5581.85 | 13784.90 | 4831.52 |
| 2022 | 64940 | 10.12 | 6570.03 | | 6570.03 | 10518.83 | 5227.54 | 8835.96 | 5518.92 | 14796.97 | 4714.77 |
| 2023 | 64940 | 10.20 | 6625.83 | | 6625.83 | 11032.49 | 5172.46 | 9133.78 | 5485.51 | 15967.22 | 4625.13 |
| 2024 | 64940 | 10.36 | 6730.45 | | 6730.45 | 11654.96 | 5155.00 | 9509.94 | 5491.76 | 17354.69 | 4570.03 |
| 2025 | 64940 | 10.56 | 6855.99 | | 6855.99 | 12347.25 | 5152.08 | 9929.52 | 5513.51 | 18915.89 | 4528.31 |
| 2026 | 64940 | 10.72 | 6960.61 | | 6960.61 | 13037.09 | 5132.00 | 10333.06 | 5516.91 | 20548.85 | 4472.03 |
| 2027 | 64940 | 10.87 | 7058.25 | | 7058.25 | 13748.77 | 5105.80 | 10739.96 | 5513.61 | 22295.71 | 4411.09 |
| 2028 | 64940 | 11.01 | 7148.92 | | 7148.92 | 14482.40 | 5073.82 | 11149.88 | 5503.89 | 24162.87 | 4345.90 |
| 2029 | 64940 | 11.09 | 7204.72 | | 7204.72 | 15179.25 | 5016.94 | 11517.82 | 5466.85 | 26056.06 | 4260.37 |
| | | | | Total Cost Over 20 yrs: | 186,834.58 | 219,296.04 | 131,999.62 | 190,698.01 | 136,613.96 | 295,481.57 | 123,925.57 |

| Future : 20kW | | | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| High | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.741 | 800.63 | 28731 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 | 29531.63 |
| 2011 | 29108 | 9.88 | 2876.10 | | 2876.10 | 2991.15 | 2821.84 | 2948.01 | 2834.62 | 3077.43 | 2797.66 |
| 2012 | 53905 | 9.88 | 5326.25 | | 5326.25 | 5760.87 | 5127.15 | 5595.89 | 5173.71 | 6098.02 | 5039.68 |
| 2013 | 56483 | 9.93 | 5611.30 | | 5611.30 | 6311.95 | 5299.64 | 6042.76 | 5371.99 | 6874.09 | 5164.60 |
| 2014 | 59176 | 10.00 | 5916.97 | | 5916.97 | 6922.02 | 5482.89 | 6531.23 | 5582.92 | 7755.94 | 5297.41 |
| 2015 | 61996 | 10.10 | 6258.87 | | 6258.87 | 7614.87 | 5690.27 | 7081.33 | 5820.34 | 8778.39 | 5450.69 |
| 2016 | 64940 | 10.19 | 6618.85 | | 6618.85 | 8374.96 | 5904.02 | 7675.84 | 6066.33 | 9933.11 | 5606.98 |
| 2017 | 64940 | 10.30 | 6688.60 | | 6688.60 | 8801.74 | 5853.66 | 7950.64 | 6041.83 | 10740.43 | 5511.54 |
| 2018 | 64940 | 10.46 | 6793.22 | | 6793.22 | 9296.99 | 5833.04 | 8276.88 | 6047.83 | 11672.01 | 5445.08 |
| 2019 | 64940 | 10.61 | 6890.86 | | 6890.86 | 9807.84 | 5805.25 | 8605.74 | 6046.28 | 12668.57 | 5372.71 |
| 2020 | 64940 | 10.65 | 6918.76 | | 6918.76 | 10241.45 | 5718.77 | 8856.60 | 5983.20 | 13610.25 | 5247.34 |
| 2021 | 64940 | 10.62 | 6897.84 | | 6897.84 | 10618.90 | 5593.90 | 9050.56 | 5879.07 | 14518.92 | 5088.79 |
| 2022 | 64940 | 10.64 | 6911.78 | | 6911.78 | 11065.99 | 5499.46 | 9295.58 | 5805.99 | 15566.66 | 4960.02 |
| 2023 | 64940 | 10.79 | 7009.43 | | 7009.43 | 11671.21 | 5471.92 | 9662.57 | 5803.09 | 16891.64 | 4892.91 |
| 2024 | 64940 | 11.00 | 7141.95 | | 7141.95 | 12367.54 | 5470.17 | 10091.38 | 5827.52 | 18415.75 | 4849.44 |
| 2025 | 64940 | 11.18 | 7260.51 | | 7260.51 | 13075.77 | 5456.06 | 10515.39 | 5838.82 | 20031.98 | 4795.50 |
| 2026 | 64940 | 11.32 | 7351.18 | | 7351.18 | 13768.63 | 5419.97 | 10912.87 | 5826.47 | 21701.89 | 4722.96 |
| 2027 | 64940 | 11.44 | 7427.90 | | 7427.90 | 14468.81 | 5373.20 | 11302.43 | 5802.37 | 23463.37 | 4642.10 |
| 2028 | 64940 | 11.55 | 7497.65 | | 7497.65 | 15188.86 | 5321.32 | 11693.77 | 5772.37 | 25341.54 | 4557.90 |
| 2029 | 64940 | 11.59 | 7525.55 | | 7525.55 | 15855.19 | 5240.35 | 12030.72 | 5710.29 | 27216.34 | 4450.09 |
| | | | | Total Cost Over 20 yrs: | $183,186 | 223736.38 | 131914.52 | 193651.82 | 136766.69 | 303887.97 | 123425.05 |

| Future : 20kW | | | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Low | | | | | | Nominal | | Good Economy | | Poor Economy | |
| Year | Energy Consumption (kWh/yr) | Energy Price (2010 cents/kWh) | Energy Costs (2010$/yr) | Equipment Costs (2010$/yr) | Total HVAC Cost (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 8219 | 9.591 | 788.27 | 28731 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 | 29519.27 |
| 2011 | 29108 | 9.58 | 2788.57 | | 2788.57 | 2900.11 | 2735.96 | 2858.28 | 2748.35 | 2983.77 | 2712.52 |
| 2012 | 53905 | 9.44 | 5088.88 | | 5088.88 | 5504.13 | 4898.66 | 5346.50 | 4943.14 | 5826.26 | 4815.09 |
| 2013 | 56483 | 9.41 | 5314.06 | | 5314.06 | 5977.59 | 5018.90 | 5722.66 | 5087.42 | 6509.95 | 4891.02 |
| 2014 | 59176 | 9.31 | 5510.22 | | 5510.22 | 6446.18 | 5105.98 | 6082.25 | 5199.13 | 7222.78 | 4933.25 |
| 2015 | 61996 | 9.35 | 5799.44 | | 5799.44 | 7055.91 | 5272.58 | 6561.53 | 5393.10 | 8134.02 | 5050.58 |
| 2016 | 64940 | 9.41 | 6109.71 | | 6109.71 | 7730.73 | 5449.86 | 7085.39 | 5599.69 | 9169.03 | 5175.68 |
| 2017 | 64940 | 9.41 | 6109.71 | | 6109.71 | 8039.96 | 5347.03 | 7262.53 | 5518.92 | 9810.86 | 5034.52 |
| 2018 | 64940 | 9.44 | 6130.63 | | 6130.63 | 8390.20 | 5264.11 | 7469.58 | 5457.95 | 10533.57 | 4913.99 |
| 2019 | 64940 | 9.52 | 6179.46 | | 6179.46 | 8795.29 | 5205.92 | 7717.29 | 5422.07 | 11360.68 | 4818.04 |
| 2020 | 64940 | 9.57 | 6214.33 | | 6214.33 | 9198.73 | 5136.52 | 7954.87 | 5374.02 | 12224.53 | 4713.08 |
| 2021 | 64940 | 9.58 | 6221.30 | | 6221.30 | 9577.41 | 5045.26 | 8162.89 | 5302.46 | 13094.92 | 4589.69 |
| 2022 | 64940 | 9.62 | 6249.20 | | 6249.20 | 10005.17 | 4972.26 | 8404.48 | 5249.41 | 14074.40 | 4484.54 |
| 2023 | 64940 | 9.64 | 6263.15 | | 6263.15 | 10428.61 | 4889.34 | 8633.82 | 5185.25 | 15093.22 | 4371.97 |
| 2024 | 64940 | 9.71 | 6305.00 | | 6305.00 | 10918.22 | 4829.14 | 8908.80 | 5144.61 | 16257.65 | 4281.15 |
| 2025 | 64940 | 9.87 | 6409.62 | | 6409.62 | 11543.36 | 4816.64 | 9283.04 | 5154.54 | 17684.34 | 4233.49 |
| 2026 | 64940 | 10.00 | 6493.31 | | 6493.31 | 12161.85 | 4787.47 | 9639.36 | 5146.53 | 19169.32 | 4171.80 |
| 2027 | 64940 | 10.10 | 6556.08 | | 6556.08 | 12770.60 | 4742.55 | 9975.86 | 5121.34 | 20709.45 | 4097.25 |
| 2028 | 64940 | 10.22 | 6639.78 | | 6639.78 | 13450.97 | 4712.46 | 10355.79 | 5111.91 | 22442.00 | 4036.39 |
| 2029 | 64940 | 10.32 | 6702.55 | | 6702.55 | 14121.26 | 4667.26 | 10715.03 | 5085.81 | 24239.95 | 3963.43 |
| | | | | Total Cost Over 20 yrs: | $171,335 | 204535.55 | 122417.17 | 177659.22 | 126764.93 | 276059.96 | 114806.75 |

| Energy Costs to Heat Pool: 20 kW | | | | 20 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy Offset | Nat'l Gas Price | Cost to Heat the | Nominal | | Good Economy | | Poor Economy | |
| Year | (kWh/yr) | 2010$/million btu | Pool (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 11008 | 7.740 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 |
| 2011 | 39629 | 9.69 | 3838.78 | 3992.33 | 3766.35 | 3934.75 | 3783.42 | 4107.50 | 3734.09 |
| 2012 | 74855 | 10.37 | 7762.13 | 8395.52 | 7471.99 | 8155.09 | 7539.84 | 8886.87 | 7344.52 |
| 2013 | 78597 | 10.28 | 8077.93 | 9086.58 | 7629.27 | 8699.05 | 7733.43 | 9895.82 | 7434.87 |
| 2014 | 82527 | 10.20 | 8415.15 | 9844.54 | 7797.79 | 9288.75 | 7940.06 | 11030.55 | 7534.01 |
| 2015 | 86654 | 10.46 | 9063.55 | 11027.20 | 8240.16 | 10254.58 | 8428.51 | 12712.10 | 7893.21 |
| 2016 | 90986 | 10.57 | 9619.23 | 12171.39 | 8580.35 | 11155.35 | 8816.24 | 14435.87 | 8148.67 |
| 2017 | 90986 | 10.56 | 9610.22 | 12646.39 | 8410.57 | 11423.53 | 8680.94 | 15431.91 | 7919.01 |
| 2018 | 90986 | 10.63 | 9667.81 | 13231.07 | 8301.34 | 11779.29 | 8607.01 | 16611.10 | 7749.20 |
| 2019 | 90986 | 10.71 | 9742.05 | 13865.98 | 8207.25 | 12166.49 | 8548.01 | 17910.36 | 7595.74 |
| 2020 | 90986 | 10.87 | 9891.21 | 14641.41 | 8175.69 | 12661.59 | 8553.71 | 19457.51 | 7501.71 |
| 2021 | 90986 | 11.01 | 10017.14 | 15420.92 | 8123.55 | 13143.35 | 8537.67 | 21084.59 | 7390.02 |
| 2022 | 90986 | 11.30 | 10282.86 | 16463.19 | 8181.70 | 13829.30 | 8637.74 | 23158.97 | 7379.16 |
| 2023 | 90986 | 11.38 | 10352.45 | 17237.58 | 8081.65 | 14270.96 | 8570.77 | 24947.79 | 7226.49 |
| 2024 | 90986 | 11.30 | 10282.22 | 17805.49 | 7875.38 | 14528.51 | 8389.85 | 26513.07 | 6981.72 |
| 2025 | 90986 | 11.38 | 10357.98 | 18654.15 | 7783.72 | 15001.45 | 8329.77 | 28578.01 | 6841.35 |
| 2026 | 90986 | 11.60 | 10554.06 | 19767.56 | 7781.43 | 15667.56 | 8365.04 | 31157.32 | 6780.74 |
| 2027 | 90986 | 11.82 | 10758.49 | 20956.48 | 7782.49 | 16370.32 | 8404.08 | 33984.09 | 6723.57 |
| 2028 | 90986 | 12.19 | 11087.55 | 22461.35 | 7869.19 | 17292.80 | 8536.21 | 37475.18 | 6740.24 |
| 2029 | 90986 | 12.54 | 11405.80 | 24030.29 | 11405.80 | 18233.88 | 11405.80 | 41249.38 | 11405.80 |
| | | Total Savings Over 20 yrs: | $181,639 | 282551.42 | 152317.69 | 238708.63 | 158660.14 | 399479.98 | 141176.14 |

| Energy Costs to Heat Pool: 40 kW | | | | 40 kW | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Energy Offset | Nat'l Gas Price | Cost to Heat the | Nominal | | Good Economy | | Poor Economy | |
| Year | (Btu/hr) | 2010$/million btu | Pool (2010$/yr) | Future | Present | Future | Present | Future | Present |
| 2010 | 11008 | 7.74 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 | 852.02 |
| 2011 | 39629 | 9.69 | 3838.78 | 3992.33 | 3766.35 | 3934.75 | 3783.42 | 4107.50 | 3734.09 |
| 2012 | 74855 | 10.37 | 7762.13 | 8395.52 | 7471.99 | 8155.09 | 7539.84 | 8886.87 | 7344.52 |
| 2013 | 78597 | 10.28 | 8077.93 | 9086.58 | 7629.27 | 8699.05 | 7733.43 | 9895.82 | 7434.87 |
| 2014 | 82527 | 10.20 | 8415.15 | 9844.54 | 7797.79 | 9288.75 | 7940.06 | 11030.55 | 7534.01 |
| 2015 | 86654 | 10.46 | 9063.55 | 11027.20 | 8240.16 | 10254.58 | 8428.51 | 12712.10 | 7893.21 |
| 2016 | 90986 | 10.57 | 9619.23 | 12171.39 | 8580.35 | 11155.35 | 8816.24 | 14435.87 | 8148.67 |
| 2017 | 95536 | 10.56 | 10090.80 | 13278.81 | 8831.17 | 11994.79 | 9115.06 | 16203.63 | 8315.02 |
| 2018 | 100313 | 10.63 | 10658.86 | 14587.39 | 9152.31 | 12986.79 | 9489.32 | 18313.91 | 8543.58 |
| 2019 | 105328 | 10.71 | 11277.68 | 16051.65 | 9500.95 | 14084.27 | 9895.42 | 20733.55 | 8793.05 |
| 2020 | 110594 | 10.87 | 12022.82 | 17796.72 | 9937.59 | 15390.23 | 10397.09 | 23650.71 | 9118.37 |
| 2021 | 116124 | 11.01 | 12784.71 | 19681.48 | 10367.96 | 16774.65 | 10896.49 | 26909.93 | 9431.77 |
| 2022 | 121931 | 11.30 | 13780.13 | 22062.44 | 10964.36 | 18532.75 | 11575.50 | 31035.50 | 9888.87 |
| 2023 | 128027 | 11.38 | 14566.99 | 24255.12 | 11371.74 | 20080.76 | 12059.99 | 35104.20 | 10168.44 |
| 2024 | 134428 | 11.30 | 15191.56 | 26306.86 | 11635.55 | 21465.27 | 12395.66 | 39171.94 | 10315.20 |
| 2025 | 141150 | 11.38 | 16068.73 | 28938.88 | 12075.18 | 23272.31 | 12922.29 | 44334.14 | 10613.24 |
| 2026 | 148207 | 11.60 | 17191.50 | 32199.36 | 12675.16 | 25520.88 | 13625.81 | 50752.12 | 11045.14 |
| 2027 | 155618 | 11.82 | 18400.80 | 35842.93 | 13310.79 | 27998.99 | 14373.93 | 58124.73 | 11499.67 |
| 2028 | 163399 | 12.19 | 19911.80 | 40337.65 | 14132.05 | 31055.61 | 15329.92 | 67300.53 | 12104.59 |
| 2029 | 171568 | 12.54 | 21507.37 | 45312.79 | 14976.47 | 34382.76 | 16319.52 | 77782.00 | 12717.98 |
| | | Total Savings Over 20 yrs: | $241,083 | 392021.64 | 193269.19 | 325879.68 | 203489.52 | 571337.60 | 175496.30 |

# Envelope Appendix

Completed by: Envelope Team
Kyle Harvey, Jim VanLeeuwen, Jacob Speelman, Mitch Brummel, and Tyler Van Dongen

# Table of Contents

# 1. Introduction

## 1.1 Purpose of Envelope

The two main purposes of the envelope are to provide security for the data center and provide a smaller space for the HVAC system to cool. The data center must be secure because of the confidential information that is stored on the servers. The envelope also provides security by preventing the servers from damage or excessive amounts of dust from the surroundings.

## 1.2 Goals of Envelope Improvements

### 1.2.1. Initial Goal

The initial goal of the envelope was to remove any amount of heat so that HVAC system did not have to. This removal of heat by the envelope would decrease the amount of energy needed to cool the data center and contribute to the increased efficiency of the new data center.

### 1.2.2. Revised Goal

When the HVAC Team made the decision for the HVAC design to use the heat generated by the data center to heat the pool, the envelope removing heat no longer contributed to the increased efficiency of the data center, but decreased it. The new goal was to remove heat only in case of HVAC Emergency where the room was over heating because of other failures.

# 2. Existing data center

## 2.1 Size

The data center which is currently being used by Calvin College is located in the basement of the library behind Calvin Information Technology (CIT). It consists of a single door which first leads into a small control room, immediately to the left of the control room is the actual data center which houses the four towers of servers. Access to this room is provided by a keycard. The entire server room is about 15 feet wide by 25 feet long, with a floor to ceiling height of about 8 feet. A tour provided by Mr. Sam Anema revealed the need for a new space to be defined for the new technology that the campus requires.

## 2.2 Existing envelope

A false floor is implemented in the current data center to encourage bottom-up cooling of the towers. This floor sits about 12 inches off of the concrete slab underneath. All the wiring for the towers is run above the drop ceiling, in order to keep them out of the way of maintenance personnel, while still allowing them to be accessible. The existing data center is enclosed by three external walls, and a single interior wall. The external walls are made of brick while the interior walls consist of gypsum board on metal studs. The current data center has had problems with emergency cooling in the past. When the HVAC system failed to cool the room, the first responders needed to put a stack of portable fans in the doorway to try to remove the heat.

Since there was only one door, no cross-ventilation could be used to remove the heat. The design in the new data center should address the issue of removing heat in case of HVAC failure.

# 3. New data center baseline design

## 3.1 Location

The location of the new data center will be built directly under weight room on the south east end of the Spoelhof Fieldhouse Complex. Figure 1 shows area of the field house where the new data center will be located.

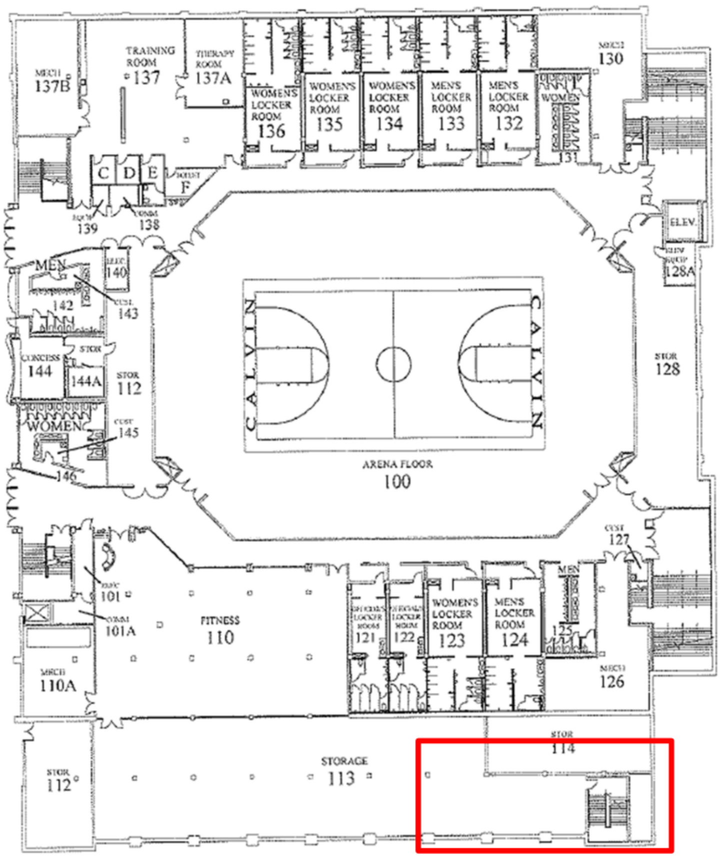



Figure 1. Location in Spoelhof Fieldhouse Complex

Below, **Error! Reference source not found.** shows a picture of the location that will be closed off for the new data center.

Figure 2. New data center location

## 3.2 Size

The proposed size of the room is approximately 45 ft long, 13 ft wide and 12 ft high. The initial blueprints, provided by CIT, of the room can be seen below in figure 2. The proposed envelope design is shown in Figure 3.

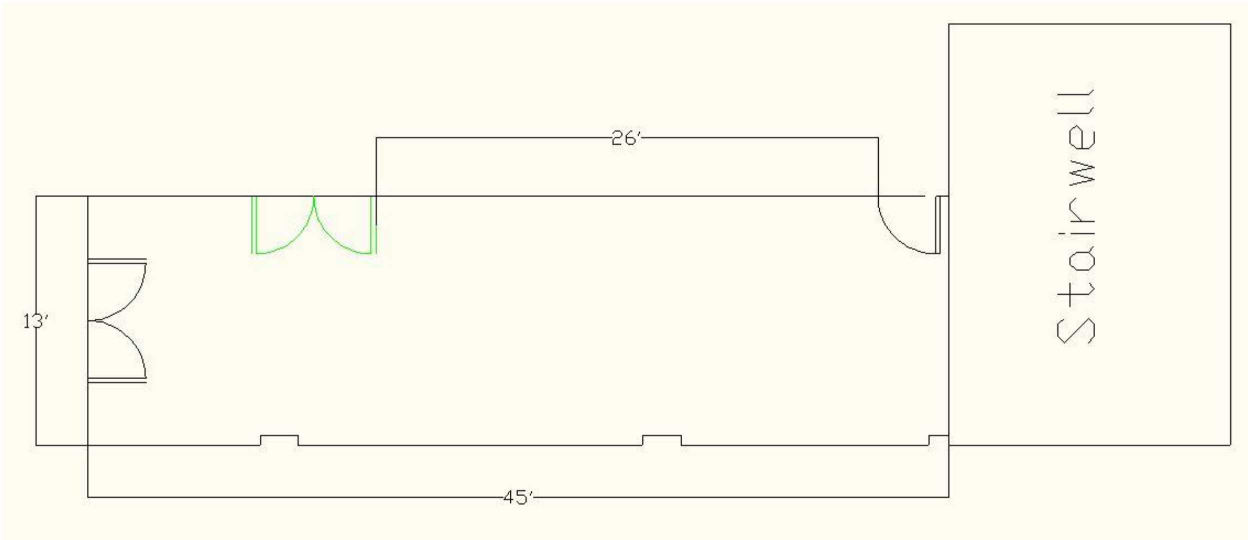



Figure 3. Proposed envelope design

The base line design includes only one single door, which is in the top right. The improved design includes the addition of one of the sets of double doors on the left. The decision of which set of double doors to implement is left to CIT depending on where they would like to place equipment.

