Save Energy Now
Industrial Assessment Report
For

Sample Company

123 Imaginary Street

Samples, XX 12345

ENERGY EFFICIENCY CENTER

OREGON STATE UNIVERSITY
ENERGY EFFICIENCY CENTER

Assessment Report No. 0

January 1, 2012

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PREFACE

The work described in this report is a service of the Oregon State University Industrial Assessment Center (IAC). The project is funded by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) Industrial Technologies Program and managed by Rutgers University Center for Advanced Energy Systems.

The primary objective of the IAC is to identify and evaluate opportunities for energy conservation, waste minimization, and productivity improvements through visits to industrial sites. Data is gathered during a one-day site visit and assessment recommendations (ARs) are identified. Some ARs may require additional engineering design and capital investment. When engineering services are not available in-house, we recommend that a consulting engineering firm be engaged to provide design assistance as needed. In addition, since the site visits by IAC personnel are brief, they are necessarily limited in scope and a consulting engineering firm could be more thorough.

We believe this report to be a reasonably accurate representation of energy use, waste generation, and production practices, and opportunities in your plant. However, because of the limited scope of our visit, the U.S. Department of Energy, Rutgers University, and the Oregon State University Industrial Assessment Center cannot guarantee the accuracy, completeness, or usefulness of the information contained in this report, nor assume any liability for damages resulting from the use of any information, equipment, method or process disclosed in this report.

Pollution prevention recommendations are not intended to deal with the issue of compliance with applicable environmental regulations. Questions regarding compliance should be addressed to either a reputable consulting engineering firm experienced with environmental regulations or to the appropriate regulatory agency. Clients are encouraged to develop positive working relationships with regulators so that compliance issues can be addressed and resolved.

The assumptions and equations used to arrive at energy, waste, productivity, and cost savings for the recommended ARs are given in the report. We believe the assumptions to be conservative. If you would like to revise the assumptions you may follow the calculation methodologies presented using adjusted assumptions to develop your own revised estimates of energy, waste, productivity, and cost savings.

Please feel welcome to contact the IAC if you would like to discuss the content of this report or if you have another question about energy use or pollution prevention. The IAC staff that visited your plant and prepared this report is listed on the preceding page.

TABLE OF CONTENTS

1. INTRODUCTION

This report describes how energy is used in your facility, and includes our recommendations on cost effective steps you can take to reduce your energy and waste costs and increase productivity. The contents are based on our recent visit to your plant. The report is divided into 6 major sections and appendices:

1. **Introduction.** The purpose, contents and organization of the report are described.

2. **Executive Summary.** Your energy use and waste generation costs, productivity, energy, and waste savings, and our recommendations are summarized here with details in the following sections.

3. **Assessment Recommendations.** This section contains our Assessment Recommendations (AR), briefly highlights the current and proposed systems and summarizes the cost savings available upon implementation. Some of our recommendations will require a significant investment to implement, while others will cost little or nothing. We have grouped our recommendations by category and then ranked them by payback period, limited by the maximum acceptable payback that you specified.

4. **Site Data.** This section contains all relevant or necessary data that was gathered on site or listed as reference values and used in the Assessment Recommendations. Utility bills and energy use by process are summarized and plotted in detail. Due to the changes in rate schedules and adjustments our calculations are an approximation and may not be exactly consistent with your bills.

5. **Sector Best Practices.** The measures presented in this section are considered to be ideal operating standards. While these recommendations were not pursued, they are generally considered to be the most efficient operating conditions and are presented as suggestions to improve your energy efficiency beyond what is formally presented in this report. We recommend that a licensed energy engineer is consulted before investing in any efficiency projects.

6. **Appendices.** All applicable appendices are presented here, and may include Utilities, Motor, Boiler, Lighting, Compressed Air, and Fans/Impeller systems. Appendices may include background information, definitions, equations, tables and graphs.

2. EXECUTIVE SUMMARY

This section includes a summary of energy use and waste generation in your plant, our recommendations, and total productivity, energy, waste, and cost savings of all recommendations if implemented.

Recommendation Summary

Following is a brief explanation of each recommendation provided in this report. If all recommendations are implemented, total cost savings will be $269,973 and will pay for costs in 1.3 years. This represents a 46.6% overall reduction in utility costs.

AR No. 1, Efficient Fan Blades
We recommend replacing the radial blade with a higher efficiency radial-tip fan blade in the manufacturing dust collection system. We estimate fan efficiency can be improved from the current average of 28.5% to a reasonable average of 70.0%, reducing fan operation costs by 59.3%.

AR No. 2, Insulate Pipes
Insulate the steam pipes in the line two press enclosure with one inch fiberglass insulation covered with an aluminum jacket to prevent corrosion. These changes are expected to reduce energy loss by 51%.

AR No. 3, Boiler Fan VFD
Install a variable frequency drives (VFD) on the 75 horsepower Natural Gas Boiler induced draft fan. Variable frequency drives control airflow by automatically adjusting fan motor speed. This is more efficient than the current mechanical damper method, and will reduce associated annual energy consumption by 54%.

AR No. 4, Flash Steam Recovery
Install a pressure vessel to capture flash steam from the return condensate. This can be used to heat the vat wells or to preheat makeup water that is currently being heated in the boiler. This will reduce boiler fuel use and associated fuel consumption by 11%.

AR No. 5, Convert Headrig to AC Drive
We recommend replacing the current headrig hydraulic drive with an electric AC regenerative drive. This will reduce energy consumption and maintenance costs and increase productivity reducing annual associated costs by 70%.

AR No. 6, Pump Efficiency
We recommend optimizing the cooling tower supply system by replacing the pump. We estimate the system pumping efficiency can be improved from the current average of 53.3% to a reasonable average of 75.0%, reducing pump operation costs by 28.9%

AR No. 7, Photovoltaic Array
We recommend installing a photovoltaic array on the building roof. This will provide an alternative

source for 38.3% of the facilities energy consumption and reduce CO2 emissions associated with electrical generation.

Our recommendations are summarized in the following table.

Assessment Recommendation Summary						
AR#	Description	Percent Savings	Energy (MMBtu)	Cost Savings	Implementation Cost*	Payback (Years)
1	Efficient Fan Blades	2.9%	964	$18,195	$5,750	0.3
2	Insulate Pipes	1.2%	386	$2,066	$0	0.0
3	Boiler Fan VFD	2.7%	909	$13,319	$8,890	0.7
4	Flash Steam Recovery	90.2%	29,837	$71,700	$65,575	0.9
5	Convert Headrig to AC Dri	2.1%	708	$157,000	$191,000	1.2
6	Pump Efficiency	0.4%	129	$3,782	$3,921	1.0
7	Photovoltaic Array	0.4%	131	$3,911	$62,875	16.1
Totals		**100.0%**	**33,064**	**$269,973**	**$338,011**	**1.3**

* *Implementation Cost in this column represents your final cost after any applicable incentives.*

Total savings is the sum of the savings for each recommendation. Percent savings is each energy savings divided by the total energy savings of all recommendations. Some recommendations may interact. Therefore, actual savings may be less than the total indicated above. In our calculations we indicate where we have assumed that other recommendations will be implemented in order to provide a realistic estimate of actual savings. When either one or another recommendation can be implemented, but not both, we have included the most desirable recommendation in this table and the alternate recommendation in the Other Measures Considered section.

Total implementation cost represents final cost after any applicable incentives as detailed within each recommendation. The incentives detailed in this report are presented as a sample of the potential savings associated with state and federal incentive programs. We encourage you to investigate more incentive and grant possibilities. A comprehensive database of state and federal incentives and grants can be found online at http://www.dsireusa.org.

Energy Use Summary

We used your utility bills to determine annual energy use for all fuels. From these bills we summarized annual energy consumption at your plant in the following table.

Energy costs and calculated savings are based on the incremental cost of each energy source. The incremental rate is the energy charge first affected by an energy use reduction and is taken from your utility rate schedules. For example, electrical use and savings include energy (kWh), demand (kW), reactive power charges (KVAR or power factor), and other fees such as basic charges, transformer rental, and taxes. However, if a recommendation does not affect your electrical demand, such as turning off equipment at night, then we use the cost of electrical energy alone. The fuel costs we used can be found in the Utility Summary in the Site Data section.

Existing Energy Use Summary						
Source	Qty.	Units	MMBtu	Use %	Cost	Cost %
Electrical Consumption	4,470,644.0	kWh	15,258	38.9%	$312,497	53.9%
Electrical Demand	12,914.0	kW-mo			$60,302	10.4%
Natural Gas	23,936.1	MMBtu	23,936	61.1%	$206,572	35.7%
Total			**39,194**	**100.0%**	**$579,371**	**100.0%**

AR No. 1 - Efficient Fan Blades

Recommendation

We recommend replacing the radial blade with a higher efficiency radial-tip fan blade in the manufacturing dust collection system. We estimate fan efficiency can be improved from the current average of 28.5% to a reasonable average of 70.0%, reducing fan operation costs by 59.3%.

Assessment Recommendation Savings Summary

Source	*Quantity*	*Units*	*Cost Savings*
Electrical Consumption	282,447	kWh (site)	$14,122
Electrical Demand	68	kW Months / yr	$4,073
Total	**964.0**	**MMBtu**	**$18,195**

Assessment Recommendation Cost Summary

Description	*Cost*	*Payback*
Implementation Cost	$5,750	0.3

Facility Background

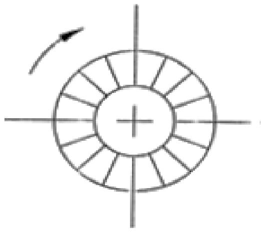
The facility currently uses radial fan blades on the dust collection fan. During the site assessment, plant personnel informed us that the fan is a material handling fan. Motor and fan nameplate information was collected during the site assessment by energy analysts. A power quality analyzer was used to collect live power readings of the motor under typical loading conditions. A manometer was used to collect various pressure readings on either side of the fan during typical loading conditions. Motor and fan data are summarized in the following Motor Analysis Tool (MAT) and Fan Efficiency Analysis Tool (FEAT) pages.

Technology Background

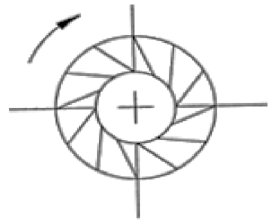
Dust collection systems can be arranged in either “material-handling” or “clean-side” configurations. Material-handling fans operate with particulates flowing through the fans and use positive pressure to push the material down stream. Clean-side fans operate down stream of the bag house where no particulates flow. They use negative pressure to pull particles from the plant into a bag house.

Material-handling fans are typically centrifugal fans in which air enters the fan axially and leaves radially. Centrifugal fans operate from a combination of centrifugal forces and angular deflection of the airflow by the blades. Centrifugal fans normally produce higher static pressure than axial-flow fans of the same wheel diameter and rotational speed. The wheel is known as the impeller or rotor, which contains a back plate, shroud, and blades. Material-handling fans are used to move air containing dust and granular materials from wood and metal working operations through ducts to cyclones or bag houses. These fans can handle high temperatures (up to 800 °F), corrosive fumes and abrasive materials from cutting or grinding operations.

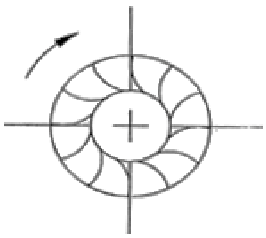
There are six types of centrifugal fan blades commonly used in dust collection systems. These blade types, efficiencies and characteristics are listed below.



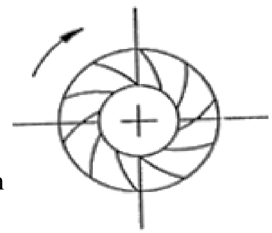
Radial Blade
- Static efficiency to 60%
- High tip speed capabilities
- Reasonable running clearances
- Best for erosive or sticky particulate



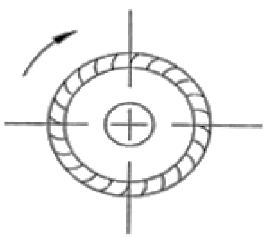
Backward Inclined
- Static efficiency to 80%
- Low-Medium tip speed capabilities



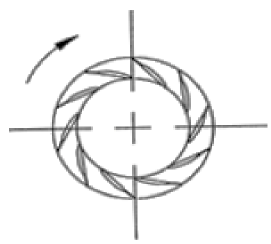
Radial Tip
- Static efficiency to 70%
- Medium-High tip speed capabilities
- Good for high particulate airstream



Backward Curved
- Static efficiency to 83%
- Medium-High tip speed capabilities
- Clean or dirty airstreams.
- Solid one-piece blade design



Forward Curved (Sirocco)
- Static efficiency to 65%
- Smallest diameter wheel for a given pressure requirement
- High volume capability
- Often used for high temps



Airfoil
- Static efficiency to 87%
- Medium-High tip speed capabilities
- Relatively tight running clearances

Radial type blades are most commonly used in industrial “material-handling” applications. Other types of blade configurations are prone to clogging and/or damage when material is passed through the fan. However the radial type blades have comparatively low efficiencies due to non-tangential flow conditions at the blades leading edge.

Proposal

We recommend replacing the radial blade with a higher efficiency radial-tip fan blade in the manufacturing dust collection system. Improved aerodynamics will enable the fan to move air more efficiently, reducing the power required from the fan motor, thus reducing associated annual energy consumption by 59.3%.

If the previously mentioned actions are taken, they will save 282,000 kWh annually and result in an annual cost savings of $18,200 for a net payback of 0.3 years after an implementation cost of $5,750.

Notes

Replacing fan blades often times provides a safer, and more enjoyable working environment for employees. Newer balanced fans are typically quieter and will help protect hearing and causes less fatigue and stress on employees. This may reduce the need for heavy duty ear protection and improve communication between employees.

Replacing fan blades often times reduces maintenance issues. Newer balanced fans vibrate less reducing bearing problems, stress cracking in duct work, while also reducing or eliminating the need for silencers.

Based on	Author	Readability Review	Engineering Review	Math Review
Original Template	*Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

AR No. 1 - Motor Analysis Tool (MAT)

Motor Identification

Motor Description	*Blower motor for end-sizer*
Motor Location	*End-sizer*

Data Collected

Motor Nameplate Data

Motor Power Supply Type		*3-Phase AC*	
Motor Enclosure Type		*TEFC*	
Motor Drive Type		*Standard V-Belt*	
Rated Horsepower	(W_R)	*150.0*	hp
Rated Voltage	(V_R)	*460*	volts
Rated Full-Load Amperage	(I_R)	*170.0*	amps
Rated Full-Load Speed	(N_R)	*1,780*	rpm
Rated Full-Load Efficiency	(η_R)		
Rated Full-Load Power Factor	(PF_R)		

Measured Data

Actual RMS Voltage	(V_A)	*475.0*	volts
Actual RMS Amperage	(I_A)	*160.0*	amps

Operational Data

Total Operation Hours	(t_t)	*4,160*	hrs./yr.
Load Factor	(LF)		

Motor Performance Analysis

Mechanical Drive Efficiency	(η_D)	*96.0%*		**(Rf. 1)**
Synchronous Speed	(N_S)	*1,800*	rpm	
Full-Load Amperage	(I_{FL})	*170.0*	amps	
Percent of Full-Load Amperage	($I_{\%}$)	*94.1%*		
Full-Load Efficiency	(η_{FL})	*95.0%*		**(Rf. 2)**
Full-Load Power Factor	(PF_{FL})	*87.0%*		
Part-Load Power Factor	(PF_{PL})	*87.0%*		**(Eq. 1, Rf. 3)**

Motor Energy Analysis

Electrical Power Input	(P)	*114.5*	kW	**(Eq. 2)**
Electrical Energy Consumption	(E)	*476,417*	kWh	**(Eq. 3)**
Mechanical Power Output	(W_o)	*140.1*	bhp	**(Eq. 4)**

Equations

Eq. 1) Part Load Power Factor (PF_{PL})

$$PF_{FL} \times \left(0.728 + \frac{0.4932}{I_{\%}} - \frac{0.2249}{I_{\%}^{2}} \right)$$

Eq. 2a) Power Input (3-Phase AC)

$$V_{(A\ or\ R)} \times I_{FL} \times I_{\%} \times PF_{PL} \times \sqrt{3} \times \frac{1kW}{1,000W}$$

Eq. 2b) Power Input (Single-Phase AC)

$$V_A \times I_A \times PF_{PL} \times \frac{1kW}{1,000W}$$

Eq. 2c) Power Input (DC)

$$V_A \times I_A \times \frac{1kW}{1,000W}$$

Eq. 3) Electrical Energy Consumption (E)

$$P \times t_M$$

Eq. 4) Mechanical Power Output (Wo)

$$P \times \eta_{FL} \times \eta_D \times \frac{1hp}{0.7457kW}$$

Notes

N. 1) Nameplate and operational data was collected during the site assessment from site personnel and equipment.

N. 2) Live current and voltage readings were collected by site personnel using a power quality analyzer.

References

Rf. 1) ACMA Publication 203, Field Performance Measurements of Fan Systems.

Rf. 2) NEMA Standards Publication MG 1-2006 (Premium Efficiency Motors).

Rf. 3) Part load power factor curve, in the Motor Appendix.

AR No. 1 - Fan Efficiency Analysis Tool (FEAT)

Fan Identification

Fan Description	*End-sizer blower*
Fan Location	*End-sizer*

Data Collected

Fan Pressure Data

Inlet Dynamic Pressure	(p_{vi})	*1.50*	in.-H_2O	**(N. 1)**
Outlet Dynamic Pressure	(p_{vo})	*1.40*	in.-H_2O	**(N. 1)**
Static Differential Pressure	(Δp_s)	*17.20*	in.-H_2O	**(N. 1)**

Ducting Data

Inlet Duct Inside Diameter	(d_i)	*24.0*	inches	**(N. 2)**
Outlet Duct Inside Diameter	(d_o)	*24.0*	inches	**(N. 2)**

Environmental Data

Barometric Pressure	(p_b)	*29.7*	in.-Hg	**(Rf. 1)**
Absolute Temperature	(T_a)	*519*	°R	**(Rf. 1)**

Input Power Data

Input Power to Fan Drive Shaft	(W_i)	*140.1*	bhp	**(Rf. 2)**

Fluid Properties

Air Density	(ρ)	*0.0758*	lb./ft.^{3}	**(Eq. 1)**
Gas Compressibility Factor	(K_p)	*0.98*		**(Rf. 3)**

Fan Specifications

Inlet

Inlet Gas Velocity	(V_i)	*4,876*	fpm	**(Eq. 2)**
Inlet Duct Cross Sectional Area	(A_i)	*3.14*	ft^2	**(Eq. 3)**
Inlet Volumetric Flow Rate	(Q_i)	*15,317*	cfm	**(Eq. 4)**

Outlet

Outlet Gas Velocity	(V_o)	*4,710*	fpm	**(Eq. 2)**
Outlet Duct Cross Sectional Area	(A_o)	*3.14*	ft^2	**(Eq. 3)**
Outlet Volumetric Flow Rate	(Q_o)	*14,798*	cfm	**(Eq. 4)**

Fan Performance

Average Volumetric Flow Rate	(Q_{avg})	*15,058*	cfm	**(Eq. 5)**
Power Output of Fan	(W_o)	*39.9*	hp	**(Eq. 6)**
Mechanical Efficiency of Fan	(η_f)	*28.5%*		**(Eq. 7)**

Equations

Eq. 1) Air Density (ρ)

$$1.325 \times \left(\frac{p_b}{T_a}\right)$$

Eq. 2) Gas Velocity ($V_{(i,o)}$)

$$1{,}096.2 \times \sqrt{\frac{p_{v(i,o)}}{\rho}}$$

Eq. 3) Duct Cross Sectional Area ($A_{(i,o)}$)

$$\frac{\pi \times d_{(i,o)}^{\ 2}}{4} \times \frac{1\,ft^2}{144 in^2}$$

Eq. 4) Volumetric Flow Rate ($Q_{(i,o)}$)

$$V_{(i,o)} \times A_{(i,o)}$$

Eq. 5) Avg. Volumetric Flow Rate (Q_{avg})

$$\frac{Q_i + Q_o}{2}$$

Eq. 6) Power Output of Fan (W_o)

$$\frac{Q_{avg} \times \Delta p_s \times K_p}{6{,}362} \times \frac{0.746 kW}{1 hp}$$

Eq. 7) Mechanical Efficiency of Fan (η_f)

$$\frac{W_o}{W_i}$$

References

Rf. 1) Environmental data is based on local weather station readings, collected from *www.wunderground.com*

Rf. 2) Input power to fan drive shaft is calculated using the Motor Analysis Tool (MAT) on the previous page.

Rf. 3) Gas compressibility factor is estimated based on the static pressure differential using Table 3.1 of the DOE EERE Fan System Assessment Training Manual, 3rd Edition.

Notes

N. 1) A digital manometer was used to collect various pressure measurements.

N. 2) A tape measure was used to determine the size of various fan components.

AR No. 1 - Efficient Fan Blades

Data Collected

Motor Data

Current Energy Consumption	(E_C)	*476,417*	kWh/yr.	**(Rf. 1)**
Current Power Draw	(P_C)	*114.5*	kW	**(Rf. 1)**
Current Operation Months	(t_M)	*12*	mo./yr.	

Fan Data

Current Fan Blade Type		*Radial*		
Current Fan Efficiency	(η_C)	*28.5%*		**(Rf. 2)**

Utility Data

Incremental Eergy Cost	(IC_E)	*$0.05000*	/kWh	**(Rf. 3)**
Incremental Demand Cost	(IC_D)	*$5.00*	/kW-mo.	**(Rf. 3)**

Assumptions

Proposed Fan Data

Proposed Fan Blade Type		*Radial-Tip*		
Proposed Fan Efficiency	(η_P)	*70.0%*		**(Rf. 4)**

Energy Savings Analysis

Proposed Energy Consumption

Proposed Energy Consumption	(E_P)	*193,970*	kWh/yr.	**(Eq. 1)**
Proposed Power Draw	(P_P)	*47*	kW	**(Eq. 2)**

Energy Savings

Energy Savings	(E_S)	*282,447*	kWh/yr.	**(Eq. 3)**
Power Draw Reduction	(P_R)	*68*	kW	**(Eq. 4)**

Cost Savings

Energy Cost Savings	(C_E)	*$14,122*		**(Eq. 5)**
Power Cost Savings	(C_P)	*$4,073*		**(Eq. 6)**

Implementation Cost Analysis

Material Costs

Radial-Tip Fan Cost	(C_M)	*$4,500*		**(Rf. 5)**

Labor Costs

Labor Rate	(C_{LR})	*$50*	/hour	**(N. 1)**
Installation Time	(t_I)	*25.0*	hours	**(N. 1)**

Economic Results

Cost Savings	(C_S)	*$18,195*	/yr.	**(Eq. 7)**
Implementation Costs	(C_I)	*$5,750*		**(Eq. 8)**
Payback	(t_{PB})	*0.3*	yrs.	

Equations

Eq. 1) Proposed Energy Usage (E_P)

$$E_C \times \frac{\eta_C}{\eta_P}$$

Eq. 2) Proposed Power Draw (P_P)

$$P_C \times \frac{\eta_C}{\eta_P}$$

Eq. 3) Energy Savings (E_S)

$$E_C - E_P$$

Eq. 4) Power Draw Reduction (P_R)

$$P_C - P_P$$

Eq. 5) Energy Cost Savings (C_E)

$$E_S \times IC_E$$

Eq. 6) Power Cost Savings (C_P)

$$P_R \times IC_D \times t_M$$

Eq. 7) Cost Savings (C_S)

$$C_E + C_P$$

Eq. 8) Implementation Costs (C_I)

$$C_M + \left(C_{LR} \times t_I\right)$$

References

Rf. 1) Developed in the previous Motor Analysis Tool (MAT) pages.

Rf. 2) Developed in the previous Fan Efficiency Analysis Tool (FEAT)pages.

Rf. 3) Developed in the Utility Analysis of the Site Data section.

Rf. 4) Developed using the FSAT (Fan System Assessment Tool) software developed by the Air Movement and Control Association (AMCA) and the Oak Ridge National Laboratory for the U.S. Department of Energy's Industries of the Future program.

Rf. 5) Grainger Catalog.

Notes

N. 1) Energy analysts estimated material and labor costs as well as labor time. Labor rates are for facility personnel to replace fan wheels.

AR No. 2
Insulate Pipes

Recommendation

Insulate the steam pipes in the line two press enclosure with one inch fiberglass insulation covered with an aluminum jacket to prevent corrosion. These changes are expected to reduce energy loss by 51%.

Assessment Recommendation Savings Summary			
Source	Quantity	Units	Cost Savings
Other Energy	386	MMBtu*	$2,066

** 1 MMBtu = 1,000,000 Btu, 1 kWh = 3,413 Btu = 10 therms*

Assessment Recommendation Cost Summary		
Description	Cost	Net Payback
Implementation Cost	$948	0.5

Facility Background

The facility currently uses steam to heat the presses that mold the fiber door skins. While walking around the facility, we noticed pipes near the presses that were filled with warm liquid but lacked insulation. We collected information on the pipes that need insulation that is summarized in the following pages.

Technology Background

Un-insulated pipes are a common source of heat loss in fluid systems. Metals are thermally conductive materials making them poor insulators. The heat flowing through the pipes is transmitted through the walls and into the surrounding environment. The rate of heat transfer from the pipes is directly proportional to the temperature differential between the surface of the pipes and the surrounding atmosphere. Insulating materials will reduce heat loss from the system.

The location of pipes can influence insulation thickness selection. Hot pipes in a well-insulated building, for instance, might in some circumstances not require insulation, as the heat loss may be considered "useful" for heating the building as the heat "lost" is effectively trapped by the structural insulation. Conversely pipes may be insulated to prevent overheating or unnecessary cooling in the rooms through

Proposal

We recommend installing 1 inch fiberglass insulation with an aluminum jacket for protection on the pipes that lack insulation.

If the Previously mentioned actions are taken, they will reduce energy costs by $2,070 for a net payback of 0.5 years after an implementation cost of $900.

Based on	Author	Readability Review	Engineering Review	Math Review
Original Template	*Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

Insulate Pipes

Oregon State University OSU Energy Efficiency Center

Data Collected

Assumed Conditions				
Average Air Speed		0	mph	**(N. 1)**
General Data				
Average Ambient Temperature		70	°F	**(N. 1)**
Pipe Geometry		Horizontal		**(N. 1)**
Pipe Material		Steel		**(N. 1)**
Incremental Energy Data				
Incremental Steam Cost	(IC_S)	$0.0050	/lb	**(N. 2)**

Assumptions

Conversion Factors				
Energy Conversion Factor	(CF_1)	1.0E-06	MMBtu/Btu	
Enthalpy Change from Gas to Fluid	(h_{fg})	839	Btu/lb	**(Rf. 1)**

Energy Savings Summary

Current Annual Heat Loss	(CE)	686.3	MMBtu	**(N. 3, 5)**
Proposed Annual Heat Loss	(PE)	339.6	MMBtu	**(N. 4, 5)**
Energy Savings	(ES)	346.7	MMBtu	**(Eq. 1)**

Notes

N. 1) Data recorded on site.

N. 2) Incremental steam cost according to plant personnel.

N. 3) Sum of current annual pipe heat losses.

N. 4) Sum of proposed annual pipe heat losses.

N. 5) Sum of pipe insulation and labor costs found on Pipe Insulation Page

N. 6) Current and proposed heat loss data generated using 3E plus.

N. 7) Temperatures were found by audit analyst using digital thermometer, these pipes were the only pipes that radiated heat during our assessment. During production, other pipes may contain hot contents that didn't while we were there, increasing potential savings from insulation.

Equations

Eq. 1) Energy Savings (ES)

$$AH_C - AH_P$$

Eq. 2) Cost Savings (CS)

$$(ES / CF_1) \times (1/h_{fg}) \times IC_S$$

Eq. 3) Implementation Cost (IC)

$$L_T \times CL_F$$

Eq. 4) Current Annual Heat Loss (AHc)

$$(HL_c \times CF_1) \times L_p$$

Eq. 5) Proposed Annual Heat Loss (AHp)

$$(HL_p \times CF_1) \times L_p$$

Eq. 6) Annual Cost Savings (CS)

$$(ES \times IC_S) / (CF_1 \times h_{fg})$$

References

Rf. 1) From steam tables for saturated steam at 210 psi

Insulate Pipes

Implementation Costs Summary

Material Costs

Pipe Insulation Cost	(TC_P)	$1,500		**(N. 5)**

Economic Results

Cost Savings	(CS)	$2,066	/yr	**(Eq. 2)**
Implementation Costs	(IC)	$948		**(Eq. 3)**
Payback	(PB)	0.5	yrs	

References

Rf. 1) RSMean Building Construction Cost Data 2009 (Cost includes insulation and jacket material)

Pipe Data Collection				
Location	**Temperature (N. 7)**	**Diameter (D_P)**	**Length (L_P)**	**Operation Hours (OH)**
Units	(°F)	(in)	(ft)	(hr/yr)
Press Enclosure (Line 2) Lines	335	4	18.0	8,760
Press Enclosure (Line 2) Lines	308	4	15.0	8,760
Press Enclosure (Line 2) Lines	306	4	14.0	8,760
Press Enclosure (Line 2) Lines	196	6	16.0	8,760
Press Enclosure (Line 2) Lines	185	3	22.0	8,760
Press Enclosure (Line 2) Lines	120	2	18.0	8,760

Pipe Insulation Energy Savings						
	Current		***Proposed***			
Location	**Heat Loss (N. 6) (HL_C)**	**Annual Heat Loss (Eq. 4) (AH_C)**	**Heat Loss (N. 6) (HL_P)**	**Annual Heat Loss (Eq. 5) (AH_P)**	**Annual Energy Savings (ES)**	**Annual Cost Savings (Eq. 7) (CS)**
Units	(MMBtu/ft/yr)	(MMBtu)	(MMBtu/ft/yr)	(MMBtu)	(MMBtu)	($/yr)
Press Enclosure (Line 2) Lines	8.01	144	1.10	20	124	$741
Press Enclosure (Line 2) Lines	6.86	145	9.67	103	42	$250
Press Enclosure (Line 2) Lines	6.78	134	9.58	95	39	$232
Press Enclosure (Line 2) Lines	3.55	92	5.78	57	35	$209
Press Enclosure (Line 2) Lines	2.04	79	3.60	45	34	$203
Press Enclosure (Line 2) Lines	5.12	92	1.10	20	72	$431
Total	**32**	**686**	**31**	**340**	**347**	**$2,066**

Pipe Insulation Implementation Cost Summary				
Pipe Diameter	**Insulation Thickness**	**Total Length (L_T)**	**Cost Per Linear Foot (Rf. 1) (C_{LF})**	**Total Cost (Eq. 3) (IC)**
(in)	(in)	(ft)	($/ft)	
2	1	18	$6.40	$115.20
3	1	22	$7.30	$160.60
4	1	47	$8.95	$420.65
6	1	16	$15.70	$251.20
Total		**103**		**$948**

AR No. 3
Boiler Fan VFD

Recommendation

Install a variable frequency drives (VFD) on the 75 horsepower Natural Gas Boiler induced draft fan. Variable frequency drives control airflow by automatically adjusting fan motor speed. This is more efficient than the current mechanical damper method, and will reduce associated annual energy consumption by 54%.