## 3.3 Drywall Design

The design of this room incorporates the use of both the exterior brick wall and the “one-hour” fire wall which consists of steel reinforced concrete. In addition to these two walls, two more walls will be placed on opposite sides completely the rectangular geometry of the room. The materials used for these walls will be gypsum board and wood framing. This design also incorporates the use of only one single door. The use of gypsum board will be implemented because of the fire retardant properties the material has. Calculations were made for the heat transfers of the room with these conditions. As expected, the relationship between the inside temperature and heat transfer is directly proportional. This can be seen below in Figure 4.

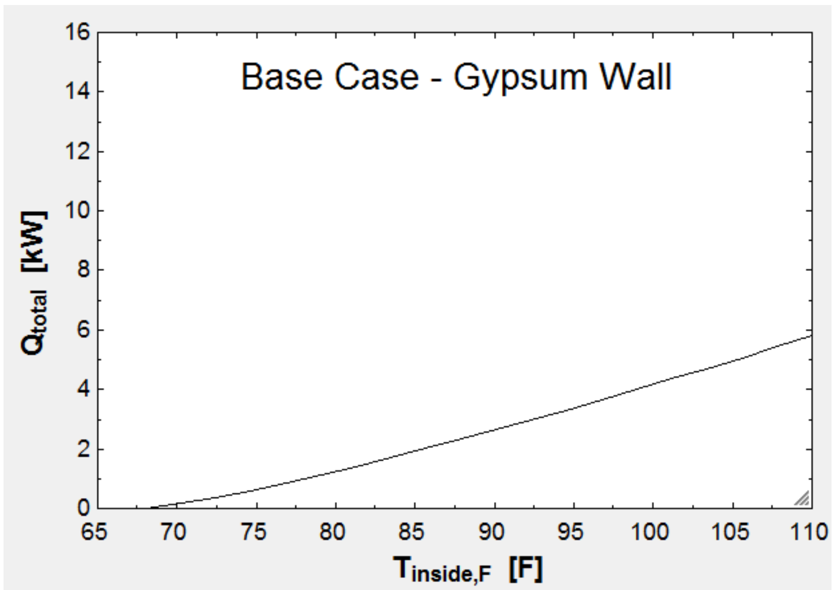



Figure 4. Heat transfer through gypsum wall

# 4. Energy efficiency design improvements

## 4.1 Additional Envelope Design Options

### 4.1.1. Chain Link Fence

Alternative options for the envelope of the new data center include a chain link fence to serve as a barrier to people alone. The chain link fence would allow for maximum heat transfer in case of an emergency, but raises many concerns. The chain link fence does not provide a barrier to smaller creatures or dust particles in the air. Chain link does not offer the best security because it can be easily cut to give access to the data center. Also, the possibility exists for a hitting net to be installed for the Calvin golf team near the new data center. The chain link would not protect the servers from a stray golf ball.

### 4.1.2. Corrugated Metal Wall

The recommended data center envelope design utilizes interior walls of corrugated aluminum. At times when the HVAC system works properly, the temperature of the data center and the temperature of the field house basement would be very similar. Therefore, no significant heat transfer would be expected through the interior walls. However, at times when the HVAC system works poorly, the temperature in the data center would rise and an elevated rate of heat transfer through the interior walls would be desirable. Aluminum has a much higher thermal conductivity than gypsum. Using a corrugated wall design would also increase the surface area for heat transfer. Considering only natural convection, the rate of heat transfer through the interior walls would be expected to be slightly higher for the aluminum wall than for the gypsum wall, as shown in the figure below.

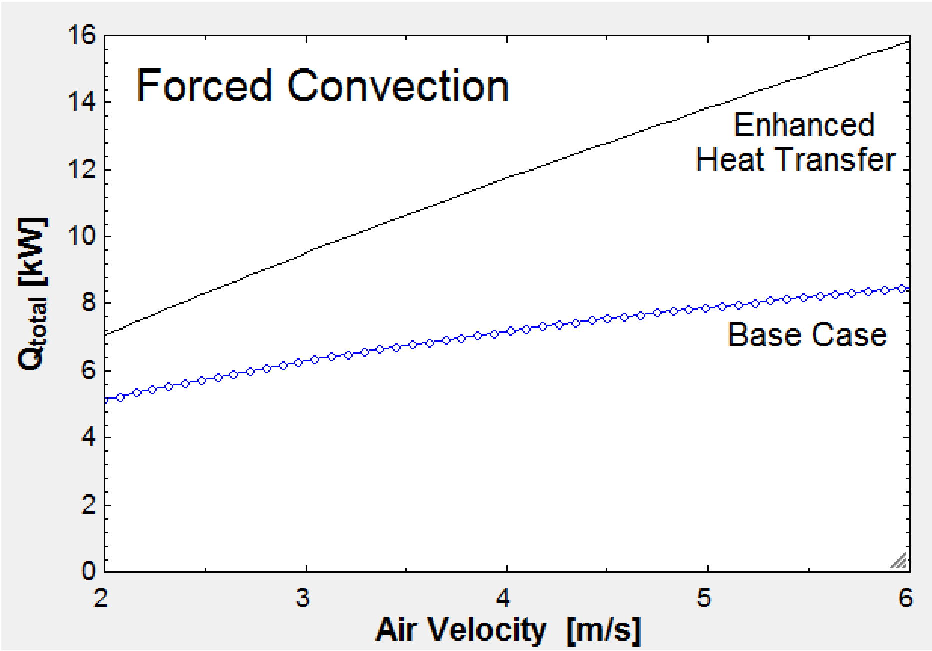


Figure 5. Heat transfer with forced convection

The difference between the two alternatives is only slight because the limiting factor for heat transfer in this case is convection and not conduction. However, the difference would become much greater if fans were used to produce forced convection over the walls. This is shown in the figure below.

As the speed of the air being forced over the walls increases, the heat transfer expected for the aluminum wall and for the base case gypsum wall become increasingly divergent.

## 4.2 Cost

The costs were estimated for base case, gypsum wall design, and the improved case, corrugated metal wall design. The cost of the two designs consists of the cost of labor, the cost of materials, and the cost of doors. Table 1. Cost comparison compares the cost of each design.

Table 1. Cost comparison

| Base Case | | Improved Case | |
|---|---|---|---|
| Gypsum Wall[1] | $600.00 | Aluminum Wall[2] | $1,693.00 |
| 1 Door | $155.00 | 3 Doors | $465.00 |
| Labor[3] | $1,000.00 | Labor | $1,000.00 |
| $1,755.00 | | $3,158.00 | |

## 5. Conclusions

The Envelope Team recommends the corrugated metal wall design. The improved design achieves the purpose of providing security for the data center and providing a smaller space for the HVAC system to cool. The corrugated metal wall design also achieves the revised goal of the envelope improvements, which is to remove heat from the data center only in case of HVAC Emergency where the room was overheating. The envelope design does not include any CERF recommendations.

## 6. Supporting Calculations

[1] Estimate by Brian Harvey, Harvey Building

[2] http://www.lowes.com/pd_12475-28906-4736008000_4294858153_4294937087?productId=3050351&Ns=p_product_quantity_sold|0&pl=1&currentURL=/pl_Roof%2BPanels_4294858153_4294937087_?Ns=p_product_quantity_sold|0

[3] See 1

```
"Tyler VanDongen"
"Revised by Jacob Speelman"

"Heat Transfer Calculations"
"4/1/2010"

"OutsideWall-Concrete, Firewall-Reinforcred Concrete, Drywall-Gypsum Board"

"Temperatures"
"Temperatures"
T_inside_F=90[F]
T_outside_F=68[F]

T_inside=converttemp(F,K,T_inside_F)
T_outside=converttemp(F,K,T_outside_F)
T_dirt=converttemp(F,K,60)
DELTAT=T_inside-T_outside

"Thermal Conductivities"
k_concrete=1.7[W/m-K]
k_reinforced=2.0[W/m-K]
k_gypsum=0.17[W/m-K]
k_dirt=1.0[W/m-K]
k_aluminum=k_('Aluminum', 300[K])

"Dimensions of the Room"
thickness_concrete=6*convert(in,m)
thickness_reinforced=6*convert(in,m)
thickness_gypsum=0.375*convert(in,m)
thickness_dirt=36*convert(in,m)
thickness_aluminum=0.0025[m]

L=45*convert(ft,m)
W=13*convert(ft,m)
H=12*convert(ft,m)

W_concrete=L
W_reinforced=W
W_aluminum=L+W
W_dirt=L

"Costing Information"
Doors=155[$]*3
Price_Gypsum=200[$]
Studs=200[$]
Accesories=100[$]
Labor=800[$]
Contigency=300[$]

Total_costs=Doors+Price_Gypsum+Studs+Accesories+Labor+Contigency

"Area Calculations"
A_dirt_wall=H*W
A_dirt_floor=L*W
A_concrete=L*W
A_reinforced=H*W
A_aluminum=((H*W)+(L*H))*CorrugationFactor
```

```
CorrugationFactor=1.047
A_gypsum=((H*W)+(L*H))

"Convection Calculations"
Gr=(H^3*g*rho^2*BETA*DELTAT)/mu^2
g=9.81[m/s^2]
rho=Density(Air,T=T_inside,P=101[kPa])
mu=Viscosity(Air,T=T_inside)
BETA=1/(T_inside)

Pr=Prandtl(Air,T=T_inside)
Nusselt_0=0.67
sqrt(Nusselt)=sqrt(Nusselt_0)+(((Gr*Pr)/300)/(1+(0.5/Pr)^(9/16))^(16/9))^(1/6)
Nusselt=(h_conv*H)/k_air
k_air=Conductivity(Air,T=T_inside)

"Resistance Calculations"
R_dirt_wall_cond=(thickness_dirt/(k_dirt*A_dirt_wall))
R_dirt_floor=(thickness_dirt/(k_dirt*A_dirt_floor))
R_concrete_cond=(thickness_concrete/(k_concrete*A_concrete))
R_reinforced_cond=(thickness_reinforced/(k_reinforced*A_reinforced))
R_gypsum_cond=(thickness_gypsum/(k_gypsum*A_gypsum))

R_dirt_wall_conv=(1/(h_conv*A_dirt_wall))
R_concrete_conv=(1/(h_conv*A_concrete))
R_reinforced_conv=(1/(h_conv*A_reinforced))
R_gypsum_conv=(1/(h_conv*A_gypsum))

R_dirt_wall=R_dirt_wall_cond+R_dirt_wall_conv
R_concrete=R_concrete_cond+R_concrete_conv
R_reinforced=R_reinforced_cond+R_reinforced_conv
R_gypsum=R_gypsum_cond+R_gypsum_conv

"Heat Transfer Calculations"
Q_outsidewall=((T_inside-T_dirt)/(R_reinforced+R_dirt_wall))*convert(W,kW)
Q_firewall=((T_inside-T_outside)/R_reinforced)*convert(W,kW)
Q_gypsum=((T_inside-T_outside)/R_gypsum)*convert(W,kW)
Q_floor=((T_inside-T_dirt)/(R_concrete+R_dirt_wall))*convert(W,kW)

Q_total=Q_outsidewall+Q_firewall+Q_gypsum
{Q_total=40[kW]}

"Heat Transfer Percentages"
Q_outsidewall_percentage=(Q_outsidewall/Q_total)*100
Q_firewall_percentage=(Q_firewall/Q_total)*100
Q_gypsum_percentage=(Q_gypsum/Q_total)*100
Q_floor_percentage=(Q_floor/Q_total)*100

"Total"
Total_power=Q_total*365[hr]


"How Much Additional Power can the Entire Basement Dissipate per 1[K] increase in Total Basement Temperature"
T_Basement_1=T_outside
```

DELTAT_Basement=10[K]
T_Basement_2=T_Basement_1+DELTAT_Basement

R_Basement_Total=R_Basement_Concrete_walls+R_Basement_DirtWall_walls+R_Basement_Concrete_floor
+R_Basement_DirtWall_floor
R_Basement_Concrete_walls=thickness_reinforced/(k_reinforced*A_Basement_walls)
R_Basement_Concrete_floor=thickness_concrete/(k_concrete*A_Basement_floor)
R_Basement_DirtWall_walls=thickness_dirt/(k_dirt*A_Basement_walls)
R_Basement_DirtWall_floor=thickness_dirt/(k_dirt*A_Basement_floor)

A_Basement_walls=((96[ft]+25[ft]+84[ft]+13[ft]+12[ft]+12[ft])*12[ft])*0.0929[m^2/ft^2]
A_Basement_floor=((12[ft]*84[ft])+(12[ft]*96[ft]))*0.0929[m^2/ft^2]

DELTAQ_Basement_Total=Q_Basement_Total_2-Q_Basement_Total_1
Q_Basement_Total_1=(T_Basement_1-T_dirt)/(R_reinforced+R_dirt_wall)*convert(W,kW)
Q_Basement_Total_2=(T_Basement_2-T_dirt)/(R_reinforced+R_dirt_wall)*convert(W,kW)

SOLUTION

**Unit Settings: [kJ]/[K]/[kPa]/[kg]/[degrees]**

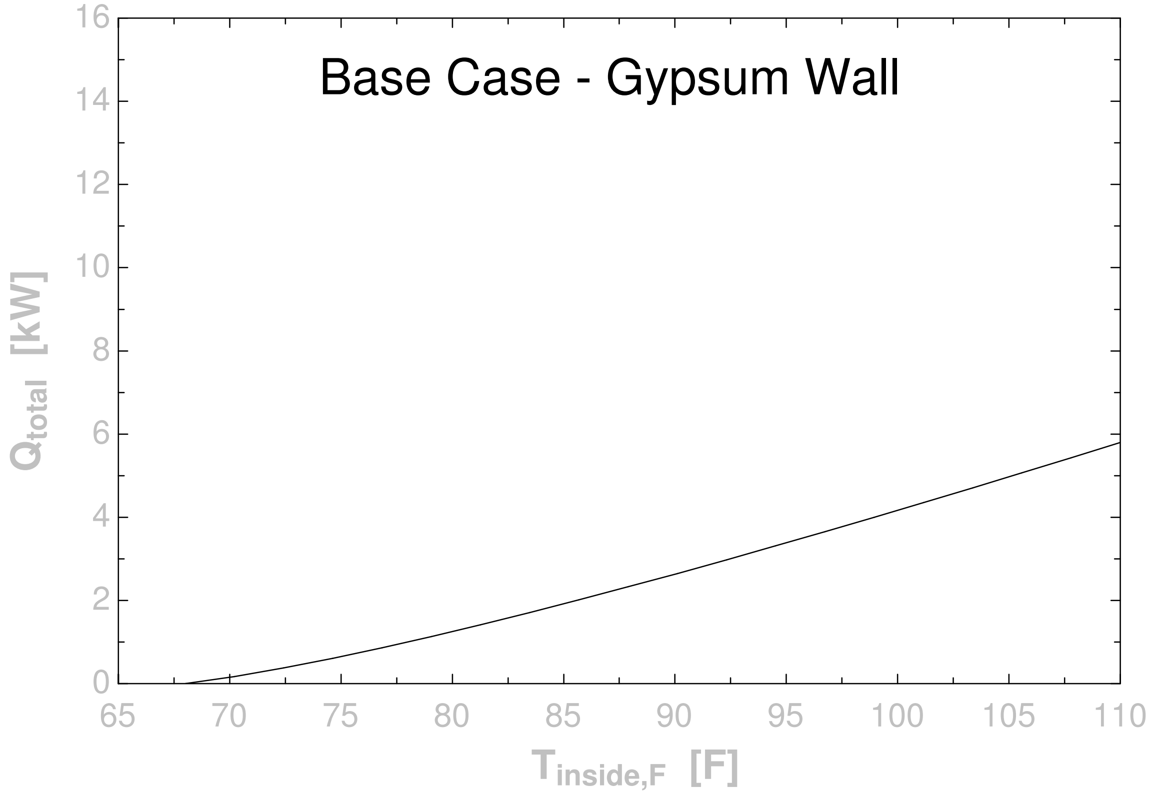
Accesories = 100 [$]
$A_{aluminum}$ = 67.7 [$m^2$]
$A_{Basement,floor}$ = 200.7 [$m^2$]
$A_{Basement,walls}$ = 269.8 [$m^2$]
$A_{concrete}$ = 54.35 [$m^2$]
$A_{dirt,floor}$ = 54.35 [$m^2$]
$A_{dirt,wall}$ = 14.49 [$m^2$]
$A_{gypsum}$ = 64.66 [$m^2$]
$A_{reinforced}$ = 14.49 [$m^2$]
$\beta$ = 0.003275 [1/K]
Contigency = 300 [$]
CorrugationFactor = 1.047
$\Delta Q_{Basement,Total}$ = 0.08785 [kW]
$\Delta T$ = 12.22 [K]
$\Delta T_{Basement}$ = 10 [K]
Doors = 465 [$]
g = 9.81 [$m/s^2$]
Gr = 7.200E+10
H = 3.658 [m]
$h_{conv}$ = 3.034 [$W/m^2$-K]
$k_{air}$ = 0.02605 [W/m-K]
$k_{aluminum}$ = 236 [W/m-K]
$k_{concrete}$ = 1.7 [W/m-K]
$k_{dirt}$ = 1 [W/m-K]
$k_{gypsum}$ = 0.17 [W/m-K]
$k_{reinforced}$ = 2 [W/m-K]
L = 13.72 [m]
Labor = 800 [$]
$\mu$ = 0.00001882 [kg/m-s]
Nusselt = 426.1
$Nusselt_0$ = 0.67
Pr = 0.7263
$Price_{Gypsum}$ = 200 [$]
$Q_{Basement,Total,1}$ = 0.03904 [kW]
$Q_{Basement,Total,2}$ = 0.1269 [kW]
$Q_{firewall}$ = 0.4365 [kW]
$Q_{firewall,percentage}$ = 16.58
$Q_{floor}$ = 0.1782 [kW]
$Q_{floor,percentage}$ = 6.768
$Q_{gypsum}$ = 2.049 [kW]
$Q_{gypsum,percentage}$ = 77.86
$Q_{outsidewall}$ = 0.1464 [kW]
$Q_{outsidewall,percentage}$ = 5.562
$Q_{total}$ = 2.632 [kW]
$\rho$ = 1.152 [$kg/m^3$]
$R_{Basement,Concrete,floor}$ = 0.0004468 [K/W]
$R_{Basement,Concrete,walls}$ = 0.0002825 [K/W]
$R_{Basement,DirtWall,floor}$ = 0.004557 [K/W]
$R_{Basement,DirtWall,walls}$ = 0.003389 [K/W]
$R_{Basement,Total}$ = 0.008675 [K/W]
$R_{concrete}$ = 0.007714 [K/W]
$R_{concrete,cond}$ = 0.001649 [K/W]
$R_{concrete,conv}$ = 0.006065 [K/W]
$R_{dirt,floor}$ = 0.01682 [K/W]
$R_{dirt,wall}$ = 0.08584 [K/W]
$R_{dirt,wall,cond}$ = 0.06309 [K/W]
$R_{dirt,wall,conv}$ = 0.02274 [K/W]
$R_{gypsum}$ = 0.005964 [K/W]
$R_{gypsum,cond}$ = 0.0008665 [K/W]
$R_{gypsum,conv}$ = 0.005097 [K/W]
$R_{reinforced}$ = 0.028 [K/W]
$R_{reinforced,cond}$ = 0.005258 [K/W]
$R_{reinforced,conv}$ = 0.02274 [K/W]
Studs = 200 [$]
$thickness_{aluminum}$ = 0.0025 [m]
$thickness_{concrete}$ = 0.1524 [m]
$thickness_{dirt}$ = 0.9144 [m]
$thickness_{gypsum}$ = 0.009525 [m]
$thickness_{reinforced}$ = 0.1524 [m]
$Total_{costs}$ = 2065 [$]
$Total_{power}$ = 960.8 [kW*hr]
$T_{Basement,1}$ = 293.2 [K]

$T_{Basement,2}$ = 303.2 [K]
$T_{inside}$ = 305.4 [K]
$T_{outside}$ = 293.2 [K]
W = 3.962 [m]
$W_{concrete}$ = 13.72 [m]
$W_{reinforced}$ = 3.962 [m]
$T_{dirt}$ = 288.7 [K]
$T_{inside,F}$ = 90 [F]
$T_{outside,F}$ = 68 [F]
$W_{aluminum}$ = 17.68 [m]
$W_{dirt}$ = 13.72 [m]

No unit problems were detected.

**Parametric Table: Table 2**

| | $T_{inside,F}$ [F] | $Q_{total}$ [kW] |
|---|---|---|
| Run 1 | 68 | 0.000148 |
| Run 2 | 70.21 | 0.1688 |
| Run 3 | 72.42 | 0.3733 |
| Run 4 | 74.63 | 0.6064 |
| Run 5 | 76.84 | 0.86 |
| Run 6 | 79.05 | 1.13 |
| Run 7 | 81.26 | 1.413 |
| Run 8 | 83.47 | 1.708 |
| Run 9 | 85.68 | 2.013 |
| Run 10 | 87.89 | 2.326 |
| Run 11 | 90.11 | 2.648 |
| Run 12 | 92.32 | 2.976 |
| Run 13 | 94.53 | 3.311 |
| Run 14 | 96.74 | 3.652 |
| Run 15 | 98.95 | 3.999 |
| Run 16 | 101.2 | 4.35 |
| Run 17 | 103.4 | 4.707 |
| Run 18 | 105.6 | 5.067 |
| Run 19 | 107.8 | 5.432 |
| Run 20 | 110 | 5.8 |


Base Case - Gypsum Wall
16
14
12
10
8
6
4
2
0
Qtotal [kW]
65
70
75
80
85
90
95
100
105
110
Tinside,F [F]

```
"Tyler VanDongen"
"Revised by Jacob Speelman"

"Heat Transfer Calculations"
"4/1/2010"

"OutsideWall-Concrete, Firewall-Reinforcred Concrete, Drywall-Gypsum Board"

"Temperatures"
T_inside_F=90[F]
T_outside_F=68[F]

T_inside=converttemp(F,K,T_inside_F)
T_outside=converttemp(F,K,T_outside_F)
T_dirt=converttemp(F,K,60)
DELTAT=T_inside-T_outside

"Thermal Conductivities"
k_concrete=1.7[W/m-K]
k_reinforced=2.0[W/m-K]
k_gypsum=0.17[W/m-K]
k_dirt=1.0[W/m-K]
k_aluminum=k_('Aluminum', 300[K])

"Costing Information"
Doors=155[$]
Price_Panels=44.57[$]
Studs=200[$]
Accesories=100[$]
Labor=800[$]
Contigency=300[$]

Num_Panels_needed=29
Panels=Price_Panels*Num_Panels_needed

Total_costs=Doors+Panels+Studs+Accesories+Labor+Contigency

"Dimensions of the Room"
thickness_concrete=6*convert(in,m)
thickness_reinforced=6*convert(in,m)
thickness_gypsum=0.375*convert(in,m)
thickness_dirt=36*convert(in,m)
thickness_aluminum=0.0025[m]

L=45*convert(ft,m)
W=13*convert(ft,m)
H=12*convert(ft,m)

W_concrete=L
W_reinforced=W
W_aluminum=L+W
W_dirt=L

"Area Calculations"
A_dirt_wall=H*W
A_dirt_floor=L*W
A_concrete=L*W
```

```
A_reinforced=H*W
A_aluminum=((H*W)+(L*H))*CorrugationFactor
CorrugationFactor=1.047
A_gypsum=((H*W)+(L*H))

"Natural Convection Calculations"
Gr=(H^3*g*rho^2*BETA*DELTAT)/mu^2
g=9.81[m/s^2]
rho=Density(Air,T=T_inside,P=101[kPa])
mu=Viscosity(Air,T=T_inside)
BETA=1/(T_inside)

Pr=Prandtl(Air,T=T_inside)
Nusselt_0=0.67
sqrt(Nusselt)=sqrt(Nusselt_0)+(((Gr*Pr)/300)/(1+(0.5/Pr)^(9/16))^(16/9))^(1/6)
Nusselt=(h_conv*H)/k_air
k_air=Conductivity(Air,T=T_inside)

"Forced Convection Calculations"
{Nusselt_L_turb=(0.037*(Re_L^0.8)*Pr)/(1+2.443*(Re_L^(-0.1))*(Pr^(2/3)-1))
Re_L=(rho*u*H)/mu
Pr=Prandtl(Air,T=T_inside)
rho=Density(Air,T=T_inside,P=101[kPa])
mu=Viscosity(Air,T=T_inside)

{u=7[m/s]}

Nusselt_L_turb=(h_conv*H)/k_air
k_air=Conductivity(Air,T=T_inside)}

"Resistance Calculations"
R_dirt_wall_cond=(thickness_dirt/(k_dirt*A_dirt_wall))
R_dirt_floor=(thickness_dirt/(k_dirt*A_dirt_floor))
R_concrete_cond=(thickness_concrete/(k_concrete*A_concrete))
R_reinforced_cond=(thickness_reinforced/(k_reinforced*A_reinforced))
R_aluminum_cond=(thickness_aluminum/(k_aluminum*A_aluminum))
R_gypsum_cond=(thickness_gypsum/(k_gypsum*A_gypsum))

R_concrete_conv=(1/(h_conv*A_concrete))
R_reinforced_conv=(1/(h_conv*A_reinforced))
R_aluminum_conv=(1/(h_conv*A_aluminum))
R_gypsum_conv=(1/(h_conv*A_gypsum))

R_dirt_wall=R_dirt_wall_cond
R_concrete=R_concrete_cond+R_concrete_conv
R_reinforced=R_reinforced_cond+R_reinforced_conv
R_aluminum=R_aluminum_cond+R_aluminum_conv
R_gypsum=R_gypsum_cond+R_gypsum_conv

"Heat Transfer Calculations"
Q_outsidewall=((T_inside-T_dirt)/(R_reinforced+R_dirt_wall))*convert(W,kW)
Q_firewall=((T_inside-T_outside)/R_reinforced)*convert(W,kW)
Q_aluminum=((T_inside-T_outside)/R_aluminum)*convert(W,kW)
Q_floor=((T_inside-T_dirt)/(R_concrete+R_dirt_wall))*convert(W,kW)
Q_gypsum=((T_inside-T_outside)/R_gypsum)*convert(W,kW)
```

Q_total_aluminum=Q_outsidewall+Q_firewall+Q_aluminum
Q_total_gypsum=Q_outsidewall+Q_firewall+Q_gypsum
*{Q_total=40[kW]}*

*"Heat Transfer Percentages"*
*{Q_outsidewall_percentage=(Q_outsidewall/Q_total)*100*
*Q_firewall_percentage=(Q_firewall/Q_total)*100*
*Q_aluminum_percentage=(Q_aluminum/Q_total)*100*
*Q_floor_percentage=(Q_floor/Q_total)*100}*

*"Total"*
*{Total_power=Q_total*365[hr]}*

*"How Much Additional Power can the Entire Basement Dissipate per 1[K] increase in Total Basement Temperature"*
T_Basement_1=T_outside
DELTAT_Basement=10[K]
T_Basement_2=T_Basement_1+DELTAT_Basement

R_Basement_Total=R_Basement_Concrete_walls+R_Basement_DirtWall_walls+R_Basement_Concrete_floor
+R_Basement_DirtWall_floor
R_Basement_Concrete_walls=thickness_reinforced/(k_reinforced*A_Basement_walls)
R_Basement_Concrete_floor=thickness_concrete/(k_concrete*A_Basement_floor)
R_Basement_DirtWall_walls=thickness_dirt/(k_dirt*A_Basement_walls)
R_Basement_DirtWall_floor=thickness_dirt/(k_dirt*A_Basement_floor)

A_Basement_walls=((96[ft]+25[ft]+84[ft]+13[ft]+12[ft]+12[ft])*12[ft])*0.0929[m^2/ft^2]
A_Basement_floor=((12[ft]*84[ft])+(12[ft]*96[ft]))*0.0929[m^2/ft^2]

DELTAQ_Basement_Total=Q_Basement_Total_2-Q_Basement_Total_1
Q_Basement_Total_1=(T_Basement_1-T_dirt)/(R_reinforced+R_dirt_wall)*convert(W,kW)
Q_Basement_Total_2=(T_Basement_2-T_dirt)/(R_reinforced+R_dirt_wall)*convert(W,kW)

SOLUTION
**Unit Settings: [kJ]/[K]/[kPa]/[kg]/[degrees]**

| | |
|---|---|
| Accesories = 100 [$] | $A_{aluminum}$ = 67.7 [m$^2$] |
| $A_{Basement,floor}$ = 200.7 [m$^2$] | $A_{Basement,walls}$ = 269.8 [m$^2$] |
| $A_{concrete}$ = 54.35 [m$^2$] | $A_{dirt,floor}$ = 54.35 [m$^2$] |
| $A_{dirt,wall}$ = 14.49 [m$^2$] | $A_{gypsum}$ = 64.66 [m$^2$] |
| $A_{reinforced}$ = 14.49 [m$^2$] | $\beta$ = 0.003275 [1/K] |
| Contigency = 300 [$] | CorrugationFactor = 1.047 |
| $\Delta Q_{Basement,Total}$ = 0.1098 [kW] | $\Delta T$ = 12.22 [K] |
| $\Delta T_{Basement}$ = 10 [K] | Doors = 155 [$] |
| g = 9.81 [m/s$^2$] | Gr = 7.200E+10 |
| H = 3.658 [m] | $h_{conv}$ = 3.034 [W/m$^2$-K] |
| $k_{air}$ = 0.02605 [W/m-K] | $k_{aluminum}$ = 236 [W/m-K] |
| $k_{concrete}$ = 1.7 [W/m-K] | $k_{dirt}$ = 1 [W/m-K] |
| $k_{gypsum}$ = 0.17 [W/m-K] | $k_{reinforced}$ = 2 [W/m-K] |
| L = 13.72 [m] | Labor = 800 [$] |
| $\mu$ = 0.00001882 [kg/m-s] | $Num_{Panels,needed}$ = 29 |
| Nusselt = 426.1 | $Nusselt_0$ = 0.67 |
| Panels = 1293 [$] | Pr = 0.7263 |
| $Price_{Panels}$ = 44.57 [$] | $Q_{aluminum}$ = 2.51 [kW] |

$Q_{Basement,Total,1}$ = 0.04879 [kW]
$Q_{firewall}$ = 0.4365 [kW]
$Q_{gypsum}$ = 2.049 [kW]
$Q_{total,aluminum}$ = 3.13 [kW]
$\rho$ = 1.152 [kg/m$^3$]
$R_{aluminum,cond}$ = 1.565E-07 [K/W]
$R_{Basement,Concrete,floor}$ = 0.0004468 [K/W]
$R_{Basement,DirtWall,floor}$ = 0.004557 [K/W]
$R_{Basement,Total}$ = 0.008675 [K/W]
$R_{concrete,cond}$ = 0.001649 [K/W]
$R_{dirt,floor}$ = 0.01682 [K/W]
$R_{dirt,wall,cond}$ = 0.06309 [K/W]
$R_{gypsum,cond}$ = 0.0008665 [K/W]
$R_{reinforced}$ = 0.028 [K/W]
$R_{reinforced,conv}$ = 0.02274 [K/W]
$thickness_{aluminum}$ = 0.0025 [m]
$thickness_{dirt}$ = 0.9144 [m]
$thickness_{reinforced}$ = 0.1524 [m]
$T_{Basement,1}$ = 293.2 [K]
$T_{dirt}$ = 288.7 [K]
$T_{inside,F}$ = 90 [F]
$T_{outside,F}$ = 68 [F]
$W_{aluminum}$ = 17.68 [m]
$W_{dirt}$ = 13.72 [m]

$Q_{Basement,Total,2}$ = 0.1586 [kW]
$Q_{floor}$ = 0.2354 [kW]
$Q_{outsidewall}$ = 0.183 [kW]
$Q_{total,gypsum}$ = 2.669 [kW]
$R_{aluminum}$ = 0.004869 [K/W]
$R_{aluminum,conv}$ = 0.004869 [K/W]
$R_{Basement,Concrete,walls}$ = 0.0002825 [K/W]
$R_{Basement,DirtWall,walls}$ = 0.003389 [K/W]
$R_{concrete}$ = 0.007714 [K/W]
$R_{concrete,conv}$ = 0.006065 [K/W]
$R_{dirt,wall}$ = 0.06309 [K/W]
$R_{gypsum}$ = 0.005964 [K/W]
$R_{gypsum,conv}$ = 0.005097 [K/W]
$R_{reinforced,cond}$ = 0.005258 [K/W]
Studs = 200 [$]
$thickness_{concrete}$ = 0.1524 [m]
$thickness_{gypsum}$ = 0.009525 [m]
$Total_{costs}$ = 2848 [$]
$T_{Basement,2}$ = 303.2 [K]
$T_{inside}$ = 305.4 [K]
$T_{outside}$ = 293.2 [K]
W = 3.962 [m]
$W_{concrete}$ = 13.72 [m]
$W_{reinforced}$ = 3.962 [m]

No unit problems were detected.

**Parametric Table: Table 3**

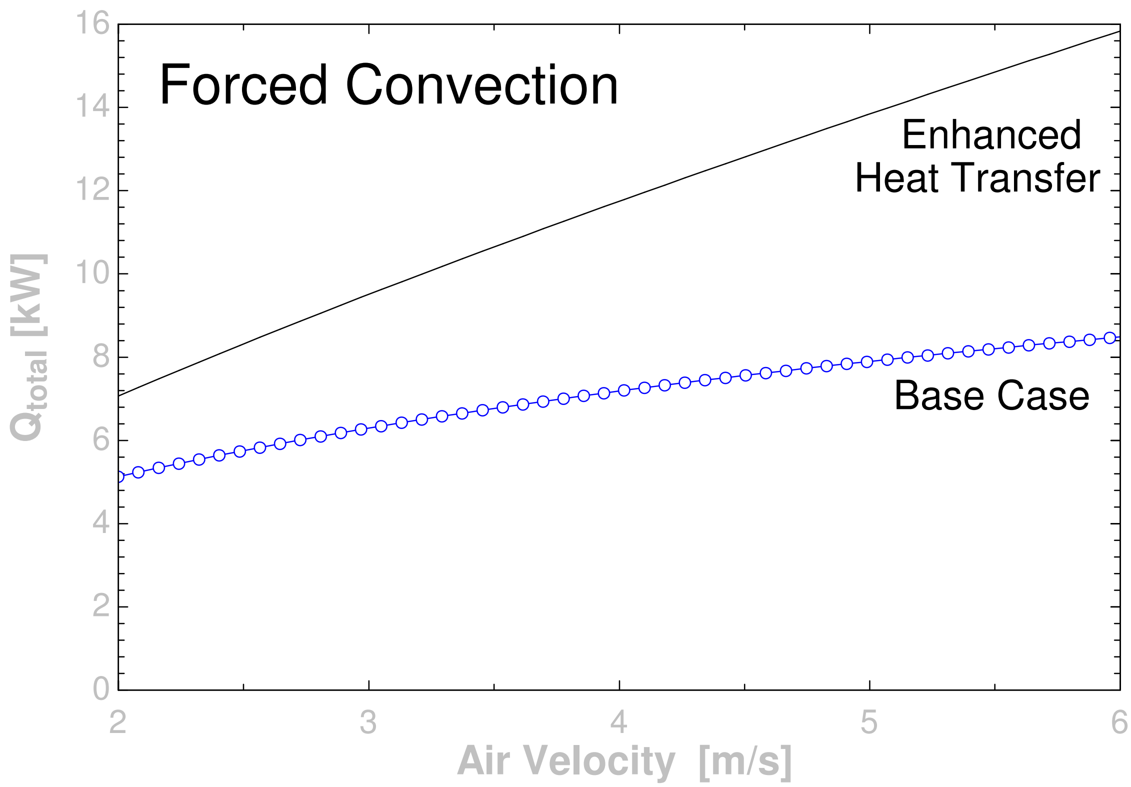
| | $Q_{total,aluminum}$ [kW] | $Q_{total,gypsum}$ [kW] | u [m/s] |
|---|---|---|---|
| Run 1 | 7.066 | 5.129 | 2 |
| Run 2 | 7.274 | 5.238 | 2.081 |
| Run 3 | 7.479 | 5.343 | 2.162 |
| Run 4 | 7.683 | 5.446 | 2.242 |
| Run 5 | 7.884 | 5.546 | 2.323 |
| Run 6 | 8.084 | 5.644 | 2.404 |
| Run 7 | 8.282 | 5.739 | 2.485 |
| Run 8 | 8.479 | 5.832 | 2.566 |
| Run 9 | 8.674 | 5.922 | 2.646 |
| Run 10 | 8.867 | 6.011 | 2.727 |
| Run 11 | 9.059 | 6.097 | 2.808 |
| Run 12 | 9.249 | 6.182 | 2.889 |
| Run 13 | 9.438 | 6.265 | 2.97 |
| Run 14 | 9.626 | 6.346 | 3.051 |
| Run 15 | 9.812 | 6.425 | 3.131 |
| Run 16 | 9.997 | 6.503 | 3.212 |
| Run 17 | 10.18 | 6.579 | 3.293 |
| Run 18 | 10.36 | 6.654 | 3.374 |
| Run 19 | 10.55 | 6.727 | 3.455 |
| Run 20 | 10.73 | 6.798 | 3.535 |
| Run 21 | 10.91 | 6.869 | 3.616 |
| Run 22 | 11.08 | 6.938 | 3.697 |
| Run 23 | 11.26 | 7.006 | 3.778 |
| Run 24 | 11.44 | 7.072 | 3.859 |

**Parametric Table: Table 3**

| | $Q_{total,aluminum}$ [kW] | $Q_{total,gypsum}$ [kW] | u [m/s] |
|---|---|---|---|
| Run 25 | 11.61 | 7.137 | 3.939 |
| Run 26 | 11.79 | 7.201 | 4.02 |
| Run 27 | 11.96 | 7.264 | 4.101 |
| Run 28 | 12.14 | 7.326 | 4.182 |
| Run 29 | 12.31 | 7.387 | 4.263 |
| Run 30 | 12.48 | 7.447 | 4.343 |
| Run 31 | 12.65 | 7.506 | 4.424 |
| Run 32 | 12.82 | 7.563 | 4.505 |
| Run 33 | 12.99 | 7.62 | 4.586 |
| Run 34 | 13.16 | 7.676 | 4.667 |
| Run 35 | 13.32 | 7.731 | 4.747 |
| Run 36 | 13.49 | 7.786 | 4.828 |
| Run 37 | 13.66 | 7.839 | 4.909 |
| Run 38 | 13.82 | 7.891 | 4.99 |
| Run 39 | 13.99 | 7.943 | 5.071 |
| Run 40 | 14.15 | 7.994 | 5.152 |
| Run 41 | 14.31 | 8.044 | 5.232 |
| Run 42 | 14.48 | 8.094 | 5.313 |
| Run 43 | 14.64 | 8.143 | 5.394 |
| Run 44 | 14.8 | 8.191 | 5.475 |
| Run 45 | 14.96 | 8.238 | 5.556 |
| Run 46 | 15.12 | 8.285 | 5.636 |
| Run 47 | 15.28 | 8.331 | 5.717 |
| Run 48 | 15.44 | 8.376 | 5.798 |
| Run 49 | 15.6 | 8.421 | 5.879 |
| Run 50 | 15.76 | 8.465 | 5.96 |
| Run 51 | 15.91 | 8.508 | 6.04 |
| Run 52 | 16.07 | 8.551 | 6.121 |
| Run 53 | 16.23 | 8.594 | 6.202 |
| Run 54 | 16.38 | 8.636 | 6.283 |
| Run 55 | 16.54 | 8.677 | 6.364 |
| Run 56 | 16.69 | 8.718 | 6.444 |
| Run 57 | 16.85 | 8.758 | 6.525 |
| Run 58 | 17 | 8.798 | 6.606 |
| Run 59 | 17.16 | 8.837 | 6.687 |
| Run 60 | 17.31 | 8.876 | 6.768 |
| Run 61 | 17.46 | 8.914 | 6.848 |
| Run 62 | 17.61 | 8.952 | 6.929 |
| Run 63 | 17.77 | 8.989 | 7.01 |
| Run 64 | 17.92 | 9.026 | 7.091 |
| Run 65 | 18.07 | 9.062 | 7.172 |
| Run 66 | 18.22 | 9.098 | 7.253 |
| Run 67 | 18.37 | 9.134 | 7.333 |
| Run 68 | 18.52 | 9.169 | 7.414 |
| Run 69 | 18.67 | 9.204 | 7.495 |
| Run 70 | 18.82 | 9.238 | 7.576 |
| Run 71 | 18.97 | 9.272 | 7.657 |
| Run 72 | 19.12 | 9.306 | 7.737 |
| Run 73 | 19.26 | 9.339 | 7.818 |
| Run 74 | 19.41 | 9.372 | 7.899 |
| Run 75 | 19.56 | 9.405 | 7.98 |
| Run 76 | 19.7 | 9.437 | 8.061 |

**Parametric Table: Table 3**

| | $Q_{total,aluminum}$ [kW] | $Q_{total,gypsum}$ [kW] | u [m/s] |
|---|---|---|---|
| Run 77 | 19.85 | 9.468 | 8.141 |
| Run 78 | 20 | 9.5 | 8.222 |
| Run 79 | 20.14 | 9.531 | 8.303 |
| Run 80 | 20.29 | 9.562 | 8.384 |
| Run 81 | 20.43 | 9.592 | 8.465 |
| Run 82 | 20.58 | 9.622 | 8.545 |
| Run 83 | 20.72 | 9.652 | 8.626 |
| Run 84 | 20.87 | 9.682 | 8.707 |
| Run 85 | 21.01 | 9.711 | 8.788 |
| Run 86 | 21.15 | 9.74 | 8.869 |
| Run 87 | 21.3 | 9.768 | 8.949 |
| Run 88 | 21.44 | 9.797 | 9.03 |
| Run 89 | 21.58 | 9.825 | 9.111 |
| Run 90 | 21.72 | 9.852 | 9.192 |
| Run 91 | 21.87 | 9.88 | 9.273 |
| Run 92 | 22.01 | 9.907 | 9.354 |
| Run 93 | 22.15 | 9.934 | 9.434 |
| Run 94 | 22.29 | 9.961 | 9.515 |
| Run 95 | 22.43 | 9.987 | 9.596 |
| Run 96 | 22.57 | 10.01 | 9.677 |
| Run 97 | 22.71 | 10.04 | 9.758 |
| Run 98 | 22.85 | 10.06 | 9.838 |
| Run 99 | 22.99 | 10.09 | 9.919 |
| Run 100 | 23.13 | 10.12 | 10 |



# HVAC Appendix

Completed by: HVAC Team

Nathan Van Heukelum, Lynette Hromada, Jen Meneely, Matthew Brouwer, Marc Eberlein, Steve DeMaagd

# Table of Contents

# 1. Introduction

The purpose of a heating, ventilation and air conditioning (HVAC) system is to remove all the heat generated by the servers. There are many different ways to accomplish this objective. The goal of this project was to find the most energy efficient and cost effective cooling solution.

# 2. Existing data center

Currently, the data center is in the basement of the Hekman Library, considered to be the first floor, in the Calvin Information Technology (CIT) office space. The servers are contained in two separate and secure rooms.

The first room contains a Liebert cooling unit model BU060E-AAM. The 060 in the model refers to 60,000 BTU/hr cooling capacity which is equivalent to 17.6 kW. This unit has a top discharge. It requires a power supply of 460 Volts 3 phase at 60 Hz and contains an advanced microprocessor.

The second room contains a Liebert cooling unit model FE114A-AAM. 114,000 BTU/hr is equivalent to 33.4 kW. This unit is air cooled and has a floor discharge system. This system also requires a power supply of 460 Volts 3 phase at 60 Hz and contains an advanced microprocessor.

A third unit is housed above the data center and is only used as a backup system in case of failure of either or both of the other two units. This third unit discharges air into the rooms through the ceiling vents.

The condensers for these units are located on top of the Hekman Library, which is above the fifth floor.