Assessment Recommendation Savings Summary			
Source	Quantity	Units	Cost Savings
Electrical Consumption	266,371	kWh (site)	$13,319
Total	**909**	**MMBtu***	**$13,319**

** 1 MMBtu = 1,000,000 Btu, 1 kWh = 3,413 Btu*

Assessment Recommendation Cost Summary		
Description	Cost	Net Payback
Implementation Cost	$8,890	0.7

Facility Background

The facility currently uses dampers to control the flow on the intake fan for the natural gas boiler. Data loggers were placed to track the fans power consumption. The consumption data is summarized in the Fan Analysis pages.

Technology Background

Dampers are an inefficient mechanism because significant power is required even when little air is necessary. Dampers operate by making it harder to move air, reducing fan output, but the motor requires more energy than would otherwise be needed. VFDs work by varying fan impeller speed instead of restricting airflow with a damper. They are more efficient than inlet dampers because the motor does not have to overcome added flow resistance.

Savings are achieved by installing a VFD to reduce the electrical demand required to operate the fan at a specified setting. The power savings available by switching to a VFD controlled system are represented by general curves of percent load power versus percent load capacity. These curves are found in the Fan Power and Capacity graph at the end of this recommendation.

Proposal

We recommend installing a VFD on the natural gas boiler intake fan. This will decrease the energy consumption when the boiler is at lower firing rates, reducing associated annual energy consumption by 54%.

If recommended actions are taken, they will save 266,000 kWh annually and result in an annual cost savings of $13,300 for a net payback of 0.7 years after an implementation cost of $8,890.

Based on	Author	Readability Review	Engineering Review	Math Review
Original Template	*Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

Fan Control Analysis Tool (FCAT)

Fan Identification

Fan Description	*Gas Fueled Boiler Intake Fan*
Fan Location	*Boiler Room*

Data Collected

General Information

Total Operation Hours	(t_T)	*8,760*	hrs	**(N. 1)**

Measured Operation Point

Motor Electrical Demand	(P)	*63.5*	kW	**(Rf. 1)**
Fan Capacity	(C)	*100%*		**(N. 1)**

Fan Flow Control

Current Control Type	*Outlet Damper*	**(N. 1)**
Proposed Control Type	*Variable Frequency Drive*	

Current Full Capacity Power

Percent of Full Capacity Power	($P_{\%}$)	*102%*		**(Eq. 1)**
Full Capacity Electrical Power	(P_F)	*62.6*	kW	**(Eq. 2)**

Savings Summary

Annual Energy Savings	*266,371*	kWh/yr	**(Rf. 2)**

Notes

N. 1) Total operation hours, fan flow control type and fan capacity data was collected during the site assessment from personnel and equipment.

References

Rf. 1) Developed in the Motor Analysis Tool (MAT) on the previous page.

Rf. 2) Annual energy savings is calculated in the Fan Control Analysis table on the following page.

Equations

Eq. 1a) Outlet Damper Percent Power($P_{\%}$)

$$-0.325C^2 + 0.94C + 0.4$$

Eq. 1b) Inlet Vane Percent Power ($P_{\%}$)

$$3.91C^3 - 6.38C^2 + 3.62C - 0.1$$

Eq. 1c) VFD Percent Power ($P_{\%}$)

$$0.1 + C^3$$

Eq. 2) Full Capacity Elec. Power (P_F)

$$\left(\frac{P}{P_{\%}}\right)$$

Eq. 3) Operation Hours (t_O)

$$t_T \times t_{\%}$$

Eq. 4) Current Power (P_C)

$$P_F \times P_{C\%}$$

Eq. 5) Proposed Power (P_P)

$$P_F \times P_{P\%}$$

Eq. 6) Demand Savings (P_S)

$$P_C - P_P$$

Eq. 7) Energy Savings (E_S)

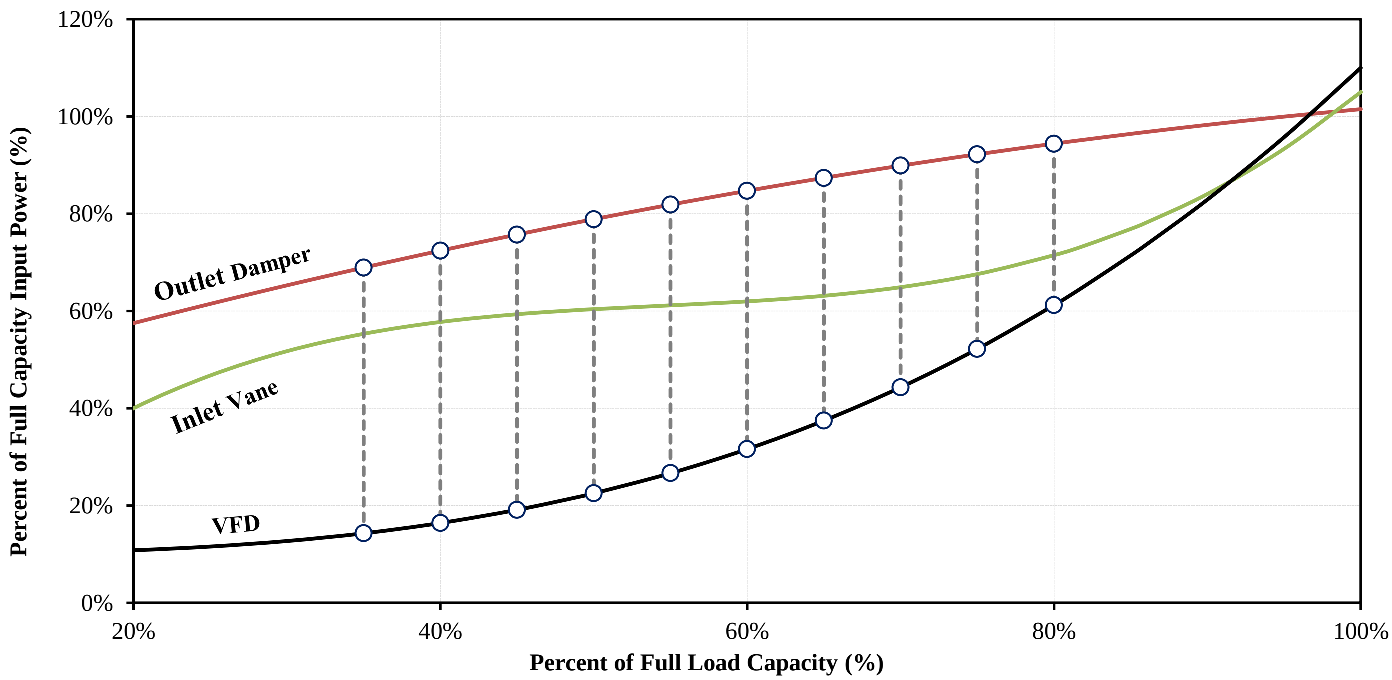
$$P_S \times t_O$$

Fan Control Analysis Tool (FCAT)

Fan Control Analysis

Flow Capacity	*Percent of Time*	*Operation Hours*	*Current % Power*	*Proposed % Power*	*Current Power*	*Proposed Power*	*Power Reduction*	*Energy Savings*
(C)	($t_{\%}$)	(t_O)	($P_{C\%}$)	($P_{P\%}$)	(P_C)	(P_P)	(P_S)	(E_S)
		(Eq. 3)	**(Eq. 1)**	**(Eq. 1)**	**(Eq. 4)**	**(Eq. 5)**	**(Eq. 6)**	**(Eq. 7)**
(%)	(%)	(hrs)	(%)	(%)	(kW)	(kW)	(kW)	(kWh)
80%	5%	438	94%	61%	59	38	21	9,097
75%	20%	1,752	92%	52%	58	33	25	43,877
70%	20%	1,752	90%	44%	56	28	29	49,954
65%	10%	876	87%	37%	55	23	31	27,351
60%	10%	876	85%	32%	53	20	33	29,101
55%	10%	876	82%	27%	51	17	35	30,269
50%	10%	876	79%	23%	49	14	35	30,896
45%	5%	438	76%	19%	47	12	35	15,511
40%	5%	438	72%	16%	45	10	35	15,345
35%	5%	438	69%	14%	43	9	34	14,970
Total	**100%**	**8,760**						**266,371**

Fan Control Performance Curve (N. 2)



Notes

N. 2) The graph above was compiled internally based on industry standard values for percent power reduction. It was approved by Alan Wallace, an experienced professor at Oregon State University specializing in motor efficiency and power systems analysis.

Boiler Fan VFD

Oregon State University OSU Energy Efficiency Center

Data Collected

Energy Consumption Data

Fan Motor HP	(E_1)	75	hp	**(Rf. 1)**
Current Energy Consumption		467,323	kWh	**(N. 1)**

Incremental Energy Data

Incremental Energy Cost	(IC_E)	$0.05000	/kWh	**(Rf. 2)**

Energy Savings Summary

Motor Savings

Annual Energy Savings	(E_S)	266,371	kWh	**(Rf. 3)**

Implementation Cost Summary

VFD Costs	(C_M)	$4,100	**(N. 2)**
Manual Bypass Drive	(C_D)	$2,890	**(N. 2)**
Labor Costs	(C_L)	$1,900	**(N. 2)**

Economic Results

Cost Savings	(CS)	$13,319	/yr	**(Eq. 1)**
Implementation Costs	(IC)	$8,890		**(Eq. 2)**
Payback	(PB)	0.7	yrs	

Notes

N. 1) Current energy consumption based on our fan power model on the following pages. This is the sum of current power multipyed by operation hours.

N. 2) We recommend installing the VFD on your current motor assuming that it is an inverter-duty motor. If your motor is not inverter-duty, the variable frequency drive will still work, but may cause some of the parts in the motor to wear out more quickly. This will shorten the life of your motor and reduce its efficiency. If this is the case, we recommend replacing your current motor with an inverter-duty motor when you install the variable frequency drive. This will increase the implementation cost and payback period.

N. 3) Demand savings are not included in this recommendation because we are not reducing the max power draw of the motor.

Equations

Eq. 1) Cost Savings (CS)

$$E_S \times IC_E$$

Eq. 2) Implementation Costs (IC)

$$C_M + C_L + C_D$$

References

Rf. 1) Collected on site

Rf. 2) Developed in the Utility Analysis of the Site Data section.

Rf. 3) Developed in the following Fan Analysis pages.

AR No. 4
Flash Steam Recovery

Recommendation

Install a pressure vessel to capture flash steam from the return condensate. This can be used to heat the vat wells or to preheat makeup water that is currently being heated in the boiler. This will reduce boiler fuel use and associated fuel consumption by 11%.

Assessment Recommendation Savings Summary			
Source	Quantity	Units	Cost Savings
Wood	29,837	MMBtu	$71,700

** 1 MMBtu = 1,000,000 Btu, 1 kWh = 3,413 Btu*

Assessment Recommendation Cost Summary		
Description	Cost	Net Payback
Implementation Cost	$65,575	0.9

Facility Background

The facility currently releases condensate flash steam into the atmosphere representing a significant energy loss. During the site assessment, plant personnel informed us that they use steam to heat both vat wells and makeup water in the condensate tank. We collected data on boiler water and wood use to determine the energy available in flash steam condensate recovery. The information is summarized in the following calculation page.

Technology Background

Currently makeup water is heated in the boiler, adding to fuel use. Energy that is being released through the flash steam is more than enough to heat the makeup water before introducing it to the boiler, additional flash steam is available for uses in the vat wells. We recommend sending recovered flash steam to both locations to decrease fuel costs.

Our calculations for available flash steam and associated potential cost savings assume that the vat wells will be heated solely with the recovered flash steam. Our estimates only include captured flash steam from the other processes. It is likely that the vat wells will require additional high pressure steam heating after preheating with flash steam. If so, potential cost savings will be higher as there will be more flash steam available to capture and reduce the cost of the wood fuel consumed.

Proposal

We recommend installing a pressure vessel to capture the flash steam from the condensate. The captured steam can then be used to preheat the makeup water as well as for other uses such as heating the vat wells. This will reduce the amount of energy needed to heat the water in the boiler and reduce associated fuel consumption by 275%.

If the recommended actions are taken, 358,000 MMBtus will be saved annually and result in an annual cost savings of $71,600 for a net payback of 0.9 years after an implementation cost of $65,600.

Based on	Author	Readability Review	Engineering Review	Math Review
Original Template	*Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

Flash Steam Recovery

Oregon State University OSU Energy Efficiency Center

Data Collected

On-Site Data				
Steam Pressure	(P_S)	210	psi	**(Rf. 1)**
Condensate Return	(CR)	81%		**(Rf. 1)**
Boiler Efficiency	(η_B)	65%		**(Rf. 1)**
Current Heat Exchanger Pump Rate	(PR)	1,000	gpm	**(Rf. 1)**
Energy Consumption Data				
Average Monthly Wood Fuel Usage	(E_1)	1,445	BDTs	**(Rf. 1)**
Average Hourly Steam Production	(S_1)	20	klbs/hr	**(N. 1)(Rf. 1)**
Incremental Energy Data				
Incremental Fuel Value	(IV_F)	$36	/BDT	**(Rf. 1)**
Conversion Factor				
Number of MMBtus per BDT	(CF)	15	MMBtu	**(Rf. 3)**

Energy Savings Summary

High Pressure Steam System Data				
High Pressure Steam Enthalpy	(E_{HP_S})	1,201	Btu/lbm	**(Rf. 4)**
Water Temp Change in Exchanger	(ΔT)	60	°F	**(N. 2)**
Heat Transferred through Exchanger	(HT)	3,600,000	Btu/hr	**(Eq. 1)**
Steam Rate to Vat Wells	(SR)	3	klb/hr	**(Eq. 2)**
Proposed Condensate System Data				
Proposed Flash Steam Pressure	(P_{FS})	5	psi	**(N. 3)**
High Pressure Condensate Enthalpy	(E_{HP_C})	359	Btu/lbm	**(Rf. 4)**
Low Pressure Condensate Enthalpy	(E_{LP})	196	Btu/lbm	**(Rf. 4)**
Low Pressure Heat of Vaporization	(h_{fg})	960	Btu/lbm	**(Rf. 4)**
Temperature of Low Pressure Steam	(T_{LP})	213	°F	**(Rf. 4)**
Return Condensate Energy Value				
Steam Use Without Vat Well	(S_2)	146,893	klbms/yr	**(N. 4)(Eq. 3)**
Return Condensate	(RC)	118,983	klbm/yr	**(Eq. 4)**
Percent of Condensate to Steam	(CtS)	17%		**(Eq. 5)**
Annual Energy Value of Flash Steam	(E_S)	19,394	MMBtus	**(Eq. 6)(N. 5)**
Annual Fuel Energy Savings	(FE_S)	29,837	MMBtus	**(Eq. 7)**
Annual Proposed Fuel Savings	(F_S)	1,989	BDTs	**(Eq. 8)**

Equations

Eq. 1) Heat Transfer in Exchanger (HT)

$$PR \times \Delta T \times \frac{60\,min}{1hour}$$

Eq. 2) Steam Rate to Vat Wells (SR)

$$\frac{HT}{E_{HP\_S}} \times \frac{1klb}{1000lbs}$$

Eq. 3) Steam w/o Vat Well (S_2)

$$(S_1 - SR) \times \frac{24hours}{day} \times \frac{30days}{month} \times \frac{12months}{year}$$

Eq. 4) Return Condensate (RC)

$$S_2 \times CR$$

Eq. 5) Percent Condensate to Steam (CtS)

$$\frac{E_{HP\_C} - E_{LP}}{h_{fg}}$$

Eq. 6) Energy Value of Steam (E_S)

$$HV_{LP} \times CtS \times RC \times \frac{1MMBtu}{1,000,000Btu} \times \frac{1000lbs}{1klb}$$

Eq. 7) Fuel Energy Savings (FE_S)

$$\frac{E_S}{\eta_B}$$

Eq. 8) Proposed Fuel Savings (F_S)

$$\frac{FE_S}{CF}$$

References

Rf. 1) Recorded during Site Assessment

Rf. 2) Developed in the Utility Analysis of the Site Data section.