# 3. New data center baseline design

## 3.1 Baseline Design

The baseline design of the new data center was taken from the quote Sam Anema received from Hedrick Associates on January 14, 2010 (Refer to section 3.2). The proposal is comprised of two pieces of equipment, a Liebert CRV Air-cooled Precision Cooling System and a 95F Ambient Liebert Direct-Drive Air Cooled Condenser.

1. Liebert CRV Air-cooled Precision Cooling System

The CRV unit is a precision cooling unit located within the row of computer racks. The unit is capable of all air conditioning needs including: cooling, humidification, dehumidification, and air filtration. It functions with a hot aisle and a cold aisle: air enters from the hot aisle is conditioned and then released to the cold aisle through an air supply baffle. This specific unit comes in two models, one operating at 20 kW and the other at 35 kW.

2. 95F Ambient Liebert Direct-Drive Air Cooled Condenser

The condenser unit provided in the quote will also be used in the baseline design. The unit is energy efficient; with cooling coils made from copper tubing along with aluminum fins for maximum heat transfer and quiet fans to reduce noise generation[1].

The equipment will be installed by Calvin's physical plant meaning no outside cost will be incurred for the installation process. The Liebert unit will be installed in the data center room and the condenser will be installed on the roof of the Spoelhof Fieldhouse. Piping will be installed from the room to the roof via an existing chase.

[1] http://www.liebertcanada.ca/sites/Network_Power/fr-CA/Products/Product_Detail/Product1/Documents/Liebert%20Outdoor%20Condenser,%2017.5-210kW/SL_10050-R07-05.pdf

## 3.2 Hedrick Quote

20 KW
Cooling

**HEDRICK ASSOCIATES**
**2360 OAK INDUSTRIAL DR. N.E.**
**GRAND RAPIDS, MI 49505**
**(616) 454-1218 FAX: (616) 454-5336**
**email: lanninge@hedrickassoc.com**

Liebert®
Keeping Business in Business™

| | | | |
|---|---|---|---|
| **COMPANY:** | Calvin College | **PROPOSAL#:** | **17184A** |
| **ATTN:** | Sam Anema | **PAGES:** | |
| **email:** | sane@calvin.edu | **DATE:** | 1/14/10 |
| **FROM:** | Eric T. Lanning | | |
| **PROJECT:** | New Server Room – 20kW Liebert CRV In-Row Cooling System | | |

We propose the following Liebert equipment for your consideration on this project.

**Quantity (1) Liebert CRV Air-cooled Precision Cooling System**

- Configuration Number: CR020RA1C7SD1811E010PA865
- Model Number: CR020RA1C7A865
- Nominal 20 kW, 70 kBtuh at approximately 90F, 27% RH
- 208 Voltage, 3 Phase, 60 Hz

**Quantity (1) 95F Ambient Liebert Direct-Drive Air-cooled Condenser**

- Model Number: TCSV28K-Y
- Variable Frequency Drive System with Internal Surge Suppression
- 208/230 Volts 3 Phase 60 Hz
- Locking Disconnect Switch

The Liebert CRV is a precision cooling unit located within a row of heat generating IT equipment racks. It is capable of providing all the necessary functions of a precision air conditioner including cooling, humidification, dehumidification, air filtration, and condensate management. Air enters the unit from the hot aisle, is filtered, cooled and conditioned, then expelled into the cold aisle through a supply air baffle.

The Liebert CRV is optimized for maximum cooling capacity in a minimal footprint. The extremely energy efficient components of the system are managed by the Liebert iCOM control system. The control monitors the environment in real-time by locating sensors on the inlet of the racks the unit is cooling. This information allows the unit to optimize its operations for both performance and energy efficiency. All operations and sensor data can be reported remotely via a variety of communication protocols, providing end users with a built-in mini-monitoring system. The supply air baffle allows the air leaving the cooling unit to be directed to the racks the Liebert CRV is conditioning; maximizing its effectiveness, reducing the chance for hot spots, and improving the overall system efficiency.

**System Details:**

- Liebert iCOM control system with Large Graphic Display, 320 x 240 dot matrix
- 2T temperature sensors to measure air temperature entering server racks - quantity 3
- Adjustable supply air baffle system
- Variable speed EC plug fans
- Digital scroll, variable capacity compressor utilizing R-410A
- Crankcase compressor heater
- Evaporator Type: tilted slab, copper tubes - aluminum fins with hydrophilic coating
- Electric Reheat
- Steam Generating Humidifier
- Dual-float condensate pump
- Rating: MERV 8 per ASHRAE 52.2 (30% efficient by ASHRAE 52.1)
- Filter clog detection with alarm
- Locking Disconnect Switch
- Top and bottom electrical and piping connections
- One remote shutdown terminal
- One alarm contact
- LIEBNULL Modem Configuration Cable - quantity 1 per site
- IntelliSlot Web Card (IS-WEBL) provides HTTP and SNMP communication, quantity 1 per unit
- Hot air rear return with front cold air discharge
- Server rack style rear door
- Superior Service Access Panel
- Installation casters with leveling feet
- Powder coated panels
- Unit Color: 7021 Knurr Black

**Services Include:**

- On-site startup by Liebert personnel
- 1st year complete parts warranty
- 2nd thru 5th Year compressor warranty (parts only)

**Total Price for 20kW System, Including Freight but NOT TAX** **$24,331**

**Terms & Conditions:**
**- Quotation Valid for 45 days**
**- Price does not include tax**
**- Terms are Net 30 Days, subject to manufacturer's approval**
**- Liebert standard Terms & Conditions apply (see attached, T&C's available at http://www.liebert.com/purchaseagreement.htm)**
**- Please address Purchase Orders to:**

**Liebert Corporation c/o Hedrick Associates**
**2360 Oak Industrial Drive N.E.**
**Grand Rapids, MI 49505**

Lead time: 5 weeks after order

HEDRICK ASSOCIATES

Eric T. Lanning

Figure 1: Hedrick Base Case Quote

# 4. Energy efficiency design improvements

## 4.1 Introduction

The goal of the HVAC team was to come up with a new design for a redundant data center. This new design must be at least 30% more efficient then the baseline design that is already in place in the basement of the library. To meet this new design requirement the HVAC team recommends the implementation of a new design that will use the heat from the data center to heat the pool in Van Noord arena. Using this heat will save Calvin College thousands of dollars each year, which can be seen in the cost savings section below.

## 4.2 Design Alternatives

Several options were considered to improve the efficiency of the HVAC system of the data center. One of the options was Coolcentric, which was a water-cooled system that removed the heat from the racks using rear door heat exchangers without using fans. This alternative was not chosen because of high initial cost and the water was not hot enough to utilize in other areas of the building. Another option was using an economizer with the base case system. The economizer would use outside air when possible to reduce the cooling load on the air conditioning system. The financial and energy analysis of the economizer is illustrated in Figures 4, 5, 6, and 7. These figures display why this option was not the best and therefore not chosen.

## 4.3 System Design and Component Description

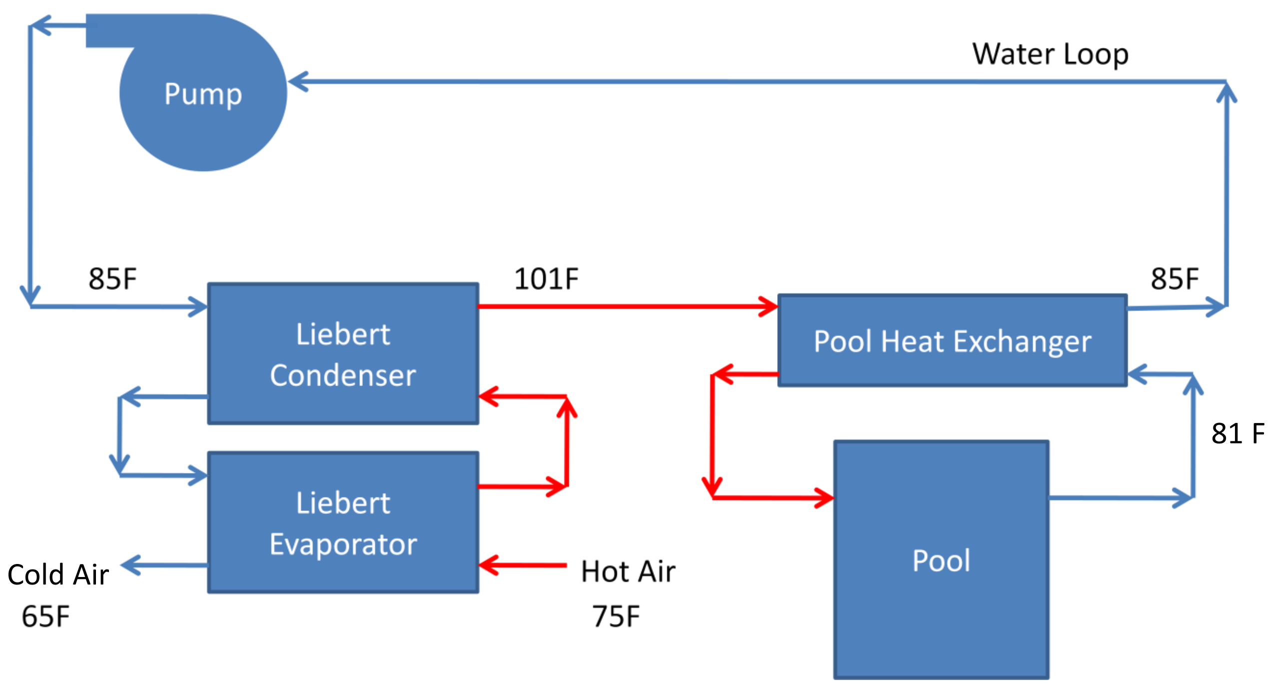



**Figure 2: Pool System Design**

This improved system, also called the CERF(Calvin Energy Recovery Fund) case, removes the heat from the data center using a 20 kW water-cooled Liebert CRV unit.

The water cooled models can use water up to 85F for their cooling. Since the data center will be in the fieldhouse, the nearby pool can act as a perfect heat sink. The pool is heated year round, so it can always accept the heat from the data center. Therefore, the final design consists of a water loop going from the data center to the pool. With this system all the heat from the data center is put into the pool. The system provides considerable energy and cost savings. This arrangement is the only way to conserve and recycle all the heat from the data center. Therefore it takes less energy to cool the water because the water simply runs through a heat exchanger with the pool. Secondly, this system saves on pool heating costs. The air conditioning system essentially transports the heat from the data center to the pool. This system saves money and energy for the college and is clearly the best option for the new data center design.

## 4.4 Financial Analysis

The following figures explain the financial analysis done for this component of the project. Figure 3 describes the capital cost of the base case versus the proposed improved case. Figures 4 and 5 illustrate the annual cost of each of the systems, including the economizer.

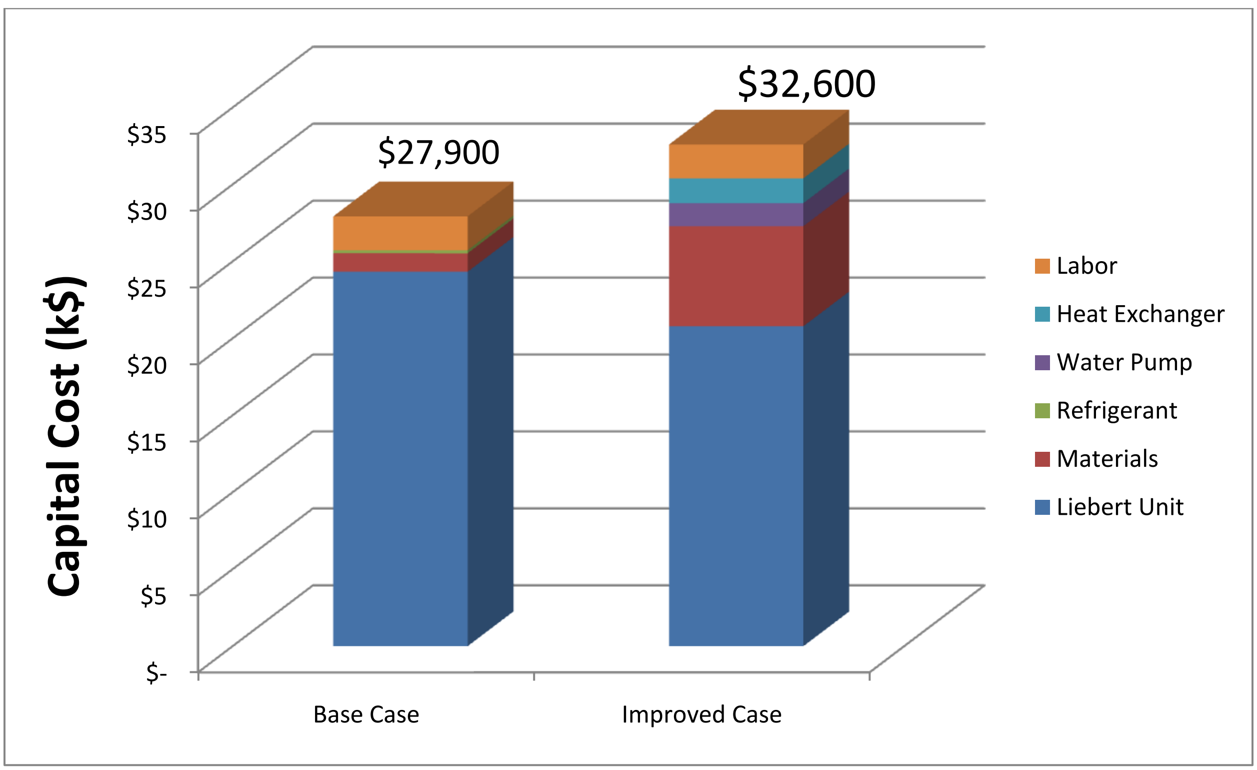



**Figure 3: Capital Cost Differences**

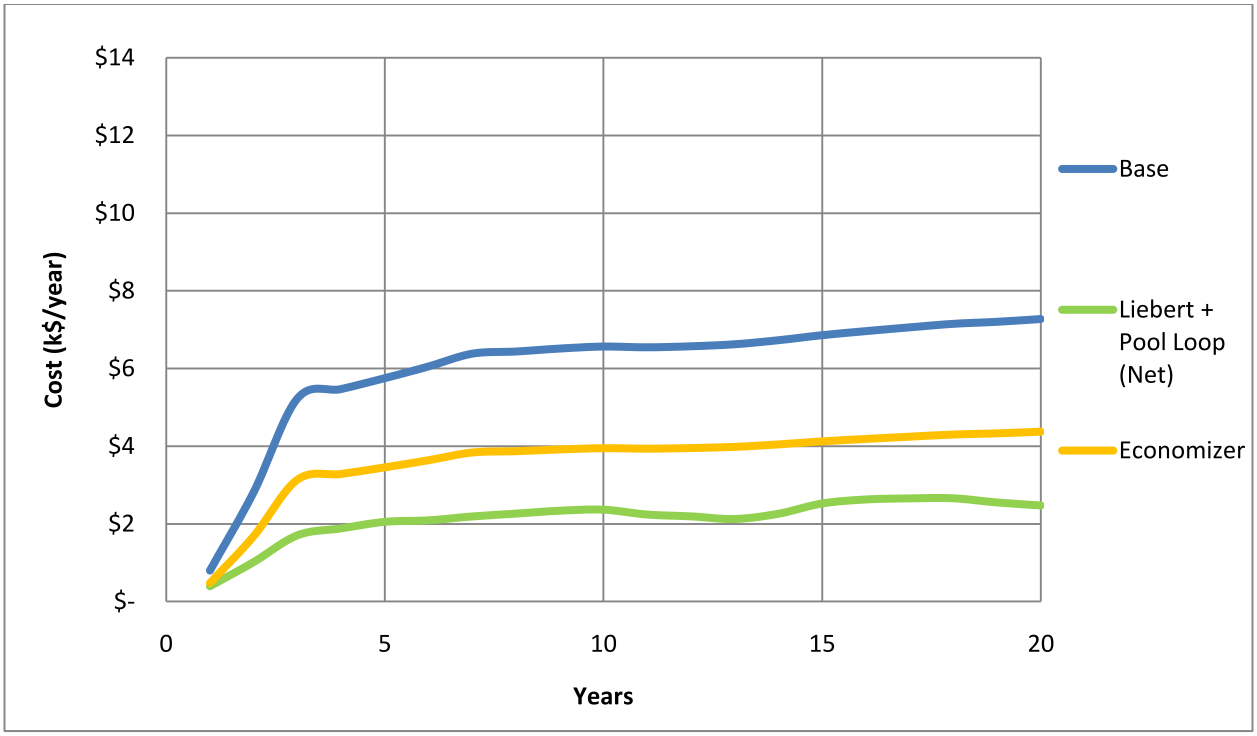



Figure 4: Annual Cost - 20 kW Scenario

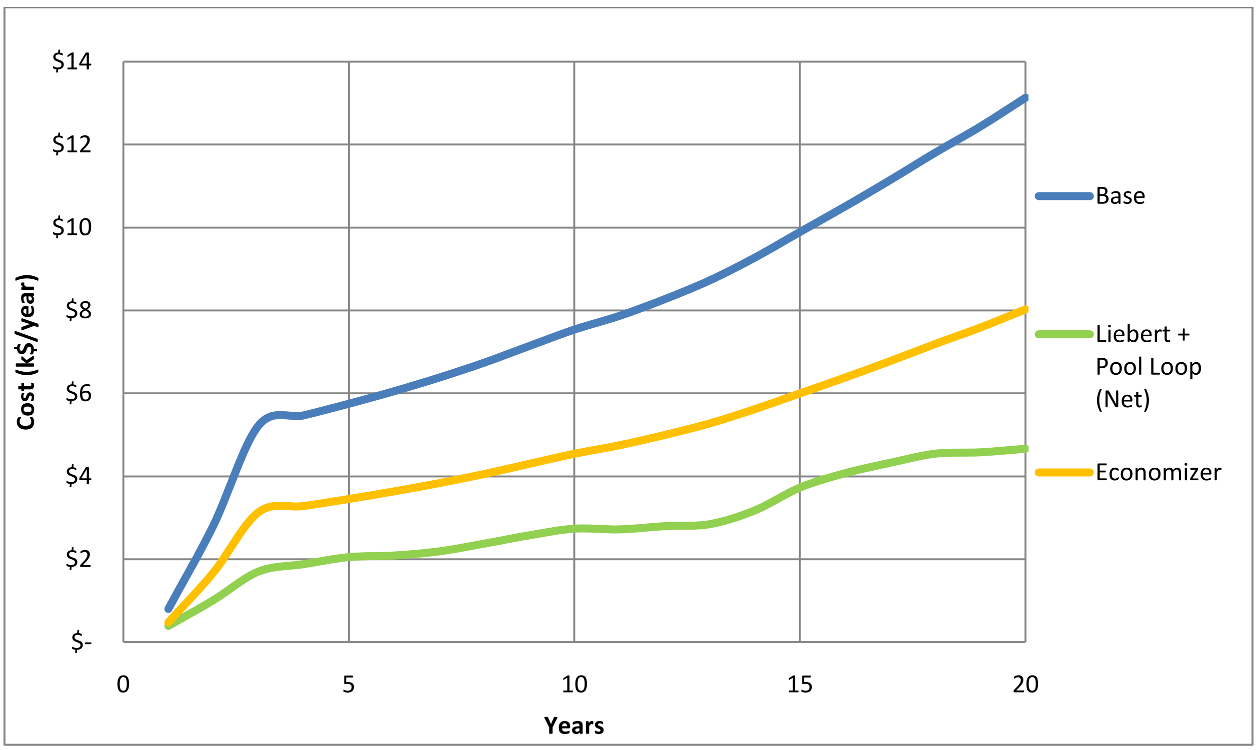



Figure 5: Annual Cost - 40 kW Scenario

## 4.5 Energy Analysis

The following figures illustrate the annual energy usage for this component of the project. They include the economizer energy usage to demonstrate the savings the pool loop has over the base case and the economizer.