Rf. 3) Foresters Co-op Wood Fuel Comparison: http://www.forco-op.com/projects/wood_fuel_comp.pdf

Rf. 4) Developed using Steam Tables

Notes

N. 1) Facility wide steam production

N. 2) Water temperature change is based on measured temperatures of 130 °F before and 190°F after

N. 3) A proposed flash steam pressure of 5 psi was chosen because the current condensate return system is operating at 5 psi

N. 4) We are proposing to replace the current steam to the vat well with recovered flash steam, we calculated the current steam use without the the vat well to determine how much steam would be produced annually without the current vat well steam load

N. 5) The flash steam energy will help supplement the energy currently being sent to the vat wells. This was estimated by plant personell to be 3 klbs/hr. Based on the heat of vaporization, current annual steam energy sent to the vat wells is 26,280 MMBtus. Given that the annual energy value of the flash steam is lower than this and the temperature of the 213°F flash steam is sufficently greater than the 190°F target vat well water temperature all of the captured energy can be used.

Flash Steam Recovery

Implementation Cost Summary

Heat Exchanger Costs

Material Costs	(C_M)	$40,000		**(Rf. 5)**
Labor Hours	(L_H)	15	hrs	**(Rf. 5)**
Hourly Rate	(L_R)	$100	/hr	**(Rf. 5)**
Labor Costs	(C_L)	$1,500		**(Eq. 9)**
Pipe Costs				
Cost per Foot	(C_F)	$80	/ft	**(Rf. 6)**
Number of feet	(F)	300	ft	**(Rf. 7)**
Total Pipe Installation Costs	(C_{PI})	$24,075		**(Eq. 10)**

Economic Results

Annual Cost Savings	(CS)	$71,610	/yr	**(Eq. 11)**
Implementation Costs	(IC)	$65,575		**(Eq. 12)**
Payback	(PB)	0.9	yrs	**(Eq. 13)**

Equations

Eq. 9) Labor Costs (C_L)

$$L_H \times L_R$$

Eq. 10) Total Pipe Installation Costs (C_{PI})

$$C_F \times F$$

Eq. 11) Annual Cost Savings (CS)

$$F_S \times IV_F \times 12 months$$

Eq. 12) Implementation Costs (IC)

$$C_M + C_L + C_{PI}$$

Eq. 13) Payback (PB)

$$IC/CS$$

References

Rf. 5) Quote from Fox Engineering, based on 2000 GPM Budget Heat Exchanger with a vat water ΔT of 60°F, and final 190°F temperature to be heated with 213°F steam.

Rf. 6) Value from RSMeans 2006 based on 4" copper pipe with insulation

Rf. 7) From plant personnel

AR No. 5
Convert Headrig to AC Drive

Recommendation

We recommend replacing the current headrig hydraulic drive with an electric AC regenerative drive. This will reduce energy consumption and maintenance costs and increase productivity reducing annual associated costs by 70%.

Assessment Recommendation Summary				
Energy (MMBtu)*	Energy (kWh)*	Cost Savings	Implementation Cost	Payback (Years)
708	207,000	$157,000	$191,000	1.2

* *1 MMBtu = 1,000,000 Btu, 1 kWh = 3,413 Btu*

Facility Background

The facility currently uses two 125 hp electric motors coupled to hydraulic pumps to power four hydraulic motors that move the headrig carriage. During the site assessment, plant personnel informed us that an AC drive would be more efficient, both in energy consumption and maintenance costs. After talking with vendors of AC driven headrigs, they also informed us that the production capabilities of the AC driven headrig is increased over a hydraulic driven one. Motor information was collected for each system and is summarized in the following Motor Data Collection pages.

Technology Background

In a hydraulic system, electrical energy is converted into mechanical work through an electric motor which in turn powers a pump that pressurizes hydraulic fluid. A separate motor then uses the pressure in the fluid to perform mechanical work. Hydraulic pumps and motors both operate at approximately 65% efficiency in ideal conditions. When operated in series, the efficiencies aggregate, as a result most hydraulic systems operate with an approximate 42% efficiency. Hydraulic systems draw power continuously no matter the loading situation, this is very inefficient, especially if demand is infrequent. Hydraulics motors do offer a high power density and variable speed controls which does make them advantageous in some applications.

A variable speed drive AC motor with a regeneration systems offers all the same benefits as a hydraulic system while consuming less energy. The VSD will offer versatile control of the system while the regenerative drive will generate electricity during deceleration further increasing efficiency. A control system will help optimize feed rate and positioning based on sensor feedback increasing productivity.

Proposal

We recommend installing an AC drive on the current headrig. This will reduce energy consumption, maintenance costs and increase productivity, reducing associated annual costs by $157,000.

If the previously mentioned actions are taken, 207,000 kWh will be saved annually and result in an annual cost savings of $157,000 for a net payback of 1.2 years after an implementation cost of $191,000.

Based on	Author	Readability Review	Engineering Review	Math Review
Original Template	*Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

Motor Data Collection

Oregon State University | OSU | Energy Efficiency Center

Motor Identification

Motor Description	F1 Headrig Bearing Drive Motor
Motor Location	Sawmill

Data Collected

Nameplate Data

Motor Type		3-Phase		**(N. 1)**
Motor Enclosure Type		TEFC		**(N. 1)**
Motor Drive Type		Direct Drive		**(N. 1)**
Rated Horsepower	(W_R)	125.0	hp	**(N. 1)**
Rated Voltage	(V_R)	460	volts	**(N. 1)**
Rated Full Load Amperage	(I_R)		amps	**(N. 1)**
Rated Full Load Speed	(N_R)	1,760	rpm	**(N. 1)**
Rated Efficiency	(η_R)			**(N. 1)**
Rated Full Load Power Factor	(PF_R)			**(N. 1)**

Motor Data

Actual RMS Voltage	(V_A)	440	volts	**(N. 2)**
Actual RMS Amperage	(I_A)	98.2	amps	**(N. 2)**

Operational Data

Load Factor	(LF)			**(N. 1)**
Use Factor	(UF)	100.0%		**(N. 1)**
Total Hours	(t_t)	2,080	hours	**(N. 1)**

Motor Specifications

Full Load Amperage	(I_{FL})	142	amps	
Percent of Full Load Amps	($I_{\%}$)	69.2%		
Synchronous Speed	(N_S)	1,800	rpm	
Motor Efficiency	(η_M)	94.5%		**(Rf. 1)**
Mechanical Drive Efficiency	(η_D)	99.0%		**(Rf. 2)**
Full Load Power Factor	(PF_F)	87.0%		
Part Load Power Factor	(PF_P)	84.5%		**(Rf. 3)(Eq. 1)**
Real Load Factor	(LF_R)	64.0%		**(Eq. 2)**
Operation Hours	(t_M)	2,080	hours	**(Eq. 3)**

Motor Power and Energy

Electrical Power Input	(P)	63.2	kW	**(Eq. 4)**
Electrical Energy Consumption	(E)	131,456	kWh	**(Eq. 5)**
Mechanical Power Output	(W_o)	79.3	hp	**(Eq. 6)**

Equations

Eq. 1) Part Load Power Factor (PF_P)

$$PF_F \times \left(0.728 + \frac{0.4932}{I_{\%}} + \frac{0.2249}{I_{\%}^{2}}\right)$$

Eq. 2) Real Load Factor (LF_R)

$$\frac{P \times \eta_M}{W_R} \times \frac{1hp}{0.746kW}$$

Eq. 3) Operation Hours (t_M)

$$t_t \times UF$$

Eq. 4a) Power Input (Nameplate, 3-Phase)

$$\frac{W_R \times LF_R}{\eta_M} \times \frac{0.746kW}{1hp}$$

Eq. 4b) Power Input (3-Phase Live Amps)

$$V_A \times I_A \times PF_P \times \sqrt{3} \times \frac{1kW}{1{,}000W}$$

Eq. 4c) Power Input (1-Phase Live Amps)

$$V_A \times I_A \times PF_P \times \frac{1kW}{1{,}000W}$$

Eq. 4d) Power Input (DC Live Amps)

$$V_A \times I_A \times \frac{1kW}{1{,}000W}$$

Eq. 5) Electrical Energy Consumption (E)

$$P \times t_M$$

Eq. 6) Mechanical Power Output (W_o)

$$P \times \eta_M \times \eta_D \times \frac{1hp}{0.746kW}$$

Notes

N. 1) Nameplate and operational data was collected during the site assessment from site personnel and equipment.

N. 2) Live current and voltage readings were collected by site personnel using a digital multimeter.

References

Rf. 1) NEMA Standards Publication MG 1-2006 (Premium Efficiency Motors).

Rf. 2) ACMA Publication 203, *Field Performance Measurements of Fan Systems.*

Rf. 3) Part load power factor curve, in the Motor Appendix.

Motor Data Collection

Oregon State University OSU Energy Efficiency Center

Motor Identification

Motor Description	F2 Headrig Bearing Drive Motor
Motor Location	Sawmill

Data Collected

Nameplate Data

Motor Type		3-Phase		**(N. 1)**
Motor Enclosure Type		TEFC		**(N. 1)**
Motor Drive Type		Direct Drive		**(N. 1)**
Rated Horsepower	(W_R)	125.0	hp	**(N. 1)**
Rated Voltage	(V_R)	460	volts	**(N. 1)**
Rated Full Load Amperage	(I_R)		amps	**(N. 1)**
Rated Full Load Speed	(N_R)	1,760	rpm	**(N. 1)**
Rated Efficiency	(η_R)			**(N. 1)**
Rated Full Load Power Factor	(PF_R)			**(N. 1)**

Motor Data

Actual RMS Voltage	(V_A)	440	volts	**(N. 2)**
Actual RMS Amperage	(I_A)	120.0	amps	**(N. 2)**

Operational Data

Load Factor	(LF)			**(N. 1)**
Use Factor	(UF)	100.0%		**(N. 1)**
Total Hours	(t_t)	2,080	hours	**(N. 1)**

Motor Specifications

Full Load Amperage	(I_{FL})	142	amps	
Percent of Full Load Amps	($I_{\%}$)	84.5%		
Synchronous Speed	(N_S)	1,800	rpm	
Motor Efficiency	(η_M)	94.5%		**(Rf. 1)**
Mechanical Drive Efficiency	(η_D)	99.0%		**(Rf. 2)**
Full Load Power Factor	(PF_F)	87.0%		
Part Load Power Factor	(PF_P)	86.7%		**(Rf. 3)(Eq. 1)**
Real Load Factor	(LF_R)	80.3%		**(Eq. 2)**
Operation Hours	(t_M)	2,080	hours	**(Eq. 3)**

Motor Power and Energy

Electrical Power Input	(P)	79.2	kW	**(Eq. 4)**
Electrical Energy Consumption	(E)	164,736	kWh	**(Eq. 5)**
Mechanical Power Output	(W_o)	99.3	hp	**(Eq. 6)**

Equations

Eq. 1) Part Load Power Factor (PF_P)

$$PF_F \times \left(0.728 + \frac{0.4932}{I_{\%}} + \frac{0.2249}{I_{\%}^{2}}\right)$$

Eq. 2) Real Load Factor (LF_R)

$$\frac{P \times \eta_M}{W_R} \times \frac{1hp}{0.746kW}$$

Eq. 3) Operation Hours (t_M)

$$t_t \times UF$$

Eq. 4a) Power Input (Nameplate, 3-Phase)

$$\frac{W_R \times LF_R}{\eta_M} \times \frac{0.746kW}{1hp}$$

Eq. 4b) Power Input (3-Phase Live Amps)

$$V_A \times I_A \times PF_P \times \sqrt{3} \times \frac{1kW}{1{,}000W}$$

Eq. 4c) Power Input (1-Phase Live Amps)

$$V_A \times I_A \times PF_P \times \frac{1kW}{1{,}000W}$$

Eq. 4d) Power Input (DC Live Amps)

$$V_A \times I_A \times \frac{1kW}{1{,}000W}$$

Eq. 5) Electrical Energy Consumption (E)

$$P \times t_M$$

Eq. 6) Mechanical Power Output (W_o)

$$P \times \eta_M \times \eta_D \times \frac{1hp}{0.746kW}$$

Notes

N. 1) Nameplate and operational data was collected during the site assessment from site personnel and equipment.

N. 2) Live current and voltage readings were collected by site personnel using a digital multimeter.

References

Rf. 1) NEMA Standards Publication MG 1-2006 (Premium Efficiency Motors).

Rf. 2) ACMA Publication 203, *Field Performance Measurements of Fan Systems.*

Rf. 3) Part load power factor curve, in the Motor Appendix.

Convert Headrig to AC Drive

Data Collected

Energy Consumption Data				
F1 Headrig Motor Energy Usage	(E_1)	131,456	kWh/yr.	**(Rf. 1)**
F2 Headrig Motor Energy Usage	(E_2)	164,736	kWh/yr.	**(Rf. 1)**
Maintenance Costs				
Hydraulic Motors Replaced	(M)	4	/yr	**(N. 1)**
Cost per Hydraulic Motor	(MC_M)	$4,000		**(N. 1)**
Hydraulic Pumps Replaced	(P)	4	/yr	**(N. 1)**
Cost per Hydraulic Pump	(MC_P)	$4,000		**(N. 1)**
Quoted Savings				
Energy Savings	(ES_Q)	70%		**(N. 2)**
Productivity Increase	(PS_Q)	0.5	lines/min	**(N. 3)**
Maintence Savings	(MS_Q)	66%		**(N. 3)**
Productivity Information				
Safety deduction on Quoted Value	(QA)	50%		**(N. 1)**
Hours Producing	(H)	8	hrs/day	**(N. 1)**
Lines per log	(L)	6	lines/log	**(N. 1)**
Current Productivity of Headrig	(P_L)	400	logs/day	**(N. 1)**
Cost per mbf Produced	(IC_P)	$140	/mbf	**(N. 1)**
Current mbf Produced per month	(P_{MBF})	1,500	mbf/mo	**(N. 4)**
Incremental Energy Data				
Incremental Energy Cost	(IC_E)	$0.05000	/kWh	**(Rf. 2)**

Savings Summary

Motor Savings				
Annual Energy Savings	(E_S)	207,334	kWh	**(Eq. 1)**
Productivity Savings				
Estimated Increase in Productivity	(PI_1)	0.25	lines/min	**(N. 4)(Eq. 2)**
	(PI_2)	20	logs/day	**(Eq. 3)**
	(PI_3)	5%		**(Eq. 4)**
Reduction in cost per mbf	(CR_I)	$7	/mbf	**(Eq. 5)**
Annual Productivity Cost Savings	(CS_P)	$126,000		**(Eq. 6)**
Maintenance Savings				
Current Maintenance Costs	(MC)	$32,000		**(Eq. 7)**
Annual Maintenance Cost Savings	(CS_M)	$21,120		**(Eq. 8)**

Notes

N. 1) Developed on site after talks with plant personnel

N. 2) Cited from case study provided by vendor of previously installed AC Drive

N. 3) Cited from vendor based on previously installed AC Drive

N. 4) Estimated productivity is reduced from vendors estimate to be conservative

Equations

Eq. 1) Annual Energy Savings (E_S)

$$(E_1 + E_2) \times ES_Q$$

Eq. 2) Increase in Productivity (PI_1)

$$PS_Q \times QA$$

Eq. 3) Increase in Productivity (PI_2)

$$\frac{PI_1 \times \frac{60\,\text{min}}{1hr} \times H}{L}$$

Eq. 4) Increase in Productivity (PI_3)

$$\frac{PI_2}{P_L}$$

Eq. 5) Reduction in cost per mbf (CR_I)

$$IC_P \times PI_3$$

Eq. 6) Productivity Cost Savings (CS_P)

$$CR_I \times P_{MBF} \times \frac{12mo}{1yr}$$

Eq. 7) Current Maintenanc Costs (MC)

$$(M \times MC_M) + (P \times MC_P)$$

Eq. 8) Productivity Cost Savings (CS_M)

$$MC \times MS_Q$$

References

Rf. 1) Developed in the previous Motor Data Collection pages.

Rf. 2) Developed in the Utility Analysis of the Site Data section.

Convert Headrig to AC Drive

Oregon State University OSU Energy Efficiency Center

Implementation Cost Summary

New Drive Installation Costs	(C_I)	$191,361	**(N. 5)**

Economic Results

Cost Savings	(CS)	$157,487	/yr	**(Eq. 9)**
Implementation Costs	(IC)	$191,361		**(Eq. 10)**
Payback	(PB)	1.2	yrs	

Notes

N. 5) Cited from vendor quote, includes installation and integration services from vendor

Equations

Eq. 9) Cost Savings (CS)

$$(ES \times IC_E) + CS_P + CS_M$$

Eq. 10) Implementation Costs (IC)

$$C_I$$

AR No. 6
Pump Efficiency

Recommendation

We recommend optimizing the cooling tower supply system by replacing the pump. We estimate the system pumping efficiency can be improved from the current average of 53.3% to a reasonable average of 75.0%, reducing pump operation costs by 28.9%

Assessment Recommendation Savings Summary			
Source	Quantity	Units	Cost Savings
Electrical Consumption	37,816	kWh (site)	$3,782
Total	**129.1**	**MMBtu***	**$3,782**

** 1 MMBtu = 1,000,000 Btu, 1 kWh = 3,413 Btu*

Assessment Recommendation Cost Summary		
Description	Cost	Net Payback
Implementation Cost	$3,921	1.0

Facility Background

During the site assessment, plant personnel assisted in collecting motor and pump information, summarized in the following Motor and Pump Data Collection pages.

Based on the instantaneous pump electrical draw, delivered flow and a calculated average pump head, the pump is delivering needed water at a 53.3% average efficiency. According to the pump performance curve, the modeled average flow and head delivered to the irrigation system can be developed at an optimum efficiency of 75.0%

Technology Background

Pump efficiency deteriorates during expected service life. These additional losses are commonly due to impeller wear, bearing fatigue, and damaged seals. Pump efficiency can also deteriorate at accelerated rates due to other environmental causes including; operating outside of the designed net positive suction head requirement causing cavitation, pumping fluids that contain abrasives such as dirt or sand, and pumping fluids with acidity levels above pump design specifications. Pumps should be tested every two to three years to confirm that they are performing properly and that no significant losses are occurring. Pumps can feasibly reach efficiencies as high as 80 percent, however they can also operate at abysmal efficiencies with no signs of suboptimal performance.

Refer to the following sections for information regarding pumps and electric motors.

- Appendix - Motors
- Appendix - Pumps

Proposal

We recommend improving pumping system efficiency by replacing the Berkeley 7T40-450 pump. This will increase pumping efficiency, reducing associated energy consumption. Alternatively, the pump could be removed, professionally inspected for wear, and refurbished. This would still require a substantial investment and likely not yield the same efficiency increase as replacement.

If the previously mentioned actions are taken, they will save 37,800 kWh annually and result in an annual cost savings of $3,780.

Based on	Author	Readability Review	Engineering Review	Math Review
Original Template	*Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

AR No. 6 - Motor Analysis Tool (MAT)

Motor Identification

Motor Description	*Cooling tower supply pump*
Motor Location	*Cooling tower*

Data Collected

Motor Nameplate Data

Motor Power Supply Type		*3-Phase AC*	
Motor Enclosure Type		*TEFC*	
Motor Drive Type		*Direct Drive*	
Rated Horsepower	(W_R)	*50.0*	hp
Rated Voltage	(V_R)	*460*	volts
Rated Full-Load Amperage	(I_R)	*57.3*	amps
Rated Full-Load Speed	(N_R)	*3,540*	rpm
Rated Full-Load Efficiency	(η_R)	*91.7%*	
Rated Full-Load Power Factor	(PF_R)	*89.0%*	

Measured Data

Actual RMS Voltage	(V_A)	*465.4*	volts
Actual RMS Amperage	(I_A)	*42.3*	amps

Operational Data

Total Operation Hours	(t_t)	*4,380*	hrs./yr.
Load Factor	(LF)		

Motor Performance Analysis

Mechanical Drive Efficiency	(η_D)	*99.0%*		**(Rf. 1)**
Synchronous Speed	(N_S)	*3,600*	rpm	
Full-Load Amperage	(I_{FL})	*57.3*	amps	
Percent of Full-Load Amperage	($I_{\%}$)	*73.8%*		
Full-Load Efficiency	(η_{FL})	*91.7%*		**(Rf. 2)**
Full-Load Power Factor	(PF_{FL})	*89.0%*		
Part-Load Power Factor	(PF_{PL})	*87.5%*		**(Eq. 1, Rf. 3)**
Real Load Factor	(LF_R)	-		

Motor Energy Analysis

Electrical Power Input	(P)	*29.8*	kW	**(Eq. 2)**
Electrical Energy Consumption	(E)	*130,715*	kWh	**(Eq. 3)**
Mechanical Power Output	(W_o)	*36.3*	bhp	**(Eq. 4)**

Equations

Eq. 1) Part Load Power Factor (PF_{PL})

$$PF_{FL} \times \left(0.728 + \frac{0.4932}{I_{\%}} - \frac{0.2249}{I_{\%}^{2}} \right)$$

Eq. 2a) Power Input (3-Phase AC)

$$V_{(A\ or\ R)} \times I_{FL} \times I_{\%} \times PF_{PL} \times \sqrt{3} \times \frac{1kW}{1,000W}$$

Eq. 2b) Power Input (Single-Phase AC)

$$V_A \times I_A \times PF_{PL} \times \frac{1kW}{1,000W}$$

Eq. 2c) Power Input (DC)

$$V_A \times I_A \times \frac{1kW}{1,000W}$$

Eq. 3) Electrical Energy Consumption (E)

$$P \times t_M$$

Eq. 4) Mechanical Power Output (Wo)

$$P \times \eta_{FL} \times \eta_D \times \frac{1hp}{0.7457kW}$$

Notes

N. 1) Nameplate and operational data was collected during the site assessment from site personnel and equipment.

N. 2) Live current and voltage readings were collected by site personnel using a power quality analyzer.

References

Rf. 1) ACMA Publication 203, Field Performance Measurements of Fan Systems.

Rf. 2) NEMA Standards Publication MG 1-2006 (Premium Efficiency Motors).

Rf. 3) Part load power factor curve, in the Motor Appendix.

AR No. 6 - Pump Efficiency Analysis Tool (PEAT)

Pump Identification

Pump Description	*Cooling tower supply pump*
Pump Location	*Cooling tower*

Data Collected

Flow Data

Volumetric Flow Rate	(Q)	*415*	gpm	**(N. 1)**

Suction System Data

Suction Pipe Diameter	(d_s)	*0.50*	feet	**(N. 2)**
Suction Gauge Pressure	(p_s)	*0.0*	psi	**(N. 3)**
Suction Gauge Elevation	(h_s)	*5.5*	feet	**(N. 2)**
Suction Line Loss Coefficient	(K_s)	*1.50*		**(N. 4)**

Discharge System Data

Discharge Pipe Diameter	(d_d)	*0.50*	feet	**(N. 2)**
Discharge Gauge Pressure	(p_d)	*71.0*	psi	**(N. 3)**
Discharge Gauge Elevation	(h_d)	*25.0*	feet	**(N. 2)**
Discharge Line Loss Coefficient	(K_d)	*2.00*		**(N. 4)**

Input Power Data

Input Power to Pump Drive Shaft	(W_i)	*36.3*	bhp	**(Rf. 1)**

Assumptions

Fluid Properties

Specific Gravity	(SG)	*1.00*	
Vapor Pressure of Fluid	(V_p)	*0.57*	ft. abs.

Environmental Data

Barometric Pressure	(p_b)	*33.95*	ft. abs.
Acceleration of Gravity	(g)	*32.17*	ft./sec.^{2}

Pump Head Analysis

Differential Elevation Head	(ΔH_h)	*19.5*	feet	**(Eq. 1)**
Differential Pressure Head	(ΔH_p)	*164.0*	feet	**(Eq. 2)**
Suction Flow Velocity	(V_s)	*4.71*	ft./sec.	**(Eq. 3)**
Discharge Flow Velocity	(V_d)	*4.71*	ft./sec.	**(Eq. 3)**
Differential Velocity Head	(ΔH_V)	*0.0*	feet	**(Eq. 4)**
Suction Friction Head	(f_s)	*0.5*	feet	**(Eq. 5)**
Discharge Fricition Head	(f_d)	*0.7*	feet	**(Eq. 5)**
Total Pump Head	(H)	*184.7*	feet	**(Eq. 6)**

Pump Performance

Power Output of Pump	(W_o)	*19.4*	whp	**(Eq. 7)**
Mechanical Efficiency of Pump	(η_p)	*53.3%*		**(Eq. 8)**

Equations

Eq. 1) Differential Elevation Head (ΔH_h)

$$h_d - h_s$$

Eq. 2) Differential Pressure Head (ΔH_p)

$$\left(\frac{p_d - p_s}{SG}\right) \times \frac{2.31\, ft\ H_2O}{1\, psi}$$

Eq. 3) Flow Velocity ($V_{(s, d)}$)

$$\frac{Q}{\pi \times \left(d_{(s,d)}/2\right)^2} \times \frac{0.1337\, ft^3}{1 gal} \times \frac{1 \min}{60 \sec}$$

Eq. 4) Differential Velocity Head (ΔH_V)

$$\frac{V_d^2 - V_s^2}{2 \times g}$$

Eq. 5) Friction Head ($f_{(s, d)}$)

$$K_{(s,d)} \times \left(\frac{V_{(s,d)}^2}{2 \times g}\right)$$

Eq. 6) Total Pump Head (H)

$$\Delta H_h + \Delta H_P + \Delta H_V + f_s + f_d$$

Eq. 7) Power Output of Pump (W_o)

$$\frac{Q \times H \times SG}{3{,}960}$$

Eq. 8) Pump Mechanical Efficiency (η_p)

$$\frac{W_o}{W_i}$$

Notes

N. 1) A digital flow meter was used to collect volumetric flow measurements.

N. 2) A tape measure was used to determine the size and length of various pump system components.

N. 3) Pressures were collected from previously installed pressure gauges during the site assessment.

N. 4) Line loss coefficients are estimated based on pipe length, diameter, and material as well as fitting type and quantity.

References

Rf. 1) Input power to pump drive shaft is calculated using the Motor Analysis Tool (MAT) on the previous page.

Pump Efficiency

Oregon State University OSU Energy Efficiency Center

Data Collected

Energy Baseline

Current Energy Consumption	(E_C)	130,701	kWh/yr.	**(Rf. 1)**
Incremental Energy Cost	(IC_E)	$0.10000	/kWh	**(Rf. 2)**

Pump Analysis

Efficiency

Current Measured Pump Efficiency	(η_c)	53.3%		**(Rf. 3)**
Proposed Pump Efficiency	(η_p)	75.0%		**(Rf. 4)**

Energy Savings Summary

Proposed Energy Consumption	(E_P)	92,885	kWh/yr.	**(Eq. 1)**
Annual Energy Savings	(E_S)	37,816	kWh/yr.	**(Eq. 2)**

Implementation Cost Summary

Pump

Berkeley 7T40-450 Submersible	(C_{M1})	$2,921		**(Rf. 5)**
Installation Labor	(C_{L1})	$1,000		**(N. 1)**

Economic Results

Cost Savings	(CS)	$3,782	/yr	**(Eq. 3)**
Implementation Costs	(IC)	$3,921		**(Eq. 4)**
Payback	(PB)	1.0	yrs	

Notes

N. 1) Installation cost is based on conversations with facility personnel. Cost includes removal of the old pump, installation of new pump, and associated labor and crane rental costs.

Equations

Eq. 1) Proposed Energy Consumption (E_P)

$$E_C \times \left(\frac{\eta_c}{\eta_p} \right)$$

Eq. 2) Annual Energy Savings (E_S)

$$E_C - E_P$$

Eq. 3) Cost Savings (CS)

$$E_S \times IC_E$$

Eq. 4) Implementation Costs (IC)

$$C_{M1} + C_{L1}$$

References

Rf. 1) Developed in the previous Motor Data Collection pages.

Rf. 2) Developed in the Utility Analysis of the Site Data section.

Rf. 3) Developed in the previous Pump Data Collection pages.

Rf. 4) Based on Pump Performance Curve on the following pages, the 40 hp curve correlates to 5 stages with a 5.38 inch impeller.