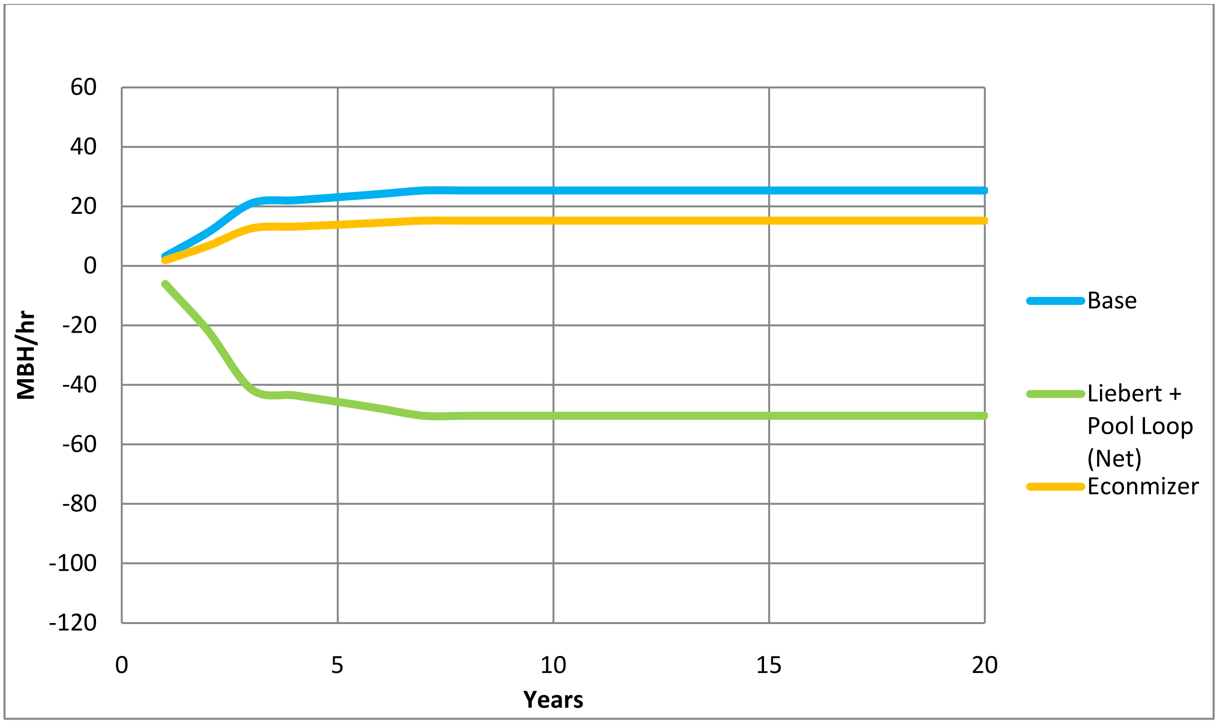



Figure 6: Annual Energy Usage - 20 kW Scenario

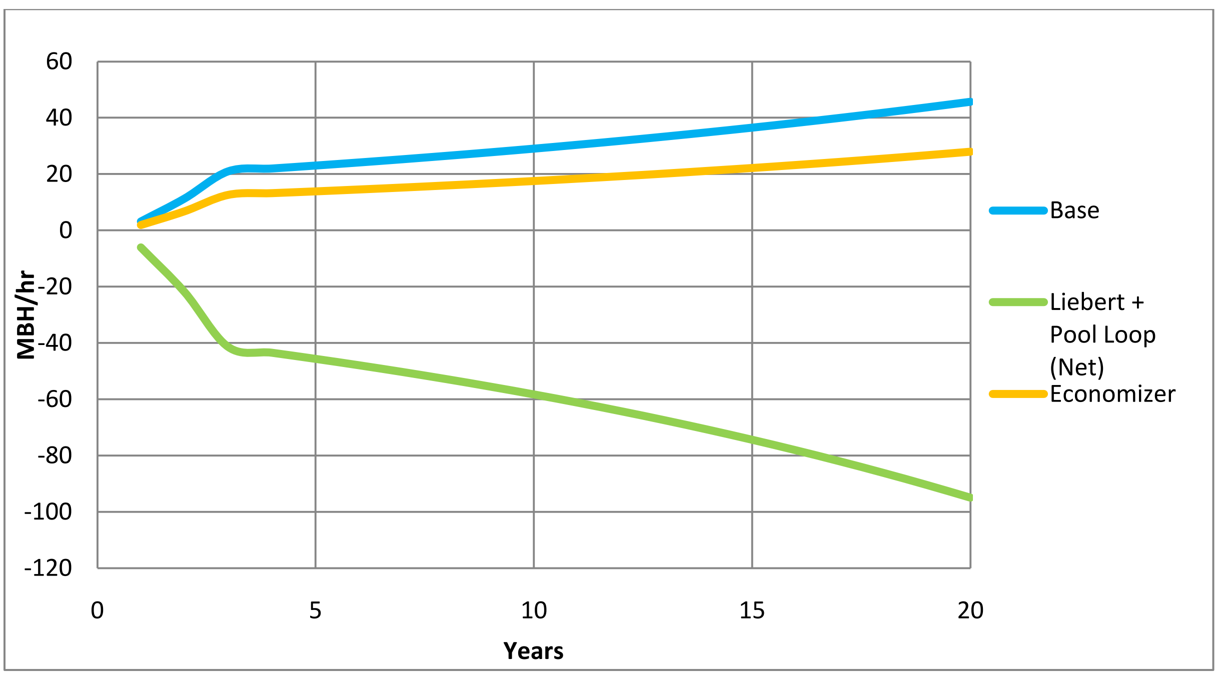



Figure 7: Annual Energy Usage - 40 kW Scenario

# 5. Conclusions

The final design will be submitted for the Calvin Energy Recovery Fund (CERF) consideration. The pool loop design was the best choice for this application because it saved Calvin College the greatest amount of money while also being energy efficient. The location of the data center allows for this unique design to be applicable. Energy efficient cooling systems like this save both money and resources.

# 6. Pool System Component Quotes

## 6.1 Heat Exchanger

| | |
|---|---|
| To: | Nate |
| Company: | Calvin College |
| From: | Eric Lanning |
| Tel: | |
| Date: | 3/18/2010 |
| Project: | Calvin Server Room HX |
| Proposal #: | 17417 |
| Fax: | Emailed |

ALFA LAVAL

HEDRICK ASSOCIATES
2360 Oak Industrial Dr. N.E.
Grand Rapids, MI 49505
(616) 454-1218
Fax: (616) 454-5336
lanninge@hedrickassoc.com

Dear Nate,

Based on the conditions specified, the following Alfa Laval plate heat exchangers are required. Please see the attached data sheets and dimensional drawings for detailed information.

| Item | Qty | Description | Price |
|---|---|---|---|
| HX-1 | 1 | TL3B-FG, with (17) ALLOY 304 plates with NBRP CLIP-ON gaskets. | $1,610.00 |

**Quoted price is FOB shipping point.**
**Freight is included to Grand Rapids, MI.**
**Tax is not included.**
**Purchase order to be made out to Hedrick Associates.**

Thank you for the opportunity to provide a quotation on this project. Should you have any further questions, please contact me at 616-454-1218.

Best regards,

Eric Lanning
ACCOUNT REPRESENTATIVE

MISSION: To optimize the performance of our customers' processes. Time and time again.

# ALFA LAVAL SUBMITTAL DATA

**Customer** : **Calvin College**

**Quote Number** : **17417**  **Project** : **Calvin Server Room HX**

**Item** : **HX-1**  **Date** : **3/18/2010**

| **Model:** | **TL3B-FG** | | |
|---|---|---|---|
| | | ***Hot Side*** | ***Cold Side*** |
| Fluid | | Water | Water |
| Volume flow rate | GPM | 14.0 | 14.0 |
| Inlet temperature | °F | 100.3 | 79.0 |
| Outlet temperature | °F | 85.0 | 94.2 |
| Pressure drop | psi | 7.23 | 7.26 |
| Heat exchanged | kBtu/h | 106.2 | |
| Mean temperature difference | °F | 6.0 | |
| Density | lb/ft³ | 62.0 | 62.1 |
| Specific heat | Btu/lb,°F | 0.998 | 0.999 |
| Thermal conductivity | Btu/ft,h,°F | 0.360 | 0.357 |
| Viscosity | cP | 0.680 | 0.728 |
| Plate material / Thickness | | ALLOY 304 / 0.40 mm | |
| Sealing material | | NBRP | NBRP |
| Connection material | | Stainless steel | Stainless steel |
| Connection locations | | S1 -> S2 | S4 <- S3 |
| Connection diameter | in | 1 | 1 |
| Pressure vessel code | | ASME | |
| Design Temperature | °F | 150.0 | 150.0 |
| Design pressure | psi | 150.0 | 150.0 |
| Liquid volume | ft³ | 0.033 | 0.033 |
| Overall length x width x height | in | 16 x 7 x 31 | |
| Net weight, empty / operating | lb | 150 / 154 | |

## 6.2 Water Cooled Liebert Unit

**HEDRICK ASSOCIATES**
**2360 OAK INDUSTRIAL DR. N.E.**
**GRAND RAPIDS, MI 49505**
**(616) 454-1218 FAX: (616) 454-5336**
**email: lanninge@hedrickassoc.com**

Liebert
Keeping Business in Business

| | | | |
|---|---|---|---|
| COMPANY: | Calvin College | PROPOSAL#: | 17184C |
| ATTN: | Nathan Van Heukelum | PAGES: | |
| email: | natevan8@gmail.com | DATE: | 3/16/10 |
| FROM: | Eric T. Lanning | | |
| PROJECT: | New Server Room – 20kVA Liebert CRV, Water Cooled | | |

We propose the following Liebert equipment for your consideration on this project.

**Quantity (1) Liebert CRV Water / Glycol Cooled Precision Cooling System**

- Configuration Number: CR020RW1C7SD1811E010PA866
- Model Number: CR020RW1C7A866
- Nominal 20 kW, 70 kBtuh at approximately 90F, 27% RH
- 208 Voltage, 3 Phase, 60 Hz

The Liebert CRV is a precision cooling unit located within a row of heat generating IT equipment racks. It is capable of providing all the necessary functions of a precision air conditioner including cooling, humidification, dehumidification, air filtration, and condensate management. Air enters the unit from the hot aisle, is filtered, cooled and conditioned, then expelled into the cold aisle through a supply air baffle.

The Liebert CRV is optimized for maximum cooling capacity in a minimal footprint. The extremely energy efficient components of the system are managed by the Liebert iCOM control system. The control monitors the environment in real-time by locating sensors on the inlet of the racks the unit is cooling. This information allows the unit to optimize its operations for both performance and energy efficiency. All operations and sensor data can be reported remotely via a variety of communication protocols, providing end users with a built-in mini-monitoring system. The supply air baffle allows the air leaving the cooling unit to be directed to the racks the Liebert CRV is conditioning; maximizing its effectiveness, reducing the chance for hot spots, and improving the overall system efficiency.

**System Details:**

- Liebert iCOM control system with Large Graphic Display, 320 x 240 dot matrix
- 2T temperature sensors to measure air temperature entering server racks - quantity 3
- Adjustable supply air baffle system
- Variable speed EC plug fans
- Digital scroll, variable capacity compressor utilizing R-410A
- Crankcase compressor heater
- Evaporator Type: tilted slab, copper tubes - aluminum fins with hydrophilic coating
- 2-way valve
- Electric Reheat

**1.) This quotation is subject to Liebert's product warranty(ies) and Liebert Terms and Conditions of Sale. 2.) All purchase orders are to be made out to Liebert Corporation care of the Liebert Sales Representative. 3.) Products under this proposal will be manufactured by Liebert in a location that maintains an ISO 9000 registered quality system. Refer to the Liebert Web Site (www.liebert.com), for current certification.**

- Steam Generating Humidifier
- Dual-float condensate pump
- Rating: MERV 8 per ASHRAE 52.2 (30% efficient by ASHRAE 52.1)
- Filter clog detection with alarm
- Locking Disconnect Switch
- Top and bottom electrical and piping connections
- One remote shutdown terminal
- One alarm contact
- LIEBNULL Modem Configuration Cable – DB9 Female to DB9 Female - quantity 1 per site
- IntelliSlot Web Card (IS-WEBL) provides HTTP and SNMP communication, quantity 1 per unit
- Hot air rear return with front cold air discharge
- Server rack style rear door
- Superior Service Access Panel
- Installation casters with leveling feet
- Powder coated panels
- Unit Color: 7021 Knurr Black

**Services Include:**

- Startup Included
- 2nd thru 5th YR Compressor Only

**Terms & Conditions:**
**- Quotation Valid for 45 days**
**- Price does not include tax**
**- Terms are Net 30 Days, subject to manufacturer's approval**
**- Liebert standard Terms & Conditions apply (see attached, T&C's available at http://www.liebert.com/purchaseagreement.htm)**
**- Please address Purchase Orders to:**

**Liebert Corporation c/o Hedrick Associates**
**2360 Oak Industrial Drive N.E.**
**Grand Rapids, MI 49505**

**Total Price for 20kW WATER COOLED System, Including Freight but NOT TAX $20,791**

Lead time: weeks after order

HEDRICK ASSOCIATES

Eric T. Lanning

# Power Supply Appendix

Completed by: Power Supply Team
Tim Opperwall, Andrew DeJong, Joel Love, Alex Boelkins, Amanda Hollinger

# Table of Contents



Abstract:

The redundant data center requires an uninterruptible power supply (UPS) so that data is not lost in the event of power failure. A UPS is one of any number of electrical or mechanical devices that provide power to the data center for the short time between power failure and activation of the generators. The best option for the new data center is the Eaton Powerware Blade with a single 12kW module that is scalable with data center growth. It has the lowest lifetime cost due to both its average efficiency of 97% and the fact that it runs at an average of 74% capacity over its 40 year lifetime. This device is the selection by CIT as the base case for the new data center. Based on calculations by the team, this is also the recommendation of the Power Supply Team. As a result, the Power Supply team offers no recommendations for use of CERF funds.

# 1. Introduction

An Uninterruptable Power Supply (UPS) must be used to protect the servers. Uninterruptible power supplies come in three basic categories: offline or standby, line-interactive, and online. All of these power supplies are battery back-ups. Standby power supplies are sets of batteries with a switch that senses power failure and connects the UPS to the system. A standby UPS requires a DC to AC inverter, and the time between power failure and UPS connection ranges from 2 to 10 ms.[1] Standby UPSs are the most efficient reaching efficiencies of 97%.[1]

Line-interactive power supplies smooth the incoming voltage before supplying it to the data center. Power enters the UPS where a fraction of it is used to maintain the charge of the batteries and the rest passes through a filter where the voltage is regulated to appropriate levels. Line interactive UPSs can reach up to 97% efficient[1].

An online UPS provides all or some of the power to the system at all times. The incoming power is used to charge the UPS, and the UPS powers the system resulting in truly uninterruptible power. However, these UPSs are only about 90% efficient[1].

One non-electrical option for uninterruptible power is a flywheel. Power is stored as kinetic energy in a spinning flywheel that is magnetically suspended in a vacuum. When electrical power is lost, the flywheel is connected to a shaft that creates electricity via a generator[2].

A UPS must be selected for Calvin College's redundant data center that is adequate for the power load of the data center and minimizes costs. The energy efficiency goal for the new data center is to be at least 30% more efficient than the current data center.

# 2. Existing data center

The data center currently being used by Calvin College uses a line interactive UPS. The model is the Liebert AP346, which is a modular unit comprised of batteries daisy-chained together. The power output of the UPS is 32 kW and the unit operates at an efficiency of 89%.

# 3. New data center baseline design

The baseline design is the design proposed by CIT against which other designs are to be compared. The goal of the power supply team is to offer a UPS design that operates more efficiently. CIT has offered the following two options as the baseline design.

## 3.1 APC Symmetra PX 20kW

The Calvin Information Technology team suggested an APC Symmetra for the new data center and the Power team determined that the 20kW Symmetra PX was the best model. This model is

[1] Eaton Brochure
[2] Pentadyne: http://www.pentadyne.com/site/flywheel-ups/technology.html

scalable in 10kW increments up to 40kW. The Symmetra will run at an average of 79% with an average efficiency of 92%. However the efficiency is decreased when capacity is below about 25% as in the first year of operation. The total present value cost of the system for the next 40 years is $573,500. That cost includes running cost, battery replacement and disposal.

### 3.2 Eaton Powerware Blade 12kW

The Calvin Information Technology team also suggested an Eaton Powerware Blade for the new data center and the Power team determined that the 12kW Blade was the best model. This model is scalable in 12kW increments up to 60kW with an efficiency of 97%[3] running at an average 74%. The total present value cost of the system for the next 40 years is $564,500. That cost includes running cost, battery replacement and disposal.

## 4. Energy efficiency design improvements

### 4.1 Additional UPS options

#### 4.1.1. Flywheel

A flywheel UPS is a mechanical alternative to battery UPSs. The flywheel uses a fraction of the incoming electrical power to initiate rotation, then stores kinetic energy that can be converted back to electrical power when needed. For the amount of power that they provide, flywheel UPS provide a very efficient and tightly packaged solution to supplying emergency power to the servers. However, the bottom line is that they provide more power than is needed especially since we may not even be using dedicated, on-site servers in the near future. The efficiency is just as high as for battery systems and the maintenance costs are significantly lower as well. The downside is that these UPSs only are built for very large systems, and the size of the new data center does not justify using a flywheel.

#### 4.1.2. Leibert NX

This model is an online UPS which delivers 40kW with a lifetime cost of $573,000. The battery replacement cost is $6,500 every three years; this cost includes the disposal of used batteries through the company.

#### 4.1.3. Eaton 9355 20kVA

This model is an online UPS which delivers a scalable 20kW with a lifetime cost of $567,000. The battery replacement cost is $2,680 for each module, with a disposal cost of $67.20 for each set by an outside company.

#### 4.1.4. Eaton Powerware Blade 48kW

[3] http://powerquality.eaton.com/Products-services/Backup-Power-UPS/BladeUPS-UPS/BladeUPS-specs.asp?CX=3&TAASPEC=1

This model is an online UPS which delivers a scalable 20kW with a lifetime cost of $585,500. The battery replacement cost is $7,750 every three years, with a disposal cost of $42. This system has an efficiency of 97%[4] and will run at an average of 51% of its capacity over its lifetime.

## 4.2 Cost Comparison

### 4.2.1. Financial

To compare all of the UPS options, a lifetime cost analysis spreadsheet has been made. The costs of purchasing, operating, and maintaining each of the aforementioned UPS options has been adjusted for interest and inflation and brought to present value. The inflation, interest, server power usage, and cost of electricity are shown in Table 1. Figure 1 shows the two server power usage scenarios considered – one reaching 40kWh in 20 years, and one stabilizing at 20kWh. The lifetime present value analysis for each UPS option is shown in Tables 2 through 8. Since many of the UPS options involve purchasing multiple power modules, the percent capacity varies over time. Figure 2 shows this variation.

Table 1. The inflation, interest, and cost of electricity over the 20 year design span.

| | Efficiency Factor | | Growth in Usage | | Growth in Electrical Cost | Interest | 5% |
|---|---|---|---|---|---|---|---|
| | 1.00 | | 1.05 | | 1.03 | Inflation | 4% |
| | | | | | | | |
| | | | | | | | |
| Year | Electical Consumption | KWH/Month | Peak Rate/KWH | Non-Peak Rate/KWH | Cost per Month | Cost per Year | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | Watts | | | | | | |
| 2010 | 2500.0 | 1824 | $ 0.15 | $ 0.05 | 159.60 | $1,915.20 | |
| 2011 | 9000.0 | 6566 | $ 0.15 | $ 0.05 | 591.80 | $7,101.56 | |
| 2012 | 17000.0 | 12403 | $ 0.16 | $ 0.05 | 1151.37 | $13,816.48 | |
| 2013 | 17850.0 | 13023 | $ 0.16 | $ 0.05 | 1245.21 | $14,942.53 | |
| 2014 | 18742.5 | 13675 | $ 0.17 | $ 0.06 | 1346.70 | $16,160.34 | |
| 2015 | 19679.6 | 14358 | $ 0.17 | $ 0.06 | 1456.45 | $17,477.41 | |
| 2016 | 20663.6 | 15076 | $ 0.18 | $ 0.06 | 1575.15 | $18,901.82 | |
| 2017 | 21696.8 | 15830 | $ 0.18 | $ 0.06 | 1703.53 | $20,442.32 | |
| 2018 | 22781.6 | 16621 | $ 0.19 | $ 0.06 | 1842.36 | $22,108.37 | |
| 2019 | 23920.7 | 17453 | $ 0.20 | $ 0.07 | 1992.52 | $23,910.20 | |
| 2020 | 25116.7 | 18325 | $ 0.20 | $ 0.07 | 2154.91 | $25,858.88 | |
| 2021 | 26372.6 | 19241 | $ 0.21 | $ 0.07 | 2330.53 | $27,966.38 | |
| 2022 | 27691.2 | 20204 | $ 0.21 | $ 0.07 | 2520.47 | $30,245.64 | |
| 2023 | 29075.8 | 21214 | $ 0.22 | $ 0.07 | 2725.89 | $32,710.66 | |
| 2024 | 30529.6 | 22274 | $ 0.23 | $ 0.08 | 2948.05 | $35,376.57 | |
| 2025 | 32056.0 | 23388 | $ 0.23 | $ 0.08 | 3188.31 | $38,259.77 | |
| 2026 | 33658.8 | 24557 | $ 0.24 | $ 0.08 | 3448.16 | $41,377.94 | |
| 2027 | 35341.8 | 25785 | $ 0.25 | $ 0.08 | 3729.19 | $44,750.24 | |
| 2028 | 37108.9 | 27075 | $ 0.26 | $ 0.09 | 4033.12 | $48,397.38 | |
| 2029 | 38964.3 | 28428 | $ 0.26 | $ 0.09 | 4361.81 | $52,341.77 | |
| | | | | | | | |
| | | | | | | $534,061.44 | |

[4] http://powerquality.eaton.com/Products-services/Backup-Power-UPS/BladeUPS-UPS/BladeUPS-specs.asp?CX=3&TAASPEC=1

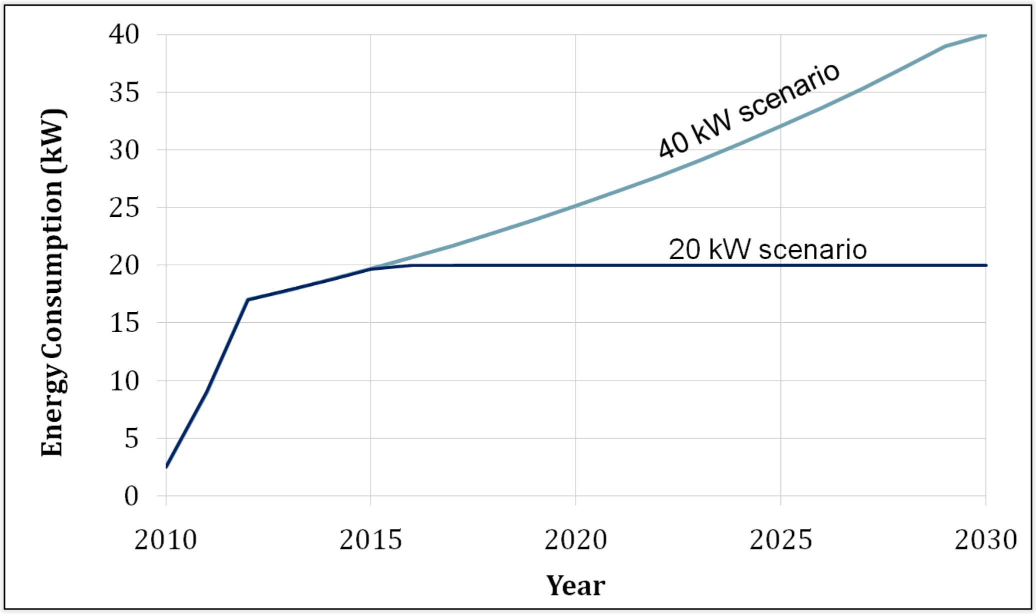



Figure 1. The two server energy requirement scenarios.

Table 2. The lifetime present value cost analysis of the Liebert NX.

| Part A | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Company | Liebert | | | | | | | |
| Name (PN) | NX | | Product numbe | (SY50K80F + (3)SYBT4) | | | | |
| Power/Unit | 40 kW | | | | | | | |
| Efficiency | 98% | | | Battery Disposal | $ 0.35 | $/lb | | |
| | | | | | | | | |
| Current $ | | | | Future $ | PDV | PDV (sum) | Percent Operation | Efficiency |
| Unit Cost | Battery Cost | Environmental Costs | Actual Power Cost | | | | | |
| $ 53,000.00 | | | $ 1,954.29 | $ 54,954.29 | $ 54,954.29 | $ 54,954.29 | 6% | 98% |
| | | | $ 7,246.49 | $ 7,536.35 | $ 7,177.48 | $ 62,131.76 | 23% | 98% |
| | | | $ 14,098.45 | $ 15,248.89 | $ 13,831.19 | $ 75,962.95 | 43% | 98% |
| | $ 6,500.00 | | $ 15,247.48 | $ 24,462.95 | $ 21,132.02 | $ 97,094.97 | 45% | 98% |
| | | | $ 16,490.14 | $ 19,291.14 | $ 15,870.87 | $ 112,965.84 | 47% | 98% |
| | | | $ 17,834.09 | $ 21,697.90 | $ 17,000.87 | $ 129,966.71 | 49% | 98% |
| | $ 6,500.00 | | $ 19,287.57 | $ 32,629.50 | $ 24,348.64 | $ 154,315.34 | 52% | 98% |
| | | | $ 20,859.51 | $ 27,449.69 | $ 19,507.98 | $ 173,823.33 | 54% | 98% |
| | | | $ 22,559.56 | $ 30,874.31 | $ 20,896.95 | $ 194,720.27 | 57% | 98% |
| | $ 6,500.00 | | $ 24,398.16 | $ 43,977.72 | $ 28,348.43 | $ 223,068.70 | 60% | 98% |
| | | | $ 26,386.61 | $ 39,058.63 | $ 23,978.61 | $ 247,047.31 | 63% | 98% |
| | | | $ 28,537.12 | $ 43,931.58 | $ 25,685.89 | $ 272,733.20 | 66% | 98% |
| | $ 6,500.00 | | $ 30,862.89 | $ 59,819.20 | $ 33,309.57 | $ 306,042.77 | 69% | 98% |
| | | | $ 33,378.22 | $ 55,577.19 | $ 29,473.77 | $ 335,516.54 | 73% | 98% |
| | | | $ 36,098.55 | $ 62,511.00 | $ 31,572.30 | $ 367,088.84 | 76% | 98% |
| | $ 6,500.00 | | $ 39,040.58 | $ 82,016.01 | $ 39,451.10 | $ 406,539.94 | 80% | 98% |
| | | | $ 42,222.38 | $ 79,081.73 | $ 36,228.25 | $ 442,768.20 | 84% | 98% |
| | | | $ 45,663.51 | $ 88,947.97 | $ 38,807.70 | $ 481,575.90 | 88% | 98% |
| | $ 6,500.00 | | $ 49,385.08 | $ 113,212.93 | $ 47,042.31 | $ 528,618.21 | 93% | 98% |
| | | | $ 53,409.97 | $ 112,526.75 | $ 44,530.66 | $ 573,148.87 | 97% | 98% |
| | | | | | | | | |
| | | | | | **$ 573,148.87** | | 61% | |

Table 3. The lifetime present value cost analysis of the Eaton 9155 10kW.

| Eaton | | | | | | |
|---|---|---|---|---|---|---|
| Name (PN) | 9155 64 Battery (3-high) | | | | | |
| Power/Unit | 10 kW | | | | | |
| Efficiency | 95% | | | Battery Disposal | $ 0.35 | $/lb |
| | Current $ | | | Future $ | PDV | Percent Operation |
| Unit Cost | Battery Cost | Environmental Costs | Actual Power Cost | | | |
| $ 12,838.00 | | | $ 2,016.00 | $ 14,854.00 | $ 14,854.00 | 25% |
| | | | $ 7,475.33 | $ 7,774.34 | $ 7,404.13 | 90% |
| $ 12,838.00 | $ 3,437.00 | $ 125.44 | $ 14,543.67 | $ 33,469.14 | $ 30,357.50 | 85% |
| | | $ - | $ 15,728.97 | $ 17,692.96 | $ 15,283.84 | 89% |
| | | $ - | $ 17,010.89 | $ 19,900.33 | $ 16,372.05 | 94% |
| | $ 6,874.00 | $ 250.88 | $ 18,397.27 | $ 31,051.60 | $ 24,329.74 | 98% |
| $ 12,838.00 | $ 3,437.00 | $ 125.44 | $ 19,896.65 | $ 45,927.40 | $ 34,271.73 | 69% |
| | | $ - | $ 21,518.23 | $ 28,316.52 | $ 20,124.02 | 72% |
| | $ 6,874.00 | $ 250.88 | $ 23,271.96 | $ 41,600.18 | $ 28,156.64 | 76% |
| | $ 3,437.00 | $ 125.44 | $ 25,168.63 | $ 40,893.27 | $ 26,360.17 | 80% |
| | | $ - | $ 27,219.87 | $ 40,292.06 | $ 24,735.83 | 84% |
| | $ 6,874.00 | $ 250.88 | $ 29,438.29 | $ 56,287.32 | $ 32,910.03 | 88% |
| | $ 3,437.00 | $ 125.44 | $ 31,837.51 | $ 56,676.46 | $ 31,559.58 | 92% |
| | | $ - | $ 34,432.27 | $ 57,332.26 | $ 30,404.52 | 97% |
| $ 12,838.00 | $ 6,847.00 | $ 249.89 | $ 37,238.50 | $ 99,005.82 | $ 50,004.67 | 76% |
| | $ 3,437.00 | $ 125.44 | $ 40,273.44 | $ 78,945.94 | $ 37,974.35 | 80% |
| | | $ - | $ 43,555.72 | $ 81,579.05 | $ 37,372.30 | 84% |
| | $ 10,311.00 | $ 376.32 | $ 47,105.51 | $ 112,574.69 | $ 49,115.96 | 88% |
| | $ 3,437.00 | $ 125.44 | $ 50,944.61 | $ 110,421.29 | $ 45,882.33 | 93% |
| | | | $ 55,096.60 | $ 116,080.22 | $ 45,936.89 | 97% |
| | | | | | **$ 603,410.29** | 83% |

Table 4. The lifetime present value cost analysis of the Eaton 9155 10kW, 32 battery pack.

| | | | | | | |
|---|---|---|---|---|---|---|
| Name (PN) | 9155 32 Battery with 4 EBM 64 | | | | | |
| Power/Unit | 10 kW | | | | | |
| Efficiency | 95% | | | Battery Disposal | $ 0.35 | $/lb |
| | Current $ | | | Future $ | PDV | Percent Operation |
| Unit Cost | Battery Cost | Environmental Costs | Actual Power Cost | | | |
| $ 31,450.00 | | | $ 2,016.00 | $ 33,466.00 | $ 33,466.00 | 25% |
| | | | $ 7,475.33 | $ 7,774.34 | $ 7,404.13 | 90% |
| $ 31,450.00 | | | $ 14,543.67 | $ 49,746.75 | $ 45,121.77 | 85% |
| | $ 2,088.00 | $ 62.72 | $ 15,728.97 | $ 20,112.22 | $ 17,373.70 | 89% |
| | | $ - | $ 17,010.89 | $ 19,900.33 | $ 16,372.05 | 94% |
| | $ 2,088.00 | $ 62.72 | $ 18,397.27 | $ 24,999.78 | $ 19,587.98 | 98% |
| $ 31,450.00 | $ 2,088.00 | $ 62.72 | $ 19,896.65 | $ 67,691.24 | $ 50,512.25 | 69% |
| | | $ - | $ 21,518.23 | $ 28,316.52 | $ 20,124.02 | 72% |
| | $ 2,088.00 | $ 62.72 | $ 23,271.96 | $ 34,792.70 | $ 23,549.07 | 76% |
| | $ 4,176.00 | $ 125.44 | $ 25,168.63 | $ 41,945.10 | $ 27,038.18 | 80% |
| | | $ - | $ 27,219.87 | $ 40,292.06 | $ 24,735.83 | 84% |
| | $ 2,088.00 | $ 62.72 | $ 29,438.29 | $ 48,629.83 | $ 28,432.86 | 88% |
| | $ 4,176.00 | $ 125.44 | $ 31,837.51 | $ 57,859.63 | $ 32,218.41 | 92% |
| | | $ - | $ 34,432.27 | $ 57,332.26 | $ 30,404.52 | 97% |
| $ 31,450.00 | $ 2,088.00 | $ 62.72 | $ 37,238.50 | $ 122,670.61 | $ 61,956.99 | 76% |
| | $ 4,176.00 | $ 125.44 | $ 40,273.44 | $ 80,276.84 | $ 38,614.53 | 80% |
| | | $ - | $ 43,555.72 | $ 81,579.05 | $ 37,372.30 | 84% |
| | $ 4,176.00 | $ 125.44 | $ 47,105.51 | $ 100,135.63 | $ 43,688.84 | 88% |
| | $ 4,176.00 | $ 125.44 | $ 50,944.61 | $ 111,918.37 | $ 46,504.39 | 93% |
| | | | $ 55,096.60 | $ 116,080.22 | $ 45,936.89 | 97% |
| | | | | $ - | **$ 650,414.71** | 83% |

Table 5. The lifetime present value cost analysis of the Eaton 9355 20kW.

| Part B | | | | | | | |
|---|---|---|---|---|---|---|---|
| Company | Eaton | | | | | | |
| Name (PN) | 9355 20 kVA 208V 2-High Module | | Part number | KB2013100000010 - 18 min | | | |
| Power/Unit | 20 | kW | | | | | |
| Efficiency | 88% | | | Battery Disposal | $ 0.35 | | $/lb |
| | | | | | | | |
| Current $ | | | | Future $ | PDV | PDV (sum) | Percent Operation |
| Unit Cost | Battery Cost | Environmental Costs | Actual Power Cost | | | | |
| $ 21,826.00 | | | $ 2,176.36 | $ 24,002.36 | $ 24,002.36 | $ 24,002.36 | 13% |
| | | | $ 8,069.96 | $ 8,392.75 | $ 7,993.10 | $ 31,995.46 | 45% |
| | | | $ 15,700.55 | $ 16,981.71 | $ 15,402.91 | $ 47,398.38 | 85% |
| | $ 2,680.00 | $ 67.20 | $ 16,980.14 | $ 22,190.58 | $ 19,169.06 | $ 66,567.43 | 89% |
| | | $ - | $ 18,364.02 | $ 21,483.31 | $ 17,674.37 | $ 84,241.81 | 94% |
| | | $ - | $ 19,860.69 | $ 24,163.57 | $ 18,932.79 | $103,174.60 | 98% |
| $ 21,826.00 | $ 2,680.00 | $ 67.20 | $ 21,479.34 | $ 58,271.15 | $ 43,482.83 | $146,657.43 | 52% |
| | | $ - | $ 23,229.91 | $ 30,568.97 | $ 21,724.80 | $168,382.23 | 54% |
| | | $ - | $ 25,123.14 | $ 34,382.76 | $ 23,271.60 | $191,653.83 | 57% |
| | $ 5,360.00 | $ 134.40 | $ 27,170.68 | $ 46,492.59 | $ 29,969.54 | $221,623.37 | 60% |
| | | $ - | $ 29,385.09 | $ 43,497.11 | $ 26,703.45 | $248,326.82 | 63% |
| | | $ - | $ 31,779.97 | $ 48,923.81 | $ 28,604.74 | $276,931.56 | 66% |
| | $ 5,360.00 | $ 134.40 | $ 34,370.04 | $ 63,824.26 | $ 35,539.73 | $312,471.29 | 69% |
| | | $ - | $ 37,171.20 | $ 61,892.78 | $ 32,823.06 | $345,294.35 | 73% |
| | | $ - | $ 40,200.65 | $ 69,614.52 | $ 35,160.07 | $380,454.42 | 76% |
| | $ 5,360.00 | $ 134.40 | $ 43,477.01 | $ 88,194.74 | $ 42,423.18 | $422,877.60 | 80% |
| | | $ - | $ 47,020.38 | $ 88,068.29 | $ 40,345.10 | $463,222.70 | 84% |
| | | $ - | $ 50,852.54 | $ 99,055.69 | $ 43,217.67 | $506,440.37 | 88% |
| | $ 5,360.00 | $ 134.40 | $ 54,997.03 | $ 122,544.53 | $ 50,919.78 | $557,360.15 | 93% |
| | | | $ 59,479.28 | $ 125,313.88 | $ 49,590.96 | $606,951.11 | 97% |
| | | | | | | | |
| | | | | | **$ 606,951.11** | | 72% |

Table 6. The lifetime present value cost analysis of the Eaton Blade 40kW.

| Part C | | | | | | | |
|---|---|---|---|---|---|---|---|
| Company | Eaton | | | | | | |
| Name (PN) | BladeUPS 48kW Rack UPS | | | | | | |
| Power/Unit | 48 | kW | | | | | |
| Efficiency | 97% | | | Battery Disposal | $ 0.35 | $/lb | |
| | | | | | | | |
| Current $ | | | | | | PDV (sum) | |
| Unit Cost | Battery Cost | Environmental Costs | Actual Power Cost | Future $ | PDV | | Percent Operation |
| $ 53,275.00 | | | $ 1,974.43 | $ 55,249.43 | $ 55,249.43 | $ 55,249.43 | 5% |
| | | | $ 7,321.20 | $ 7,614.05 | $ 7,251.47 | $ 62,500.90 | 19% |
| | | | $ 14,243.80 | $ 15,406.09 | $ 13,973.78 | $ 76,474.68 | 35% |
| | $ 7,744.00 | $ 42.00 | $ 15,404.67 | $ 26,086.35 | $ 22,534.37 | $ 99,009.05 | 37% |
| | | $ - | $ 16,660.15 | $ 19,490.01 | $ 16,034.48 | $ 115,043.53 | 39% |
| | | $ - | $ 18,017.95 | $ 21,921.59 | $ 17,176.14 | $ 132,219.67 | 41% |
| | $ 7,744.00 | $ 42.00 | $ 19,486.41 | $ 34,508.30 | $ 25,750.62 | $ 157,970.30 | 43% |
| | | $ - | $ 21,074.55 | $ 27,732.67 | $ 19,709.09 | $ 177,679.39 | 45% |
| | | $ - | $ 22,792.13 | $ 31,192.60 | $ 21,112.38 | $ 198,791.77 | 47% |
| | $ 7,744.00 | $ 42.00 | $ 24,649.69 | $ 46,166.10 | $ 29,759.08 | $ 228,550.85 | 50% |
| | | $ - | $ 26,658.64 | $ 39,461.30 | $ 24,225.81 | $ 252,776.66 | 52% |
| | | $ - | $ 28,831.32 | $ 44,384.49 | $ 25,950.69 | $ 278,727.35 | 55% |
| | $ 7,744.00 | $ 42.00 | $ 31,181.07 | $ 62,387.53 | $ 34,739.71 | $ 313,467.07 | 58% |
| | | $ - | $ 33,722.33 | $ 56,150.15 | $ 29,777.62 | $ 343,244.69 | 61% |
| | | $ - | $ 36,470.70 | $ 63,155.44 | $ 31,897.79 | $ 375,142.48 | 64% |
| | $ 7,744.00 | $ 42.00 | $ 39,443.06 | $ 85,056.86 | $ 40,913.81 | $ 416,056.29 | 67% |
| | | $ - | $ 42,657.67 | $ 79,897.01 | $ 36,601.74 | $ 452,658.03 | 70% |
| | | $ - | $ 46,134.27 | $ 89,864.96 | $ 39,207.78 | $ 491,865.81 | 74% |
| | $ 7,744.00 | $ 42.00 | $ 49,894.21 | $ 116,849.52 | $ 48,553.39 | $ 540,419.20 | 77% |
| | | | $ 53,960.59 | $ 113,686.82 | $ 44,989.73 | $ 585,408.93 | 81% |
| | | | | | | | |
| | | | | | **$ 585,408.93** | | 51% |

Table 7. The lifetime present value cost analysis of the Eaton Blade 12kW.

| Part D | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Company | Eaton | | | | | | | | |
| Name (PN) | 12 KW Blade module - expanded in 12 kW increments | | | | | | | | |
| Power/Unit | 12 | kW | | | | | | | |
| Efficiency | 97% | | | Battery Disposal | $ 0.35 | $/lb | | | |
| | | | | | | | | | |
| Current $ | | | | | | PDV (sum) | | Efficiency | Power usage |
| Unit Cost | Battery Cost | Environmental Costs | Actual Power Cost | Future $ | PDV | | Percent Operation | | kWh |
| $ 18,860.00 | | | $ 2,016.00 | $ 20,876.00 | $ 20,876.00 | $ 20,876.00 | 21% | 95% | 22593 |
| | | | $ 7,321.20 | $ 7,614.05 | $ 7,251.47 | $ 28,127.47 | 75% | 97% | 81334 |
| $ 10,475.00 | $1,936.00 | $ 42.00 | $ 14,243.80 | $ 28,875.26 | $ 26,190.71 | $ 54,318.18 | 71% | 97% | 153631 |
| | | $ - | $ 15,404.67 | $ 17,328.15 | $ 14,968.71 | $ 69,286.89 | 74% | 97% | 161312 |
| | | $ - | $ 16,660.15 | $ 19,490.01 | $ 16,034.48 | $ 85,321.37 | 78% | 97% | 169378 |
| | $3,872.00 | $ 84.00 | $ 18,017.95 | $ 26,734.67 | $ 20,947.31 | $ 106,268.69 | 82% | 97% | 177847 |
| | | $ - | $ 19,486.41 | $ 24,656.53 | $ 18,399.08 | $ 124,667.77 | 86% | 97% | 186739 |
| | | $ - | $ 21,074.55 | $ 27,732.67 | $ 19,709.09 | $ 144,376.86 | 90% | 97% | 196076 |
| $ 10,475.00 | $3,872.00 | $ 84.00 | $ 22,792.13 | $ 50,942.42 | $ 34,479.84 | $ 178,856.70 | 63% | 97% | 205880 |
| | | $ - | $ 24,649.69 | $ 35,084.19 | $ 22,615.58 | $ 201,472.28 | 66% | 97% | 216174 |
| | | $ - | $ 26,658.64 | $ 39,461.30 | $ 24,225.81 | $ 225,698.09 | 70% | 97% | 226983 |
| | $5,808.00 | $ 126.00 | $ 28,831.32 | $ 53,519.61 | $ 31,291.81 | $ 256,989.90 | 73% | 97% | 238332 |
| | | $ - | $ 31,181.07 | $ 49,921.90 | $ 27,798.38 | $ 284,788.28 | 77% | 97% | 250249 |
| $ 10,475.00 | | $ - | $ 33,722.33 | $ 73,591.80 | $ 39,027.30 | $ 323,815.58 | 81% | 97% | 262761 |
| | $5,808.00 | $ 126.00 | $ 36,470.70 | $ 73,431.21 | $ 37,087.75 | $ 360,903.33 | 85% | 97% | 275899 |
| | | $ - | $ 39,443.06 | $ 71,034.72 | $ 34,168.91 | $ 395,072.24 | 89% | 97% | 289694 |
| | | $ - | $ 42,657.67 | $ 79,897.01 | $ 36,601.74 | $ 431,673.99 | 70% | 97% | 304179 |
| | $5,808.00 | $ 126.00 | $ 46,134.27 | $ 101,423.80 | $ 44,250.87 | $ 475,924.85 | 74% | 97% | 319388 |
| | | $ - | $ 49,894.21 | $ 101,076.51 | $ 41,999.38 | $ 517,924.23 | 77% | 97% | 335357 |
| | $1,936.00 | $ 42.00 | $ 53,960.59 | $ 117,854.17 | $ 46,638.90 | $ 564,563.13 | 81% | 97% | 352125 |
| | | | | | | | | | |
| | | | | | **$ 564,563.13** | | 74% | 97% | |

Table 8. The lifetime present value cost analysis of the APC Symmetra PX 20 kW.

| Part E | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| company | APC | | | | | | | |
| Name (PN) | Symmetra PX 20kW Scalable to 40kW N+1, 208V + (1)SYBT4 Battery Unit, SY20K40F | | | | | | | |
| Power/Unit | 20 | kW | | | | | | |
| Efficiency | 92% | | | Battery Disposal | $ 0.35 | $/lb | | |
| http://www.apcc.com/tools/ups_selector/index.cfm | | | | | | | | |
| Current $ | | | | | | PDV (sum) | | |
| Unit Cost | Battery Cost | Environmental Costs | Actual Power Cost | Future $ | PDV | | Percent Operation | Efficiency |
| $ 30,250.00 | | | $ 2,253.18 | $ 32,503.18 | $ 32,503.18 | $ 32,503.18 | 13% | 85% |
| | | | $ 7,719.09 | $ 8,027.85 | $ 7,645.57 | $ 40,148.75 | 45% | 92% |
| | | | $ 15,017.92 | $ 16,243.38 | $ 14,733.22 | $ 54,881.97 | 85% | 92% |
| | $1,750.00 | $ 70.00 | $ 16,241.88 | $ 20,317.15 | $ 17,550.72 | $ 72,432.69 | 89% | 92% |
| | | | $ 17,565.59 | $ 20,549.25 | $ 16,905.92 | $ 89,338.62 | 94% | 92% |
| | | | $ 18,997.18 | $ 23,112.98 | $ 18,109.62 | $ 107,448.24 | 98% | 92% |
| $ 4,850.00 | $1,750.00 | $ 70.00 | $ 20,545.45 | $ 34,436.23 | $ 25,696.85 | $ 133,145.09 | 69% | 92% |
| | $1,750.00 | $ 70.00 | $ 22,219.91 | $ 31,634.88 | $ 22,482.32 | $ 155,627.41 | 72% | 92% |
| | | | $ 24,030.83 | $ 32,887.85 | $ 22,259.79 | $ 177,887.20 | 76% | 92% |
| | $1,750.00 | $ 70.00 | $ 25,989.34 | $ 39,581.37 | $ 25,514.50 | $ 203,401.70 | 80% | 92% |
| | $1,750.00 | $ 70.00 | $ 28,107.48 | $ 44,299.98 | $ 27,196.34 | $ 230,598.05 | 84% | 92% |
| | | | $ 30,398.24 | $ 46,796.69 | $ 27,361.05 | $ 257,959.10 | 88% | 92% |
| | $1,750.00 | $ 70.00 | $ 32,875.69 | $ 55,548.92 | $ 30,931.72 | $ 288,890.82 | 92% | 92% |
| $ 4,850.00 | $1,750.00 | $ 70.00 | $ 35,555.06 | $ 70,307.83 | $ 37,285.74 | $ 326,176.56 | 73% | 92% |
| | | | $ 38,452.80 | $ 66,587.81 | $ 33,631.37 | $ 359,807.93 | 76% | 92% |
| | $1,750.00 | $ 70.00 | $ 41,586.70 | $ 78,173.02 | $ 37,602.56 | $ 397,410.49 | 80% | 92% |
| | $1,750.00 | $ 70.00 | $ 44,976.02 | $ 87,648.06 | $ 40,152.59 | $ 437,563.08 | 84% | 92% |
| | | | $ 48,641.56 | $ 94,748.93 | $ 41,338.64 | $ 478,901.72 | 88% | 92% |
| | $1,750.00 | $ 70.00 | $ 52,605.85 | $ 110,256.79 | $ 45,813.97 | $ 524,715.69 | 93% | 92% |
| | $1,750.00 | $ 70.00 | $ 56,893.23 | $ 123,699.92 | $ 48,952.26 | $ 573,667.95 | 97% | 92% |
| | | | | | | | | |
| | | | | | **$ 573,667.95** | | 79% | 92% |

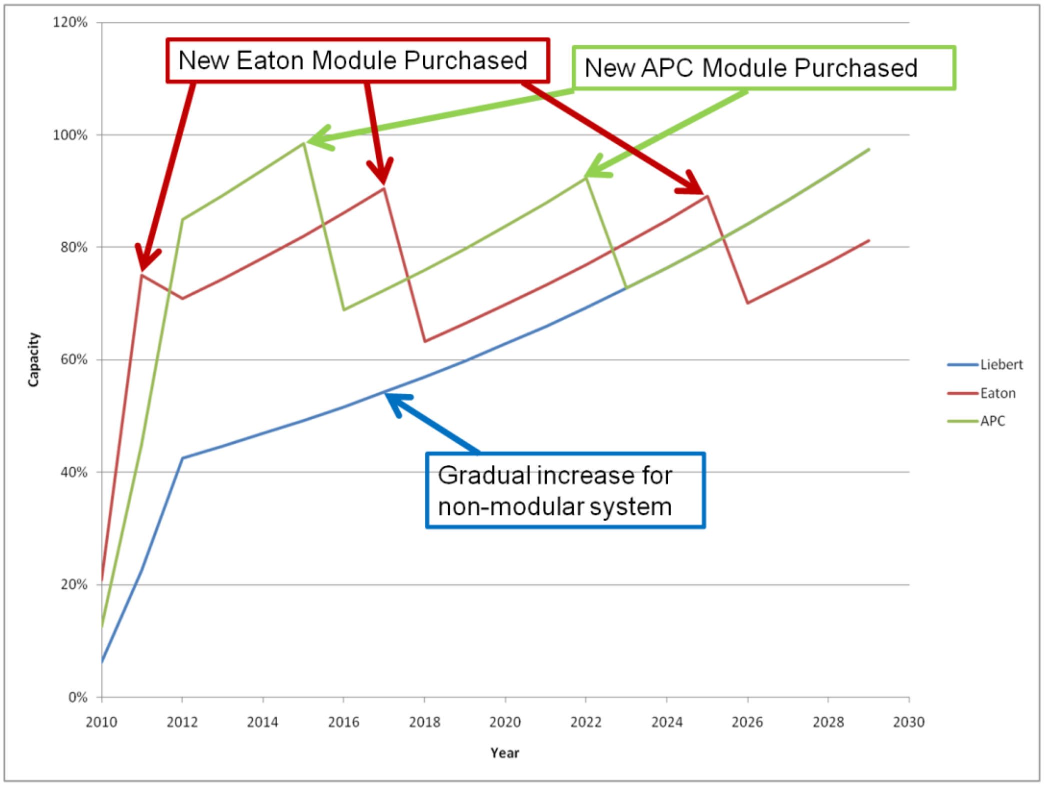



Figure 2. The capacity level for three of the UPS options. The capacity changes when an additional module is added.