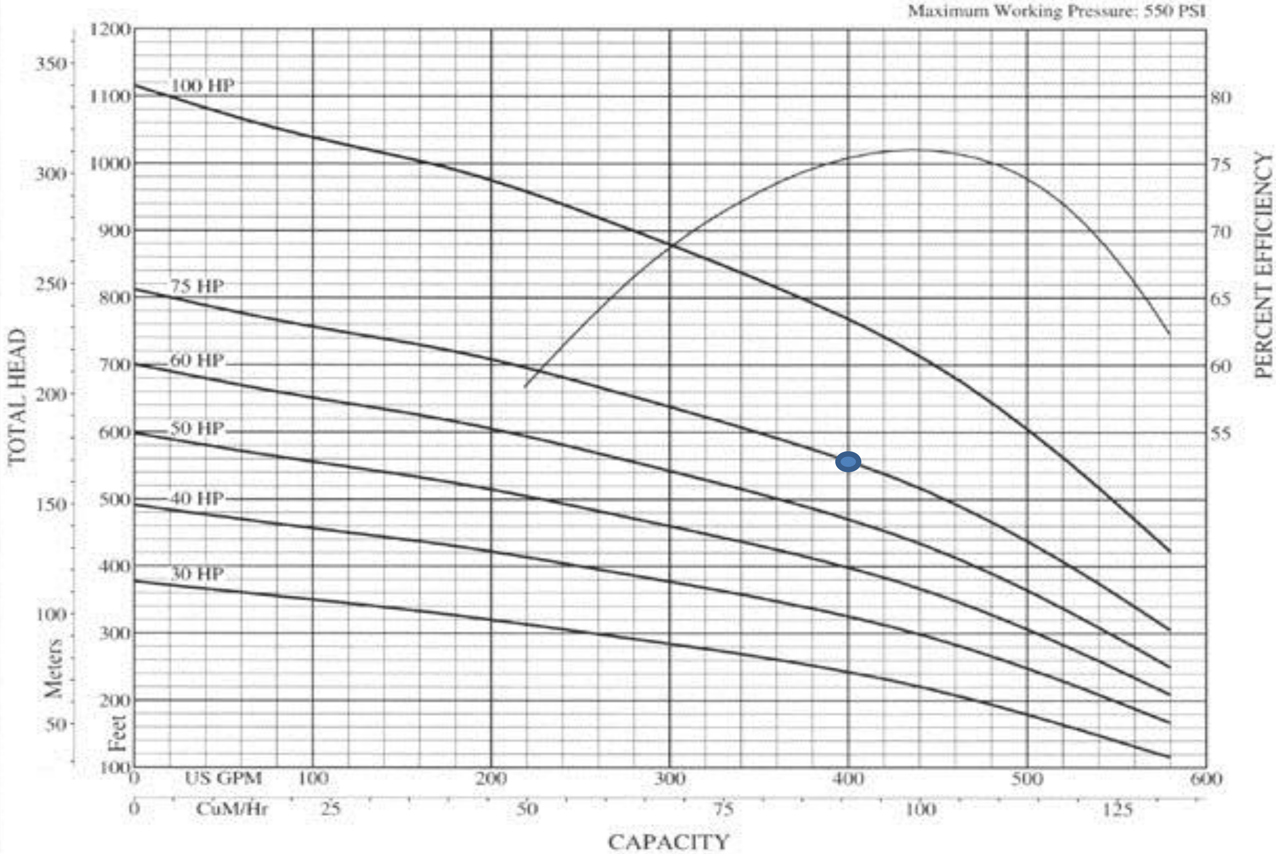
Rf. 5) Based on the Retail Price List on the following pages.

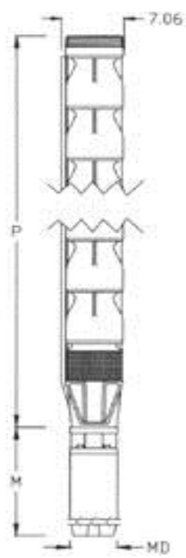
BERKELEY®

SUBMERSIBLE TURBINE

7T-450

Nominal RPM: 3450
Based on Fresh Water @ 68° F.
Maximum Working Pressure: 550 PSI





OUTLINE DIMENSIONS / WEIGHTS

HP	stages	Motor size	P length	M* length	MD* dia.	Mtr. wt.	Pump wt.
30	4	6"	39.44	35.69	5.38	162	136
40	5	6"	45.94	40.81	5.38	195	161
50	6	6"	52.44	57.83	5.38	310	187
60	7	6"	58.94	63.83	5.38	340	212
75	8	8"	66.94	46.79	7.58	450	290
100	11	8"	86.44	54.29	7.58	520	366
Note: dimensions = inches; weight = U.S. lbs.							

M* Maximum length (Franklin Electric Motor)
MD* Motor diameter (Franklin Electric Motor)

SPECIFICATIONS

Minimum Well I.D.	8.0 Inches
Minimum Submergence @ BEP (above inlet)	10.0 Feet
Capacity Range	100 – 580 GPM
Discharge	5" F x 6" M NPT
See manufacturer's data for motor cooling requirements	

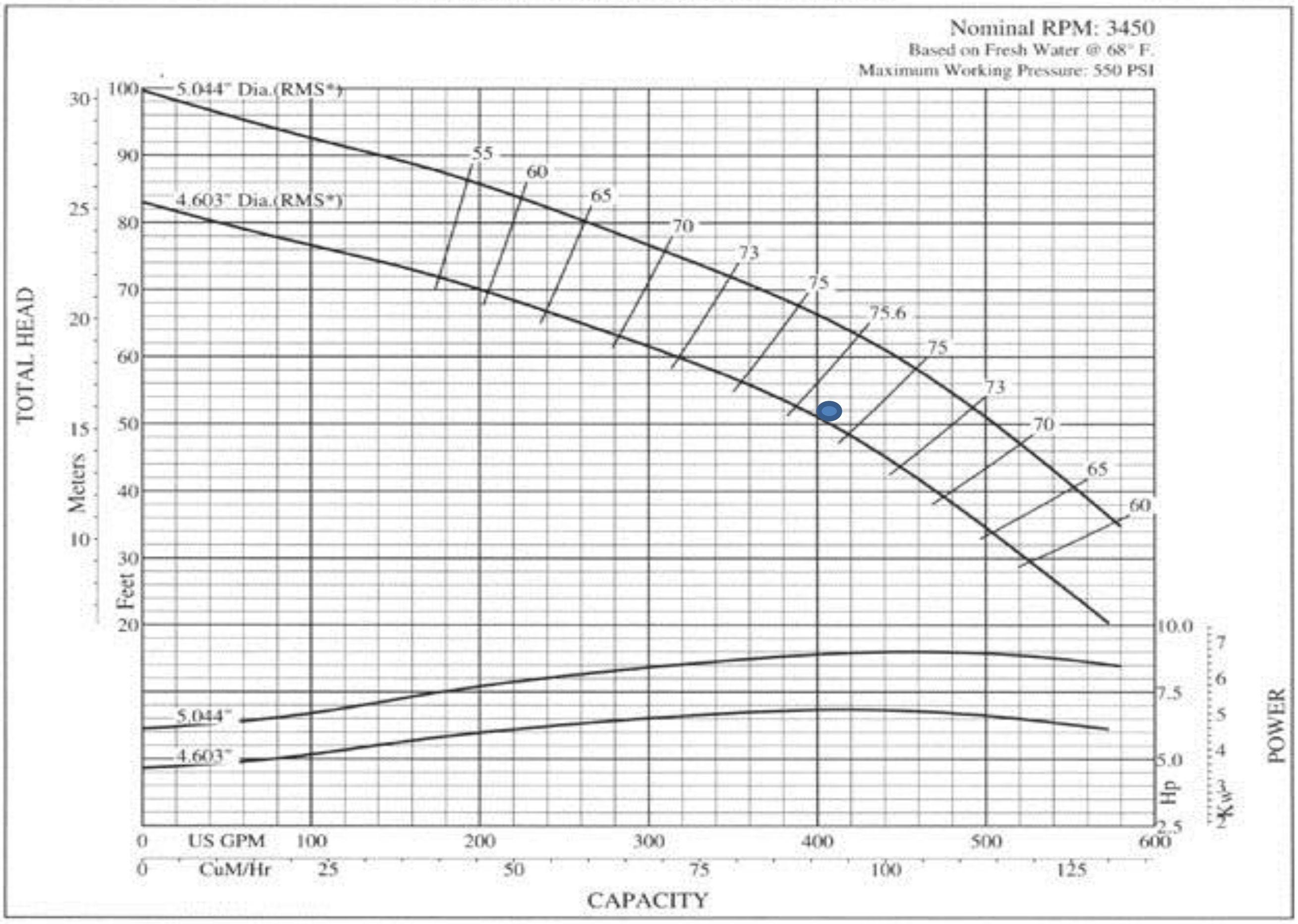
SUPERSEDES
All Previous

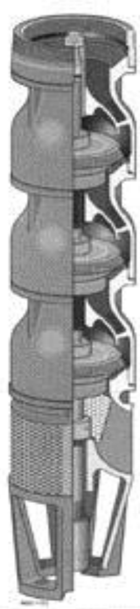
Date **04/15/96**
Section **ST**
Page **20.03**

BERKELEY®

SUBMERSIBLE TURBINE
SINGLE STAGE PERFORMANCE

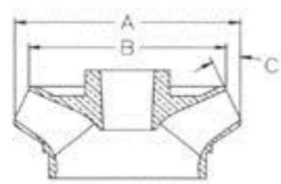
7T-450





IMPELLER DIMENSIONS

RMS* Diameter	A Diameter	B Diameter	C Angle
5.044	5.375	4.690	24°
4.603	4.956	4.220	24°
* Root–Mean–Square			



MATERIALS OF CONSTRUCTION

Part Name	Common Material Name	Material Spec Number
Discharge Adapter	Cast Iron	ASTM A48 Class 30
Top Bowl	Cast Iron	ASTM A48 Class 30
Intermediate Bowl	Cast Iron	ASTM A48 Class 30
Bearings, Top and Suction Case	Bronze	ASTM B144–3B (SAE 660)
Impeller	Silicon Bronze	ASTM B584 UNS C87500
Pump Shaft	Stainless Steel	AISI 416
Impeller Collets	Steel	1226
Suction Bracket	Cast Iron	ASTM A48 Class 30
Bowl Bearing	Rubber	Neoprene
Sand Cap	Bronze	ASTM B144–3B (SAE 660)
Strainer	Stainless Steel	AISI 302 UNS S30200
Cable Guard	Stainless Steel	AISI 302 UNS S30200
Shaft Coupling	Stainless Steel	AISI 416 UNS S41600

SUPERSEDES	
All Previous	
Date	04/15/96
Section	**ST**
Page	**20.02**

Note: Efficiency based on average staging

7" Submersible Pump Ends

7T – Stainless Steel Impellers, Cast Iron Bowls

	Pump Model	HP	Stage(s)	Discharge	Motor Diameter	416 SS Shaft Catalog Number	416 SS Shaft List Price*	Hard Chrome Plated† Shaft Catalog Number	Hard Chrome Plated† Shaft List Price*	Weight (lbs.)
175 GPM	7T5-175	5	2	4" NPT	6"	B85413	$1,721	B85413HC	$2,973	93
	7T7.5-175	7.5	3	4" NPT	6"	B85414	2,122	B85414HC	2,362	117
	7T10-175	10	4	4" NPT	6"	B85415	2,522	B85415HC	2,811	141
	7T15-175	15	6	4" NPT	6"	B85416	3,324	B85416HC	3,716	189
	7T20-175	20	7	4" NPT	6"	B85417	3,726	B85417HC	4,167	213
	7T25-175	25	9	4" NPT	6"	B85418	4,527	B85418HC	5,062	261
	7T30-175	30	11	4" NPT	6"	B85419	5,327	B85419HC	5,959	309
	7T40-175	40	14	4" NPT	6"	B85420	6,530	N/A	N/A	381
	7T50-175	50	17	4" NPT	6"	B85421	7,734	N/A	N/A	453
250 GPM	7T5-250	5	1	4" NPT	6"	B85422	1,318	B85422HC	1,459	69
	7T7.5-250	7.5	2	4" NPT	6"	B85423	1,721	B85423HC	1,901	93
	7T10-250	10	2	4" NPT	6"	B85424	1,721	B85424HC	1,901	93
	7T15-250	15	3	4" NPT	6"	B85425	2,122	B85425HC	2,362	117
	7T20-250	20	4	4" NPT	6"	B85426	2,522	B85426HC	2,811	141
	7T25-250	25	5	4" NPT	6"	B85427	2,921	B85427HC	3,263	165
	7T30-250	30	6	4" NPT	6"	B85428	3,324	B85428HC	3,716	189
	7T40-250	40	8	4" NPT	6"	B85429	4,127	B85429HC	4,615	237
	7T50-250	50	11	4" NPT	6"	B85430	5,327	B85430HC	5,959	309
	7T60-250	60	13	4" NPT	6"	B85431	6,129	N/A	N/A	357
350 GPM	7T5-350	5	1	5" F x 6" M	6"	B77538	1,318	B77538HC	1,459	59
	7T7.5-350	7.5	1	5" F x 6" M	6"	B77539	1,318	B77539HC	1,459	59
	7T10-350	10	2	5" F x 6" M	6"	B77540	1,721	B77540HC	1,901	83
	7T15-350	15	3	5" F x 6" M	6"	B77541	2,122	B77541HC	2,362	108
	7T20-350	20	3	5" F x 6" M	6"	B77542	2,122	B77542HC	2,362	108
	7T25-350	25	4	5" F x 6" M	6"	B77543	2,522	B77543HC	2,811	133
	7T30-350	30	5	5" F x 6" M	6"	B77544	2,921	B77544HC	3,263	158
	7T40-350	40	6	5" F x 6" M	6"	B77545	3,324	B77545HC	3,716	183
	7T50-350	50	8	5" F x 6" M	6"	B77546	4,127	B77546HC	4,615	232
	7T60-350	60	9	5" F x 6" M	6"	B77547	4,526	B77547HC	5,061	257
	7T75-350	75	11	5" F x 6" M	8"	B77548	5,846	N/A	N/A	359
	7T100-350	100	14	5" F x 6" M	8"	B77549	7,046	N/A	N/A	434
450 GPM	7T7.5-450	7.5	1	5" F x 6" M	6"	B77550	1,318	B77550HC	1,459	59
	7T10-450	10	2	5" F x 6" M	6"	B77551	1,721	B77551HC	1,901	85
	7T15-450	15	2	5" F x 6" M	6"	B77552	1,721	B77552HC	1,901	85
	7T20-450	20	3	5" F x 6" M	6"	B77553	2,122	B77553HC	2,362	110
	7T25-450	25	3	5" F x 6" M	6"	B77554	2,122	B77554HC	2,362	110
	7T30-450	30	4	5" F x 6" M	6"	B77555	2,522	B77555HC	2,811	136
	7T40-450	40	5	5" F x 6" M	6"	B77556	2,921	B77556HC	3,263	161
	7T50-450	50	6	5" F x 6" M	6"	B77557	3,324	B77557HC	3,716	187
	7T60-450	60	7	5" F x 6" M	6"	B77558	3,726	B77558HC	4,167	212
	7T75-450	75	8	5" F x 6" M	8"	B77559	4,643	N/A	N/A	290
	7T100-450	100	11	5" F x 6" M	8"	B77560	5,846	N/A	N/A	366
500 GPM	7T10-500	10	1	5" F x 6" M	6"	B77561	1,318	B77561HC	1,459	60
	7T15-500	15	1	5" F x 6" M	6"	B77562	1,318	B77562HC	1,459	60
	7T20-500	20	2	5" F x 6" M	6"	B77563	1,721	B77563HC	1,901	86
	7T25-500	25	2	5" F x 6" M	6"	B77564	1,721	B77564HC	1,901	86
	7T30-500	30	3	5" F x 6" M	6"	B77565	2,122	B77565HC	2,362	112
	7T40-500	40	3	5" F x 6" M	6"	B77566	2,122	B77566HC	2,362	112
	7T50-500	50	4	5" F x 6" M	6"	B77567	2,522	B77567HC	2,811	138
	7T60-500	60	5	5" F x 6" M	6"	B77568	2,921	B77568HC	3,263	164
	7T75-500	75	6	5" F x 6" M	8"	B77569	3,842	N/A	N/A	242
	7T100-500	100	8	5" F x 6" M	8"	B77570	4,643	N/A	N/A	294
	7T125-500	125	10	5" F x 6" M	8"	B77571	5,445	N/A	N/A	346

***List Price includes Pump End only. For motor and control prices, refer to pages 10-16.**
† Hard chrome plated per SAE-QQ-C-320 Class II Type 2 to a final thickness of .005/.007.

AR No. 7 - Photovoltaic Array

Recommendation

We recommend installing a photovoltaic array on the building roof. This will provide an alternative source for 38.3% of the facilities energy consumption and reduce CO2 emissions associated with electrical generation.

Assessment Recommendation Savings Summary

Source	*Quantity*	*Units*	*Cost Savings*
Electrical Consumption	38,304	kWh (site)	$3,830
Electrical Demand	16	kW Months / yr	$80
Total	**131**	**MMBtu**	**$3,911**

Assessment Recommendation Cost Summary

Description	*Cost*	*Payback*
Implementation Cost	$62,875	16.1

Facility Background

Currently your facility relies on utility companies to supply your electrical energy needs. Electricity provided by utility companies is commonly generated using fossil fuels such as coal, oil, and natural gas. The combustion of these fuels releases a variety of harmful pollutants into the atmosphere, including carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2). These pollutants are the leading cause of acid rain and smog and represent a significant portion of greenhouse gas emissions. Renewable energy sources, on the other hand, are clean, naturally replenished, and will play a key role in generating a reliable energy future.

Technology Background

The amount of solar energy that strikes the earth every day is enormous. Photovoltaic's use a special material that silently and directly converts this energy into electricity at the atomic level without using complex machinery usually associated with electrical generation. This is possible because of a material property known as the photoelectric effect, which allows the material to absorb photons of light and release electrons. These free electrons can then be captured resulting in an electrical current that can be used as electricity. Because the resulting electrical current is Direct Current (DC), an inverter must be used to convert it into Alternating Current (AC) before it can be used.

There are two main factors that effect the output capacity of photovoltaic arrays:

- **Number of photons:** This is how many photons actually strike the photovoltaic panel, it is most commonly affected by the size and orientation of the panels.

- ***Array orientation:*** The power output of photovoltaic panels is greatly affected by their orientation and tilt angle to the sun. Because the sun's position and angle changes in the sky depending on the time of year, solar systems are most efficient if used with a solar tracking mechanism. Static mounted systems can still provide adequate performance if optimized using sun charts to determine the best position and angle.
- ***Array size:*** Photovoltaic panels are broken into cells which are then connected in parallel. This allows the provided voltage to remain constant no matter the number of cells, this means the power output of a solar system is directly proportional to its area.

- **Photon intensity (Light wavelength):** This is the amount of energy each photon contains, it is most commonly affected by the local climate and the latitudinal position of the panels.
  - ***Latitudinal position:*** Geographic locations further from the equator experience a seasonal reduction in solar radiation availability. For best performance in these locations the panel angle is often set to the angle of the latitude, however, performance can be improved by adjusting the panel angle on a per season basis or by using a solar tracking system to continuously adjust the panels to the optimum angle.

  - ***Climate:*** Local climate can significantly affect the power output of photovoltaic arrays. During the winter the sun sits lower in the sky increasing the amount of atmosphere light must pass through thus decreasing the light intensity. Additionally, locations with cloudy, rainy, or snowy conditions for large portions of the year may encounter significant power decreases.

Proposal

We recommend installing a photovoltaic array on the building roof. A photovoltaic array will reduce electrical costs and carbon emissions associated with electrical generation. This will reduce associated annual energy consumption by 38.3%.

If the previously mentioned actions are taken, they will save 38,304 kWh annually and result in an annual cost savings of $3,911 for a net payback of 16.1 years after an implementation cost of $62,875.

Notes

While the recommended square footage of photovoltaic arrays is based on available roof space, the structural capacity of the roof has not been evaluated. It may be more feasible to locate the photovoltaic array elsewhere.

Changing the solar field size will change the cost savings and implementation cost, but not the payback period. Therefore a system of smaller or larger capacity could be installed with the same payback period.

Based on	Author	Readability Review	Engineering Review	Math Review
Unmodified Template	*Insert Name*	*Insert Name*	*Insert Name*	*Insert Name*

AR No. 7 - Photovoltaic Array

Site Data

General Data

Site Location		*Sample Site*		

Station Data

Station Name		*CORVALLIS MUNI*		**(Rf. 1)**
Station Time Zone		*-8*		**(N. 1, Rf. 1)**
Station Latitude		*44.483*	degrees	**(Rf. 1)**
Station Longitude		*-123.283*	degrees	**(Rf. 1)**
Station Elevation		*252.6*	ft.	**(Rf. 1)**

Utility Data

Annual Energy Consumption	(E_C)	*100,000*	kWh	**(Rf. 2)**
Incremental Electricity Cost	(IC_E)	*$0.10000*	/kWh	**(Rf. 2)**
Incremental Demand Cost	(IC_D)	*$5.00*	/kW-mo.	**(Rf. 2)**

Assumptions

Reflectance of Foreground	(ρ_g)	*0.20*		**(Rf. 3)**

PV Module Specifications

Electrical Characteristics

STC Power Rating	(P_{MP})	*250.0*	W	**(Rf. 4)**
PTC Power Rating	(P_{MPP})	*227.3*	W	**(Rf. 4)**
Module Efficiency	(η_M)	*14.7%*		**(Rf. 4)**

Temperature Coefficients

Power Temperature Coefficient	(δ)	*-0.45%*	/°C	**(Rf. 4)**

Mechanical Characteristics

Cell Type		*Monocrystalline Cell*		**(Rf. 4)**
Cell Width	(w_C)	*125*	mm	**(Rf. 4)**
Cell Length	(L_C)	*125*	mm	**(Rf. 4)**
Number of Cells	(N_C)	*96*		**(Rf. 4)**
Module Width	(w_M)	*41.8*	inches	**(Rf. 4)**
Module Length	(L_M)	*63.1*	inches	**(Rf. 4)**
Module Surface Area	(A_M)	*18.3*	ft.^{2}	**(Eq. 1)**
Module Weight	(F_M)	*44.1*	lbs.	**(Rf. 4)**

Operating Conditions

Nominal Operating Cell Temp.	(T_{NOCT})	*45*	°C	**(Rf. 4)**

References

Rf. 1) National Solar Radiation Data Base, *Typical Meteorological Year 3*, http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

Rf. 2) Developed in the Utility Analysis of the Site Data section.

Rf. 3) ASHRAE F29.36, Grass reflectance at 30° or crushed rock at any angle.

Rf. 4) POSHARP *Database* , www.posharp.com/photovoltaic/database.aspx

Equations

Eq. 1) Module Surface Area (A_M)

$$w_M \times L_M$$

Notes

N. 1) Hours from Greenwich Mean Time, negative west.

N. 2) STC stands for Standard Test Conditions which are 1,000 W/m^2 solar irradiance, 1.5 air mass, and 25°C cell temperature.

N. 3) PTC stands for PV USA Test Conditions which are 1,000 W/m^2 solar irradiance, 1.5 air mass, 20°C ambient air temperature at 10 meters above ground and 1 m/s wind speed.

AR No. 7 - Photovoltaic Array

PV Array Specifications

Configuration

Number of Modules	(N_M)	*100*		
Total Array Surface Area	(A_A)	*1,831.7*	ft.^{2}	**(Eq. 2)**
STC Power Output	(P)	*25.0*	kW	**(Eq. 3)**

Orientation

Installation Type		*Set Inclination*		
Orientation (Azimuth)	(Ψ)	*0.0*	degrees	**(N. 4)**
Inclination (Tilt Angle)	(Σ)	*30.0*	degrees	**(N. 5)**

Inverter Specifications

Inverter Efficiency	(η_I)	*95.0%*		**(Rf. 5)**

Energy Saving Analysis

Annual Energy Production	(E_S)	*38,304*	kWh	**(N. 6)**
Annual Energy Cost Savings	(C_E)	*$3,830*	/yr.	

Demand Reduction Analysis

Operation Hours (Start)		*800*		
Operation Hours (End)		*1,700*		
Average Monthly Demand Savings	(D_S)	*1.3*	kW	**(N. 7)**
Annual Demand Cost Savings	(C_D)	*$80*	/yr.	

Implementation Cost Analysis

Average Inverter Cost	(C_I)	*$715*	/kW	**(Rf. 6)**
Average Module Cost	(C_M)	*$1,800*	/kW	**(Rf. 6)**

Economic Results

Annual Cost Savings	(C_S)	*$3,911*	/yr.	**(Eq. 4)**
Implementation Costs		*$62,875*		**(Eq. 5)**
Payback	(t_{PB})	*16.1*	yrs.	

References

Rf. 5) ENF *Solar Components* , www.enf.cn/database/components-inverter

Rf. 6) Solarbuzz *Retail Pricing Environment* , http://solarbuzz.com/facts-and-figures/retail-price-environment, The index calculation includes a number of elements. Pricing covers the solar module and the other major components, other electrical components, assembly and installation costs, transportation and ongoing maintenance.

Equations

Eq. 2) Total Array Surface Area (A_A)

$$A_M \times N_M$$

Eq. 3) STC Power Output (P)

$$P_{MP} \times N_M \times \frac{1kW}{1,000W}$$

Eq. 4) Cost Savings (CS)

$$(E_S \times IC_E) + (D_S \times IC_D \times 12mo.)$$

Eq. 5) Implementation Costs (IC)

$$(C_I + C_M) \times P$$

Notes

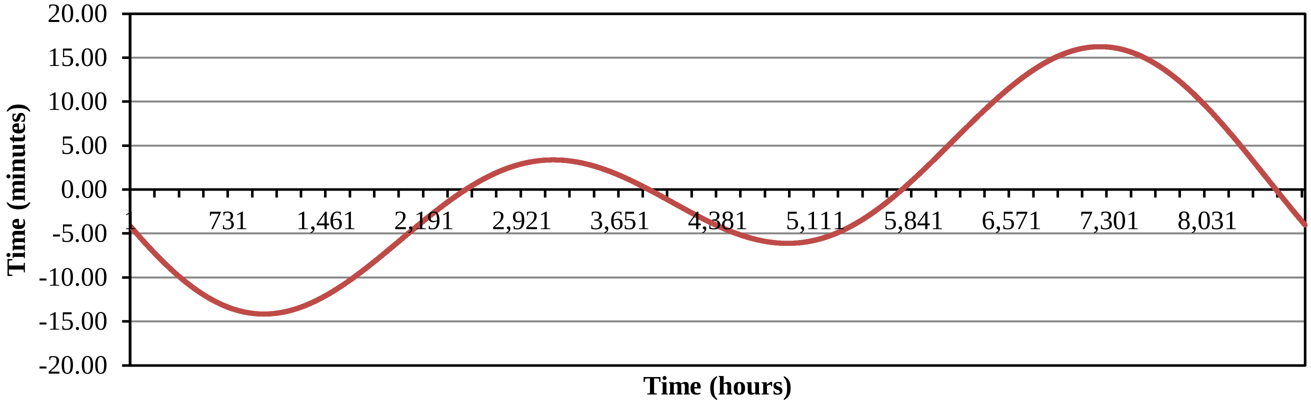
N. 4) Angle of array from South, with West of South being positive.

N. 5) Inclination is the angle between the module and the horizontal plane.

N. 6) Annual energy production is calculated on a hourly basis from Typical Metrological Year data. See the following pages for an in depth analysis.

N. 7) Average monthly demand is calculated from the minimum array output during the facility operation hours for each month.

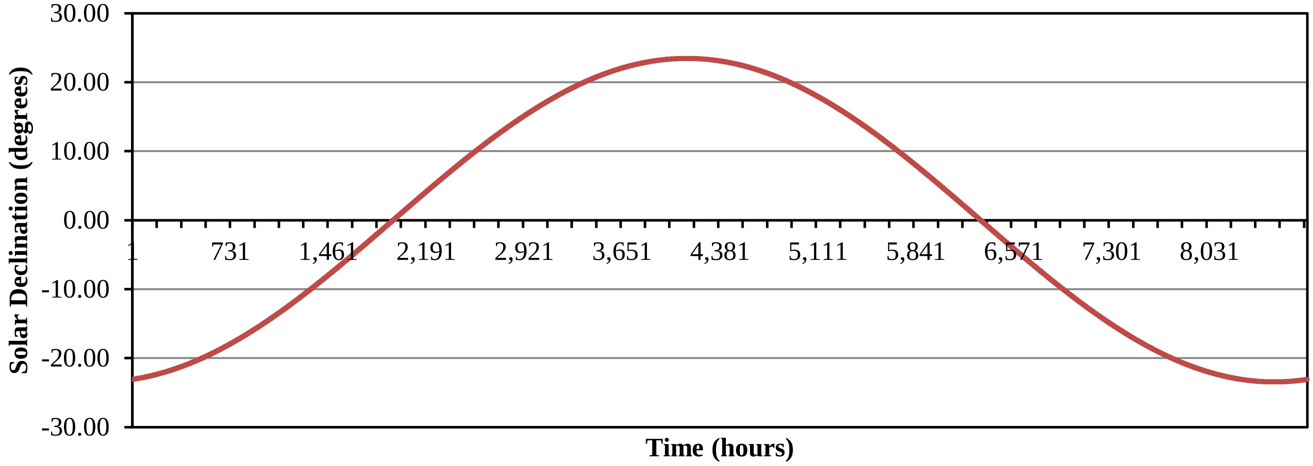
Equation of Time (Δt) (Rf. 7)



The equation of time represents the difference between apparent solar time (AST) and mean solar time (MST) for a given location due to obliquity of the ecliptic and the eccentricity of earths orbit around the sun. It varies over the course of a year according to the following expression:

$$\frac{\Delta t}{\min} = 229.18\left[-0.0334\sin\left(\frac{2\pi}{365.24}\frac{t-t_{\_}}{day}\right)+0.04184\sin\left(\frac{4\pi}{365.24}\frac{t-t_{\_}}{day}+3.5884\right)\right]$$

Solar Declination (δ) (Rf. 8)