A large portion of this cost is the cost of electricity, which heavily depends on the UPS efficiency. Consequently, a high efficiency UPS generally cost less than a low efficiency UPS. This fact caused the Eaton Powerware Blade scalable model with a 12kW module to be the lowest cost because of its 97% efficiency. The total costs as a percent of the base case (the Eaton Blade 12kWh UPS) is shown in Figure 3.

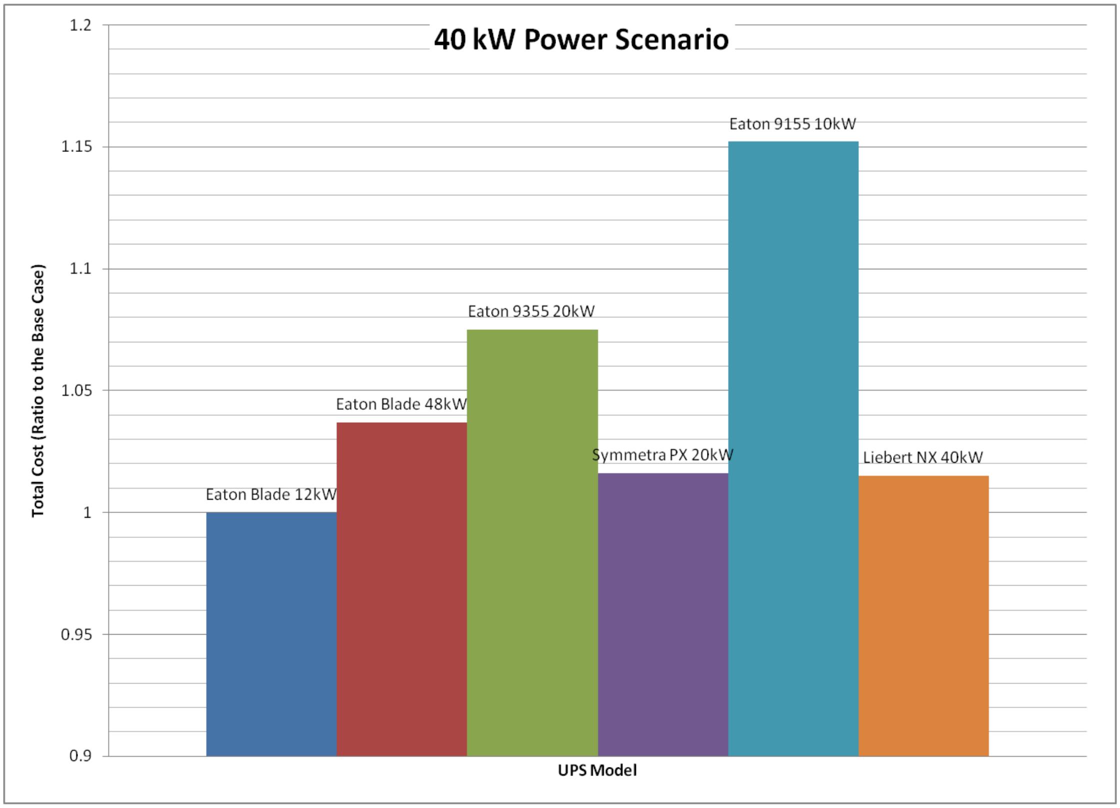



Figure 3. The comparative lifetime present value cost of each UPS option as a percent of the base case.

### 4.2.2. Environment

The environmental cost of the batteries was modeled by the cost to dispose of the used UPS batteries through Battery solutions in Brighton, Michigan. They quoted the price of battery disposal at $0.35/lb. This cost includes everything required to eliminate negative environmental impacts of the batteries.

## 4.3 Additional Considerations

Because the life cycle cost of each UPS option is so similar, additional considerations have been made to determine the optimum UPS for this project.

### 4.3.1. Instrumentation

None of the UPS alternatives are compatible with the NetBOTZ 500, which is the instrumentation package selected by the Instrumentation Team.

### 4.3.2. HVAC

Due to the high efficiencies of UPSs, heat generation is minimal. The UPS does not significantly impact the load on the HVAC system. Also, the increased efficiency of the new UPS is not only an improvement over the old UPS, but it decreases the load on the HV AC system, improving its overall efficiency.

### 4.3.3. Envelope

All UPS options are the same in physical size. They all fit into one server-rack-sized case. The footprint of this case is 7 $ft.^2$. Therefore, no additional envelope considerations are necessary.

## 5. Conclusions

The best option for the new data center is the Eaton Powerware Blade with a single 12kW module. It has the lowest lifetime cost due to both its efficiency of 97% and the fact that it runs at an average of 74% capacity over its 40 year lifetime. This is the option chosen by both CIT and the Engineering 333 class. CIT chose this option based on cost effectiveness, the engineering students confirmed it based on cost, efficiency, and environmental sustainability.

# Instrumentation Appendix

Completed by: Instrumentation Team
Betsy Huyser, Jason Dornbos, Jason Handlogten, Justin Karsten, Matt Milan

# Table of Contents

# 1. Introduction

The new redundant data center requires that NOC (Network Operations Center) personnel are able to monitor certain conditions within the data center to monitor the safety of the server equipment. Server equipment will fail if it gets too hot or if the surrounding environment becomes too humid, therefore the baseline instrumentation design must monitor both temperature and humidity in the data center. The system must also be capable of remotely alerting NOC personnel when there is a problem.

Instrumentation systems require two basic components: hardware and software. The hardware reads data while the software is responsible for collecting and displaying the data. In addition to the instrumentation required for the baseline design, the instrumentation for the CERF design, or the more energy efficient design, must be capable of measuring energy savings due to the efficiency improvements.

# 2. Existing data center

## 2.1 Current NetBotz Configuration

The data center currently being used by Calvin College uses NetBotz 310 and 320 models. These units connect directly to the local network, and do not connect to any central NetBotz server. These NetBotz modules monitor temperature and humidity, as well as take pictures of anyone who enters the data center. If the humidity is out of the acceptable range, or the temperature exceeds the set maximum, the NetBotz module will send a text message, place a phone call, or send an email to the CIT staff to alert them of a potential problem. If a person enters the existing data center, a picture is taken and emailed to the CIT staff. This allows the network controllers to monitor access to the servers. Currently, these NetBotz units do not connect to any central NetBotz server.

## 2.2 Current Power Loads

The current power loads on the existing data center can be divided up into two distinct categories: HVAC Power and Server Power. The server power is the power that comes from the UPS and is used to run the servers, NetBotz, and other computer equipment. The HVAC power comes directly from the wall circuit (skipping past the UPS) and powers the HVAC system. The server power has a maximum value of 40kW, but usually runs at 70-75% of the maximum (≈30kW). The HVAC system runs at about 35kW at the maximum, and 24.5kW on average.

# 3. New data center baseline design

## 3.1 NetBotz

The baseline design for the new redundant data center includes the newest version of the same NetBotz system used in the old data center. The main unit of the system is the NetBotz 500, which acts as the brain of the system and collects all of the data from the various sensors.

In order to monitor temperature, there are temperature sensors for each rack included with the cooling system. This data will be run to the software and combined with the NetBotz data. Additionally, the NetBotz 500 has a temperature sensor to measure the overall room temperature. This will make sure that the room does not overheat and that each individual rack is kept at an appropriate temperature as well.

In addition to environmental conditions in the room, contacts from CIT requested that the power used by the racks and the HVAC system be measured as well. In order to monitor power to each rack, a Metered Rack Power Distribution Unit (PDU) will be placed in each rack. Each PDU will connect directly to the NetBotz 500. In order to monitor power to the HVAC system, an AC current transducer will be placed on the system's incoming power supply. The transducer can run to a NetBotz 4-20mA Sensor pod, which connects to the NetBotz 500. The UPS power will also be measured with a current transducer that connects to the 4-20mA Sensor pod.

### 3.2 Statseeker Network Monitoring Software

The software that CIT currently uses is Statseeker. It has not been fully tested so CIT is not certain about its capabilities. CIT plans to do any configuring and programming required for this software system.

## 4. Energy efficiency design improvements

### 4.1 Additional Sensors

The instrumentation system for the energy efficient layout starts with the base case design. However, the more efficient design includes a heat exchanger with the pool that must be monitored as well. In order to properly measure this heat exchange, two platinum resistance temperature devices (RTDs) and one ultrasonic flow meter were added to the instrumentation system. With these additional measurements, the energy savings created by offsetting the cost of heating the pool can be calculated. The heat exchanger would be paid for by the CERF fund, therefore the energy savings created by heating the pool must be measured and reported to CERF. The approximate placement of these additional sensors is shown in Figure 1.

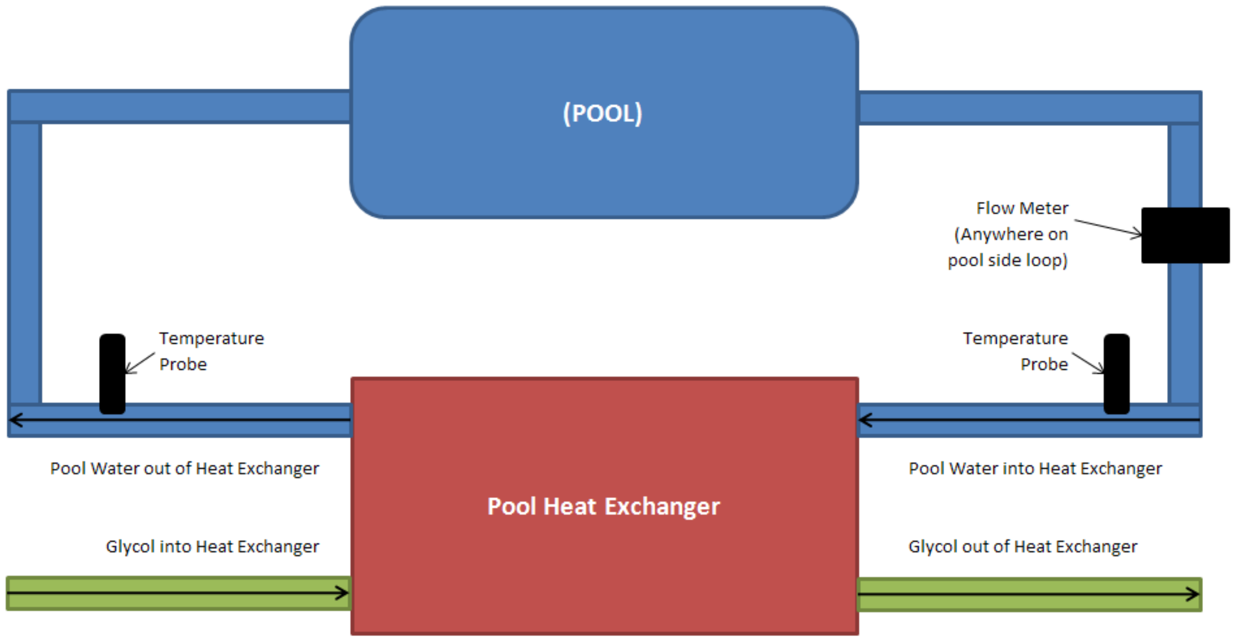



Figure 1: Schematic of Sensor Placement for Pool Energy Savings Monitoring

## 4.2 LabVIEW

LabVIEW instrumentation was chosen for the additional portion of the instrumentation system. LabVIEW software is already available on select computers on campus, and there are people on campus who are familiar with the use and maintenance of LabVIEW systems. In this system, two LabVIEW modules read measurements, one from the platinum RTDs and the other from the ultrasonic flow meter. This data is collected by a LabVIEW fieldpoint unit and sent via Ethernet to the Calvin network. A software program was written that can take this data and calculate energy savings; the user interface for this program is shown in Figure 2.


Figure 2: Image of User Interface Screen for LabVIEW Energy Savings Software Program

## 4.3 Data Flow

The flow of information is very important in this design. There are many different sensors gathering data and all of the information needs to end up on the Calvin network, where it is then available for NOC personnel or CERF personnel. Figures 3 and 4 are diagrams showing the data flow through the various components. Figure 3 details the data flow through the NetBotz system, and Figure 4 shows the data flow through the LabVIEW system.

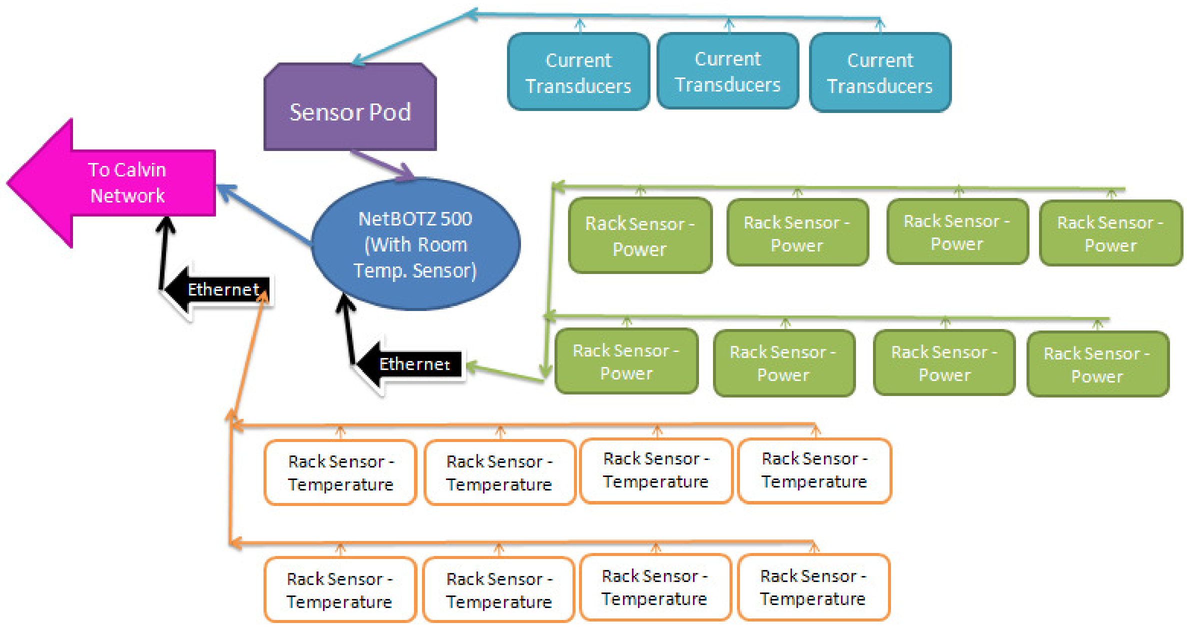



Figure 3: Flow of Data through NetBotz System

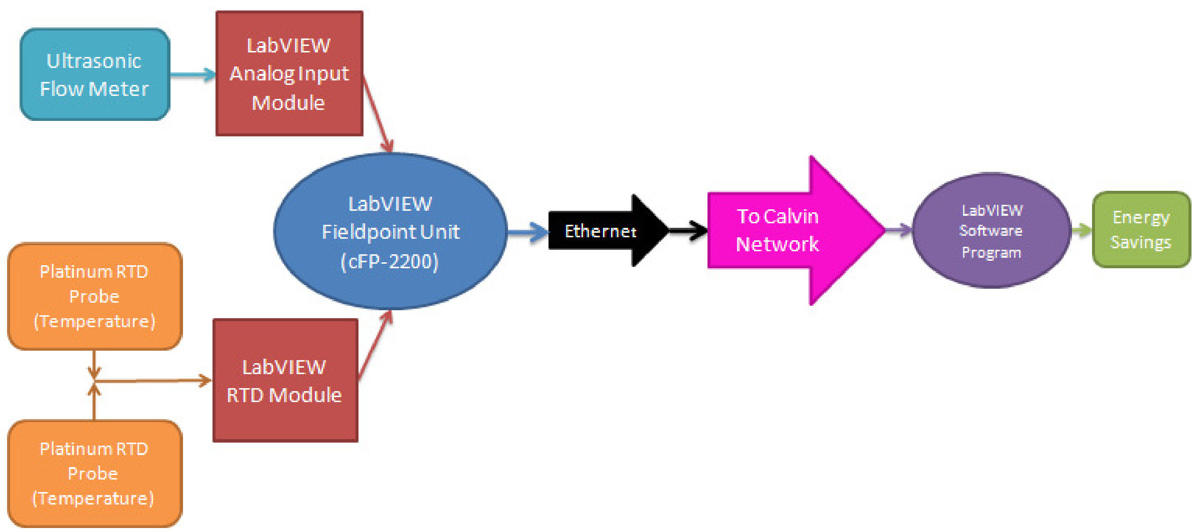



Figure 4: Flow of Data through LabVIEW System

# 5. Conclusions

The best option for the new data center is to implement two separate instrumentation systems, one for the data center environment and one to measure energy savings of the system. The first system is necessary for warning CIT when there are problems and gives them the ability to shut down units remotely. This system integrates with their current monitoring system and eliminates the need for CIT to rely on the more complex and expensive LabVIEW system. The LabVIEW system needs to be implemented for energy accountancy reasons. The pool heat exchanger needs to be justified with hard data, otherwise CERF will not fund the energy efficient design. This system keeps track of energy savings, and allows for future customizations to be implemented. Since the pool heat exchanger is of no concern to CIT, this more complex and customizable system can be implemented without requiring CIT workers to be trained on LabVIEW equipment.

# 6. Supporting Information

## 6.1 Base Case Layout

- Temperature
    - Rack
        - The HVAC system incorporates temperature sensors for each rack. This data can run to the NetBotz system.
    - Room
        - NetBotz 500 has a built in sensor for the room temperature.
    - Pool
        - Two platinum resistance temperature devices (RTDs) will be placed around the heat exchanger to measure the temperature of the pool water. One will be downstream from the heat exchanger and one will be upstream. These connect to a LabVIEW RTD module that connects to a LabVIEW fieldpoint unit.
    - HVAC
        - This is possibly unnecessary. This will not overheat and energy calculations are being determined through power consumption.
- Power
    - Rack
        - Metered Rack Power Distribution Unit. This gives information to the NetBotz 500 through Ethernet cable
    - HVAC

        - An AC current transducer will be placed on the incoming power supply to the HVAC. This runs to the NetBotz 4-20mA Sensor pod which connects to the NetBotz 500.

    - Pool

        - The energy dumped to the pool will be calculated using temperatures and volumetric flow rate. An ultrasonic flow meter will be placed on the pool side of the heat exchanger. This flow meter will connect to a LabVIEW AI (Analog Input) module that connects to a LabVIEW fieldpoint unit.

    - Pump

        - A pump will be used for the cooling loop to the pool. The power usage of this pump will be determined using a current transducer. This transducer will connect to the 4-20mA sensor pod and feed back to the main NetBotz.

## 6.2 Base Case Costing

| Component | Unit Cost | Qty. | Cost | |
|---|---|---|---|---|
| *RACK* | | | | |
| Metered Rack PDU | $0.00 | 8 | $0.00 | With Cabinets |
| Temperature Sensor | $0.00 | 8 | $0.00 | With HVAC |
| *GENERAL* | | | | |
| Netbotz 500 | $2,177.99 | 1 | $2,177.99 | |
| *ROOM* | | | | |
| 4-20mA Sensor Pod | $379.99 | 1 | $379.99 | |
| Current Transducer | $97.08 | 3 | $291.24 | |
| *LABOR* | | | | |
| Estimated installation cost | - | - | $200.00 | |
| | | Total: | $3,049.22 | |
| | | Total With 10% Contingency: | $3,354.14 | |
| | | Est. Annual Maintenance Cost: | $335.41 | |

## 6.3 Pool Monitoring Parts List for CERF Case

### Flow meter: ultrasonic. Preso PTTF Transit Time Flow Meter

**Part # or Name:** Preso PTTF Ultrasonic
**Description:** Flow meter with 4-20mA output standard, >2" pipe
**Unit Price/Quantity:** $1708 (1, includes cost of transmitter, transducer, and PC cable)
**Other Info:** Paul orders these through RL Deppmand, quote was from Preso rep for components required for basic setup

http://www.preso.com/index.cfm?fa=prd.home&sec=731

### Temperature measurement: platinum RTD probes

**Part # or Name:** PR-10-2-100-1/8-6-E
**Description:** RTD probe, lead type 2 (3-wire configuration), 100 ohms, 1/8" dia.SS sheath, 6" long, with 36" PFA insulated leads terminating in stripped ends, European curve (alpha = 0.00385)
**Unit Price/Quantity:** $63.00 (2)
**Other Info:** Paul orders these through Sean Elkins from Power Supply

http://www.omega.com/ppt/pptsc.asp?ref=PR-10

### LabVIEW brain

**Part # or Name:** 777317-2200 (cFP-2200)
**Description:** LabVIEW Real-Time/Ethernet Controller 128 MB DRAM
**Est. Shipping:** 12 – 20 days
**Unit Price/Quantity:** $ 1,599.00 (1)

http://www.ni.com/labview/

### Other LabVIEW Hardware

**Part # or Name:** 777318-110 (NI-cFP-AI-110)
**Description:** 8 ch, 16-Bit Analog Input Module (mA, mV, V)
**Unit Price/Quantity:** $ 529.00 (1)
**Part # or Name:** (NI cFP-RTD-122)
**Description:** cFP-RTD-122, 16 Bit RTD Input Module (RTD, Ohms)
**Unit Price/Quantity:** $ 529.00 (1)
**Part # or Name:** 778618-01 (cFP-CB-1)
**Description:** Connector Block
**Unit Price/Quantity:** $ 169.00 (2)
**Part # or Name:** 778617-08 (cFP-BP-8)
**Description:** 8-Slot Backplane
**Unit Price/Quantity:** $ 799.00 (1)
**Part # or Name:** 778586-90 PS-4, 24 VDC, Universal Power Input Din Rail Mt
**Description:** PS-4 Power Supply, 24 VDC, Universal Power Input Din Rail Mount
**Unit Price/Quantity:** $ 249.00 (1)

http://www.ni.com/labview/

### 6.4 CERF Case Costing

| Component | Unit Cost | Qty. | Cost | |
|---|---|---|---|---|
| *RACK* | | | | |
| Metered Rack PDU | $0.00 | 8 | $0.00 | With Cabinets |
| Temperature Sensor | $0.00 | 8 | $0.00 | With HVAC |
| *GENERAL* | | | | |
| Netbotz 500 | $2,177.99 | 1 | $2,177.99 | |
| LabVIEW Brain - cFP-2200 | $1,559.00 | 1 | $1,559.00 | Incremental Efficient Cost |
| LabVIEW Module NI-cFP-AI-110 | $529.00 | 1 | $529.00 | Incremental Efficient Cost |
| LabVIEW Module NI cFP-RTD-122 | $529.00 | 1 | $529.00 | Incremental Efficient Cost |
| LabVIEW Connector Block cFP-CB-1 | $169.00 | 2 | $338.00 | Incremental Efficient Cost |
| LabVIEW Back Plane cFP-BP-8 | $799.00 | 1 | $799.00 | Incremental Efficient Cost |
| Power Input - 778586-90 PS-4 | $249.00 | 1 | $249.00 | Incremental Efficient Cost |
| *ROOM* | | | | |
| 4-20mA Sensor Pod | $379.99 | 1 | $379.99 | |
| Current Transducer | $97.08 | 3 | $291.24 | |
| *POOL* | | | | |
| Platinum RTD | $63.00 | 2 | $126.00 | Incremental Efficient Cost |
| Ultrasonic Flow Meter | $1,708.00 | 1 | $1,708.00 | Incremental Efficient Cost |
| *LABOR* | | | | |
| Estimated installation cost | - | - | $400.00 | |
| | | Total: | $9,086.22 | |
| | | Total With 10% Contingency: | $9,994.84 | |
| | | Est. Annual Maintenance Cost: | $999.48 | |

## 6.5 LabVIEW Program Coding and Excel Output

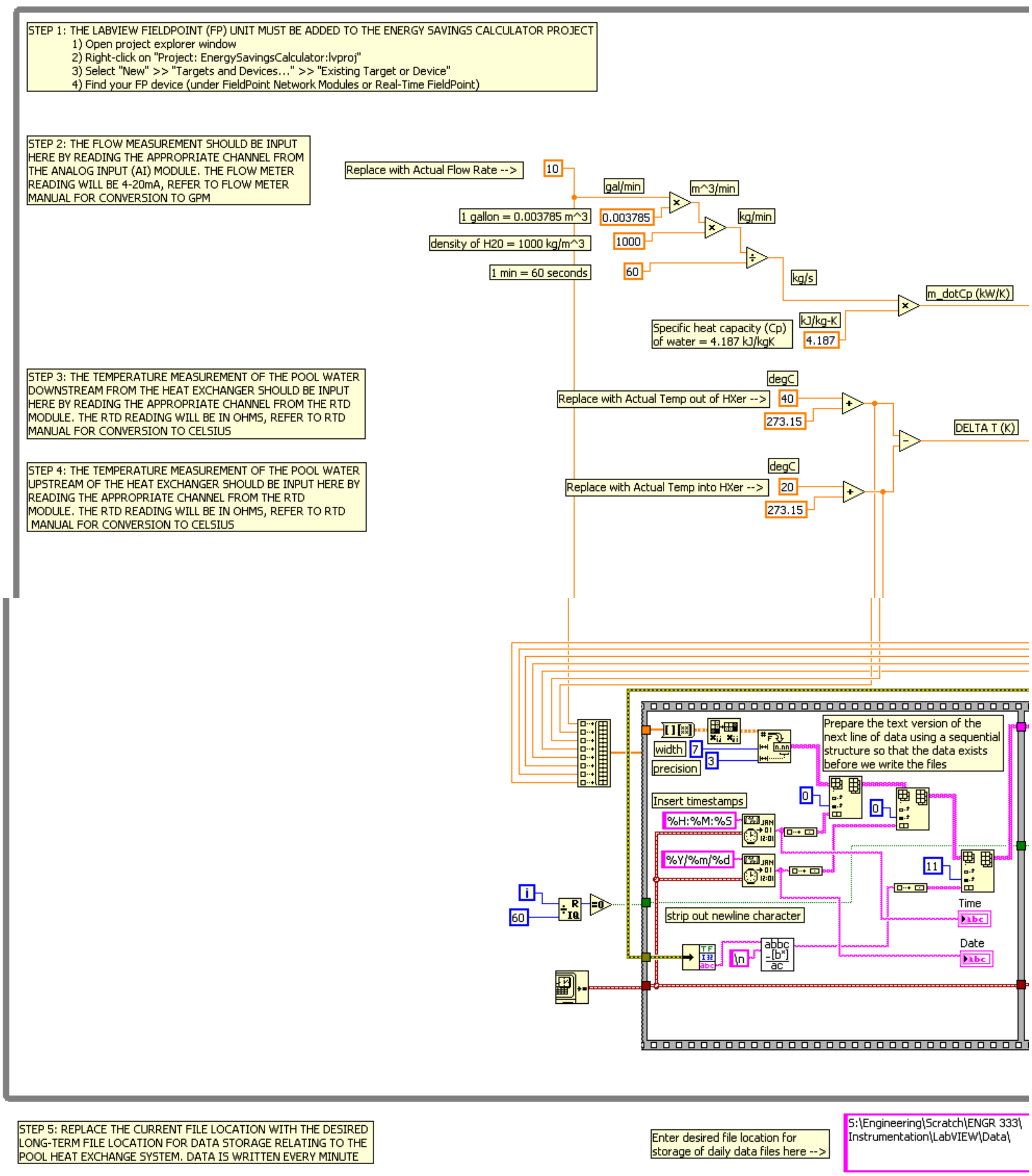



Figure 5: Left Half of LabVIEW Software Code

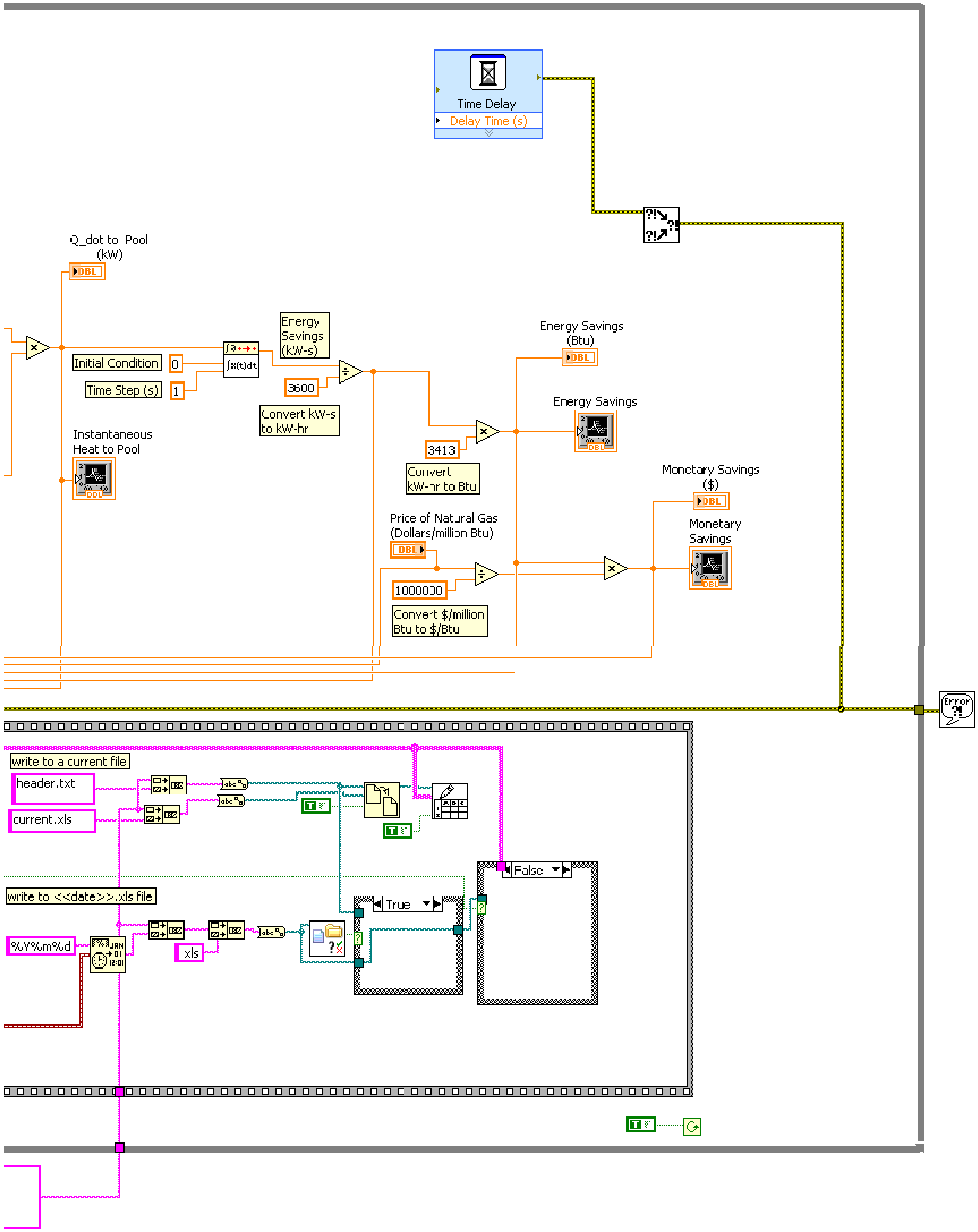



Figure 6: Right Half of LabVIEW Software Code

Table 1: Sample Data File, Written to Excel from LabVIEW (arbitrary numbers)

| Date | Time | Flow Rate | Pool Water Temperature Out of HXer | Pool Water Temperature Into HXer | Q_dot to Pool | Energy Saving s | Energy Savings | Natural Gas Price | Monetary Savings | Err |
|---|---|---|---|---|---|---|---|---|---|---|
| [mm/dd/yy yy] | [hh:mm:ss] | [gpm] | [K] | [K] | [kW] | [kW-hr] | [Btu] | [$/million Btu] | [$] | |
| 4/27/2010 | 15:10:49 | 10 | 313.15 | 293.15 | 52.826 | 0.007 | 25.041 | 7.8 | 0 | |
| 4/27/2010 | 15:11:51 | 10 | 313.15 | 293.15 | 52.826 | 0.885 | 3021.612 | 7.8 | 0.024 | |
| 4/27/2010 | 15:12:53 | 10 | 313.15 | 293.15 | 52.826 | 1.766 | 6026.53 | 7.8 | 0.047 | |
| 4/27/2010 | 15:13:56 | 10 | 313.15 | 293.15 | 52.826 | 2.646 | 9031.448 | 7.8 | 0.07 | |
| 4/27/2010 | 15:14:58 | 10 | 313.15 | 293.15 | 52.826 | 3.527 | 12036.37 | 7.8 | 0.094 | |
| 4/27/2010 | 15:16:00 | 10 | 313.15 | 293.15 | 52.826 | 4.407 | 15041.28 | 7.8 | 0.117 | |
| 4/27/2010 | 15:17:02 | 10 | 313.15 | 293.15 | 52.826 | 5.287 | 18046.2 | 7.8 | 0.141 | |
| 4/27/2010 | 15:18:03 | 10 | 313.15 | 293.15 | 52.826 | 6.168 | 21051.12 | 7.8 | 0.164 | |
| 4/27/2010 | 15:19:05 | 10 | 313.15 | 293.15 | 52.826 | 7.048 | 24056.04 | 7.8 | 0.188 | |
| 4/27/2010 | 15:20:07 | 10 | 313.15 | 293.15 | 52.826 | 7.929 | 27060.96 | 7.8 | 0.211 | |
| 4/27/2010 | 15:21:09 | 10 | 313.15 | 293.15 | 52.826 | 8.809 | 30065.87 | 7.8 | 0.235 | |
| 4/27/2010 | 15:22:11 | 10 | 313.15 | 293.15 | 52.826 | 9.69 | 33070.79 | 7.8 | 0.258 | |
| 4/27/2010 | 15:23:12 | 10 | 313.15 | 293.15 | 52.826 | 10.57 | 36075.71 | 7.8 | 0.281 | |
| 4/27/2010 | 15:24:14 | 10 | 313.15 | 293.15 | 52.826 | 11.451 | 39080.63 | 7.8 | 0.305 | |
| 4/27/2010 | 15:25:16 | 10 | 313.15 | 293.15 | 52.826 | 12.331 | 42085.55 | 7.8 | 0.328 | |
| 4/27/2010 | 15:26:18 | 10 | 313.15 | 293.15 | 52.826 | 13.211 | 45090.46 | 7.8 | 0.352 | |
| 4/27/2010 | 15:27:20 | 10 | 313.15 | 293.15 | 52.826 | 14.092 | 48095.38 | 7.8 | 0.375 | |
| 4/27/2010 | 15:28:22 | 10 | 313.15 | 293.15 | 52.826 | 14.972 | 51100.3 | 7.8 | 0.399 | |

# Alternative Options Appendix

Completed by: Power Supply Team
Tim Opperwall, Andrew DeJong, Joel Love, Alex Boelkins, Amanda Hollinger

# Table of Contents

# 1. Introduction

As the need for data storage, processing speed, and system flexibility has increased over the years, various companies have seen a dramatic shift in the way they handle their computing needs. Large companies such as Google and Amazon have large data centers around the world that are not always being used at full capacity. By opening the available processing power to other users over the internet, they are able to provide a dynamic and scalable computing service to other companies. This shift towards more dynamic, location-independent, and service based computing has been termed “cloud computing”. All data storage and processing power is provided by a separate company and accessed over a secure internet connection. This transition is still occurring and Calvin College is trying to determine where cloud computing can meet their needs and still provide an adequate solution to the increasing computing requirements.

# 2. Cloud Computing Basics

## 2.1 Advantages

For new startups, cloud computing offers a much lower capital cost than purchasing an entire set of servers and the associated storage. As Brad Jefferson of New York based Animoto notes: "Cloud computing is really a no-brainer for any start-up because it allows you to test your business plan very quickly for little money." The company only pays for the amount of processing that it uses and as a result, companies are able to develop IT costs as an operational cost rather than a large initial investment.

Another advantage is the scalability of cloud computing. It is typically impossible to predict how much computing power will be needed in five years, which makes it hard to design a cost-effective data center. By utilizing cloud computing, it is very easy to dynamically scale your server requirements as the need arises. Once again, this presents a large cost savings.

Finally, because cloud computing uses other resources and is essentially a service, there is a greater sense of business agility. There is no need for a fully committed IT department that is in charge of the servers and data storage for a company. The cloud removes these commitments and hopefully provides a reliable service with no down time.

## 2.2 Disadvantages

For all of its advantages, cloud computing has been relatively slow to gain complete market acceptance. The most restrictive component is bandwidth. For companies (or colleges) that access and generate large amounts of data, there is simply not enough “room” for this data to be sent back and forth to a server room thousands of miles away. Perhaps this will be alleviated with a complete fiber internet network, but until that day, bandwidth is the largest hindrance to cloud computing.

Data security is another issue when using the cloud. The cloud provider essentially has access to all of a company’s data which can create a large security risk. For some companies, their data is simply not “cloud-worthy” because of these security concerns. In this case, it makes more sense to use a local computing network rather than leaving it in the cloud for all to see.

While it can be an advantage, the remoteness of cloud computing can provide a false sense of confidence when dealing with data. Although it may be in the cloud, there is still a physical server somewhere that is prone to outages, fire, and repairs. Cloud computing is simply not a cure-all solution that meets every IT need in a company; there are still pros and cons that need to be addressed.

### 2.3 Current Trends

Already, cloud computing is dynamically changing in ways that were never guessed. Numerous applications are already available in the cloud and can be accessed anywhere in the world (i.e. Gmail, Facebook, etc.). As large companies continue to increase their server capacity, competition will increase and the operating price will drop. Also, technology will continue to advance which will encourage more companies to shift towards cloud computing

## 3. Cloud Computing and Calvin College

### 3.1 Current Server Setup

Currently, there are approximately 3000+ desktops on the campus of Calvin College. All data is fed to the server room using a localized network. The disk arrays are currently fiber connected which is extremely fast and allows quick access from anywhere on campus. It is very hard to accurately predict a server growth rate, and as a result, hard to know where Calvin needs to go in the future. Currently, the servers use approximately 4 kW of electricity. The electrical needs could easily follow either one of the lines shown in the figure below.

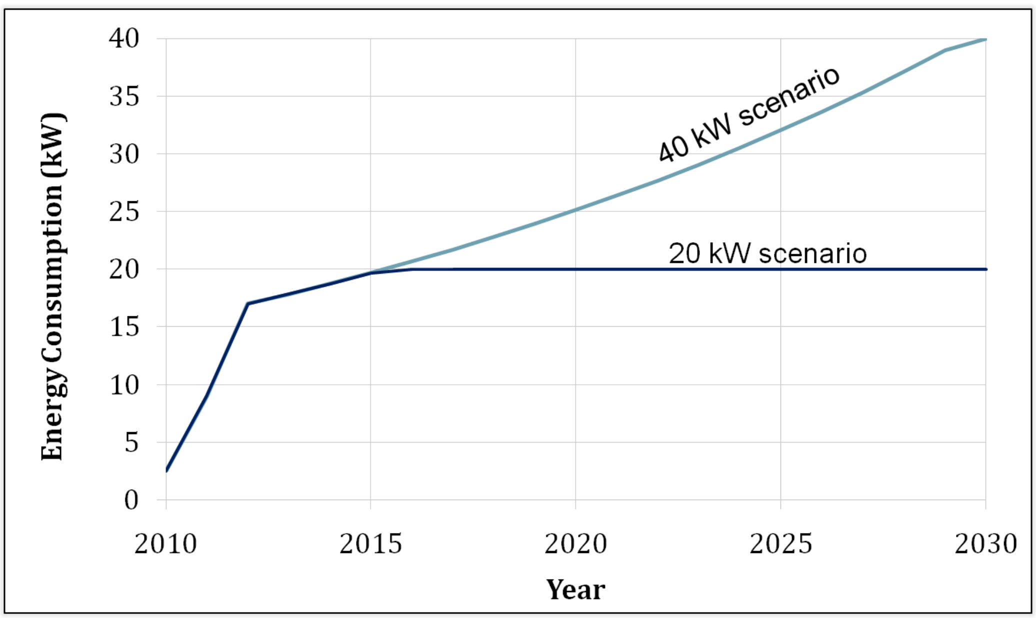



Figure 1. The two server energy requirement scenarios.

### 3.2 Current Issues

#### 3.2.1 Bandwidth

Every weekend, 15 terabytes of data is backed up to various drives in the server room. This large amount of data makes it impossible to shift entirely to cloud computing. Perhaps this will be alleviated when a Google Fiber network gets installed in Grand Rapids, but until then, bandwidth is one of the greatest factors preventing a transition to cloud computing.

#### 3.2.2 Private Data

Calvin College handles a large amount of data that should not be available to others. And if this data was on servers in the cloud, there is always a possibility of information theft. This sensitive data includes social security numbers, credit card information, as well as personal student info. Although it is a relatively small percent of the total data, it is not possible to divide it into different storage areas according to the level of security.

### 3.3 Cloud Transitions

Already, Calvin College has seen a shift towards cloud computing. Student email accounts are currently hosted by Google using some far-away server room and more change is coming. The next version of Knightvision will be in the cloud, offering greater flexibility and program options.

### 3.4 Virtual Desktop Infrastructure (VDI)

Another potential shift is toward virtual desktops. This is essentially cloud computing on a much more localized level. For example, all engineering programs could eventually be run on the main servers, allowing access from any computer on campus (not just those in the engineering labs). However, if Calvin did this, it would increase the server room requirements substantially. Every twenty desktops that become virtual require a new server to handle the processing. CIT does currently see this as an increasing trend. However, the new servers would not be located in either the current data center or the redundant data center and would likely require a new facility.

## 4. Conclusion

A complete transition to cloud computing is not currently feasible at Calvin College because of the sheer volume of data. However, there are several similar technologies that are being utilized and may gain greater use in the coming years. CIT sees a high possibility of using more virtual desktops on campus, but this trend does not affect the Redundant Data Center Project because the servers would be located in a new room. Also, more applications (such as Student Mail, Knightvision, etc.) will move to the cloud as the software and technology develops.

Given the continual increase in computing technology, it is tough to predict how Calvin College's computing needs will be met in the next 20 years. However, Calvin's network is likely to utilize some aspect of cloud computing in the way that makes the most sense.