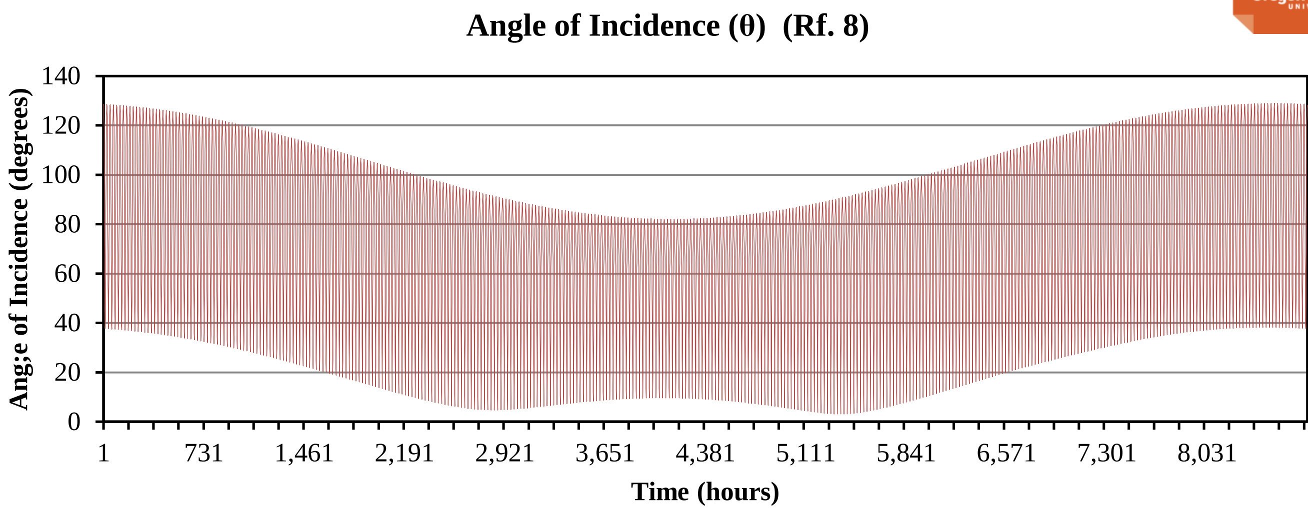


Solar declination is the angle between the earth-sun line and the earth's equatorial plane. This angle varies with date and can be approximated using the following equations. The change in solar declination is the primary reason for our changing seasons.

$$\delta = 23.45\sin\left[2\pi\left(284+N\right)/365\right]$$

$$AST = LST + Equation\ of\ Time + \left(4\min\right)\left(LST\ Merdian - Local\ Longitude\right)$$

$$H = 15^{o}\left(number\ of\ hours\ from\ solar\ noon\right)$$

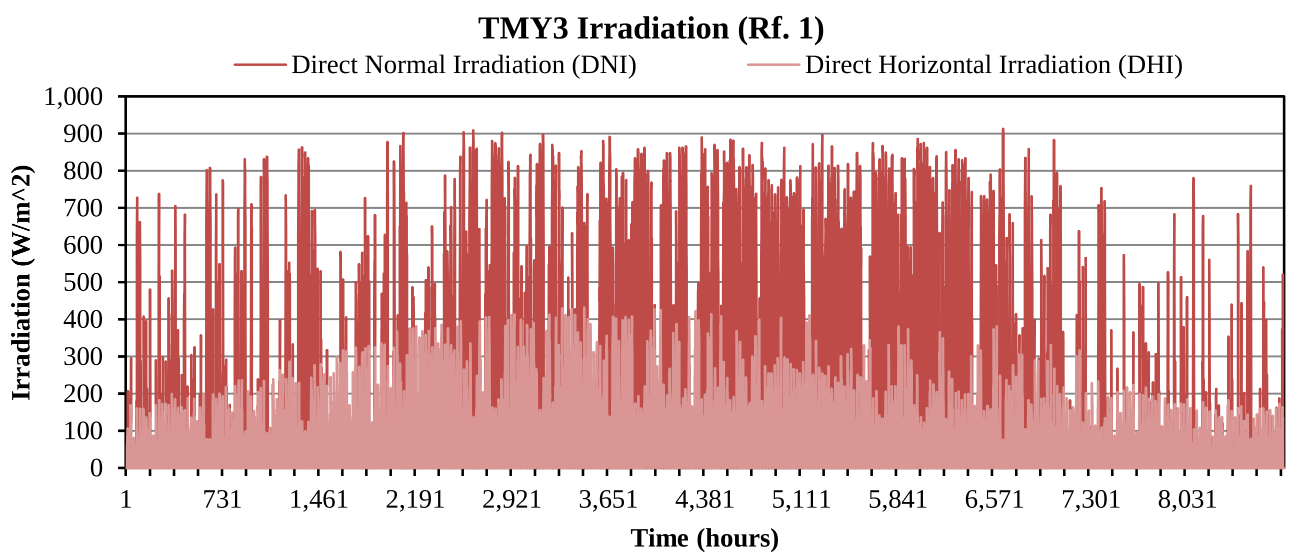


The incident angle is the angle between the line normal to the irradiated surface and the earth-sun line. It affects the direct component of the solar radiation striking the surface and the ability of the surface to absorb, transmit or reflect solar irradiation.

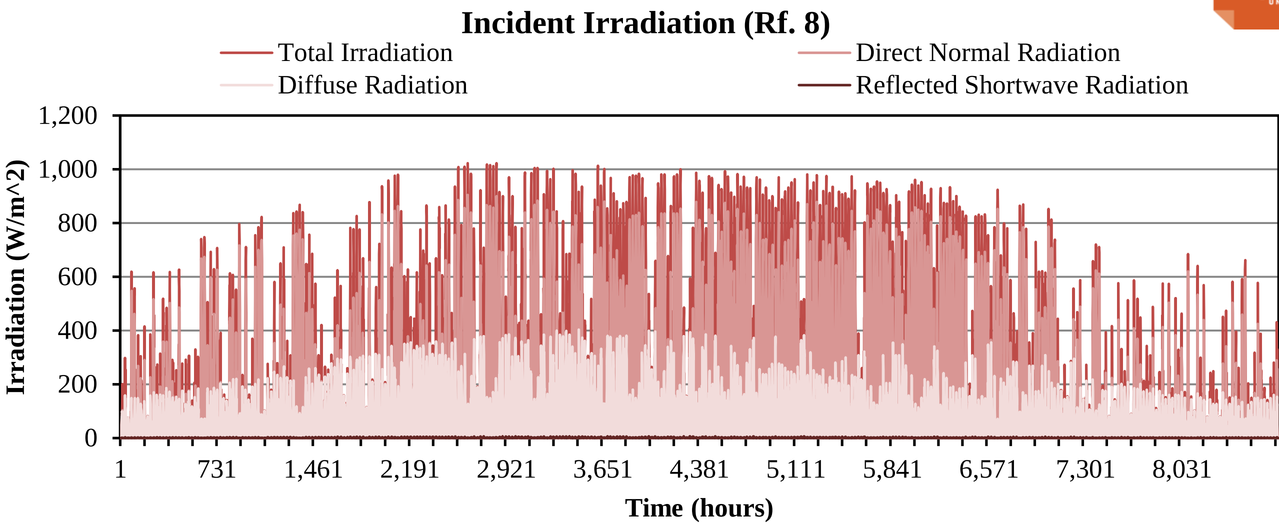
$$\sin\beta = \cos(LAT)\cos\delta\cos H + \sin(LAT)\sin\delta$$

$$\sin\phi = \cos\delta\sin H / \cos\beta$$

$$\cos\theta = \cos\beta\cos\gamma\sin\Sigma + \sin\beta\cos\Sigma$$



Typical Meteorological Year (TMY) data sets derived from the 1991-2005 National Solar Radiation Data Base (NSRDB) archives.

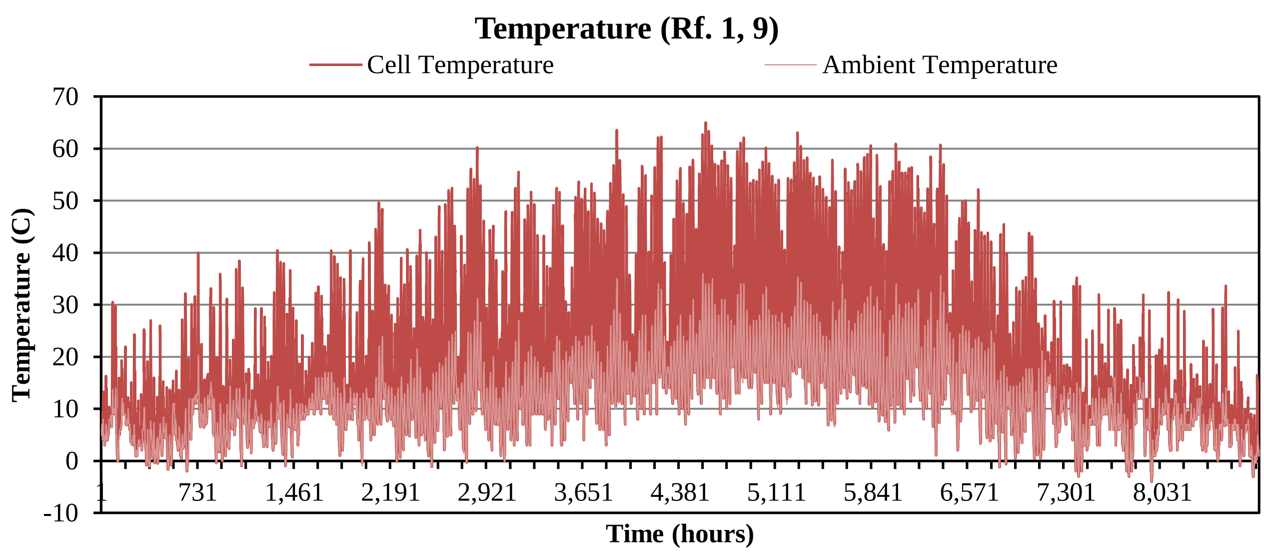


Total solar irradiation of a surface at a given tilt and orientation with incident angle (θ) is the sum of the direct component from the sun, the diffuse component from the sky, and any reflected shortwave radiation from the earth or other nearby surfaces.

$$I_{t\theta} = I_{DN} \cos\theta + I_{d\theta} + I_r$$

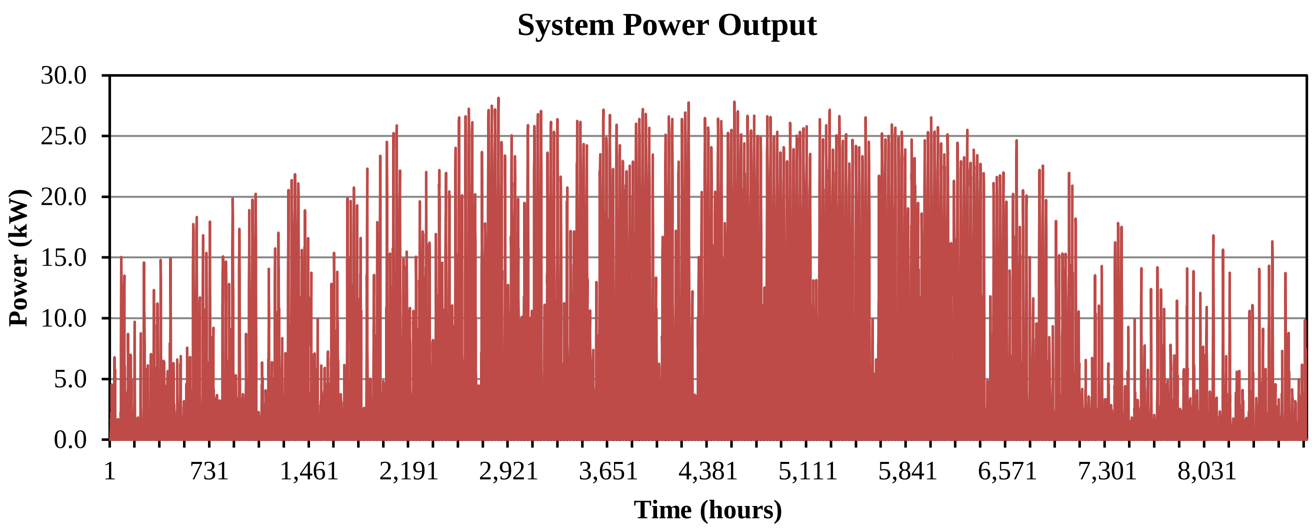
$$I_{d\theta} = I_{dH} \left(1 + \cos\Sigma\right) / 2$$

$$I_r = I_{tH} \rho_g \left(1 - \cos\Sigma\right) / 2$$



Typical Meteorological Year (TMY) data sets derived from the 1991-2005 National Solar Radiation Data Base (NSRDB) archives.

$$T_{cell} = T_{air} + I_{t\theta}\left(\frac{T_{NOCT} - 20}{800}\right)$$



$$P_{real} = P_{MP} \times \frac{I_{t\theta}}{1,000W/m^2} \times \left[1 - \lambda_P \left(T_{cell} - 25\right)\right]$$

$$P_{system} = P_{module} \times N_M \times \eta_I$$

References

Rf. 7) Whitman A M 2007, "A Simple Expression for the Equation of Time", *Journal Of the North American Sundial Society 14* , pp 29–33.

Rf. 8) ASHRAE, *HVAC Applications Handbook.* 1995. Chapter 30, "Solar Energy Utilization"

Rf. 9) Ross, R.G. Jnr. and Smokler, M.I. (1986), *Flat-Plate Solar Array Project Final Report, Volume VI: Engineering Sciences and Reliability* , Jet Propulsion Laboratory Publication 86-31.

4. SITE DATA

General Background

Facility Description

SIC Code:	2421	Location:	Oregon
NAICS Code:	321113	Area of Plant:	200,000 sq. ft.
Annual Sales:	$40,000,000	Employees:	200
Annual Production:		Audit date:	1/1/2012
Principal Products:	Board	Client hours:	8

The plant consists of a sawmill, planer mill, a boiler operation room, two sets of kilns and multiple storage sheds. Logs are brought into the sawmill on conveyors and debarked. They go through the sawmill to be cut into different sized boards. Bark from the debarking process is sent to the hog fueled boiler for fuel via pneumatic conveyors. The cut boards are stacked and stored or sent to the planer. After the planer, boards are sent to the kilns to be dried then stacked and sorted for shipping.

Best Practices

Your company has already implemented the following energy saving, waste reduction, and productivity improvement practices.

- Economizer and boiler air pre-heater
- Frequency drive on hog fueled boiler intake fan
- Motion sensors on lights in the boiler room
- Frequency driven moisture sensing control on kiln fans
- Clean side fan on planer dust collection

Process Description

The plant produces a wide variety of boards from cut logs. Logs are brought into the sawmill on conveyors and debarked. They go through the sawmill to be cut into different sized boards. Bark from the debarking process is sent to the hog fueled boiler for fuel via pneumatic conveyors. The cut boards are stacked and stored or sent to the planer. After the planer, boards are sent to the kilns to be dried then stacked and sorted for shipping.

Raw Materials:

Logs

Principal Products:

Boards

Production Detail Description

Barker

The logs are fed to the barker where the bark is removed and sent to the hog fueled boiler.

Energy Application	Quantity	Total Power
Barker Motor	1	75 hp
Feed Motors	2	150 hp
Bark Blower	1	75 hp

Sawmill

Once the logs have been debarked, they travel through the sawmill to be cut into boards based on defects and sizes. They are automatically stacked before being sent to the planer and kilns.

Energy Application	Quantity	Total Power
4" Edger Right	1	200 hp
4" Edger Left	1	400 hp
Bandmills	2	400 hp
Chippers	2	500 hp

Planer

Lumber is sent through the planer for finishing before being rated based on quality. Unused excess wood is combined with planer shavings and is sent out of the building with pneumatic conveyors.

Energy Application	Quantity	Total Power
Top Head Motor	1	200 hp
Bottom Head Motor	1	150 hp

Boiler Room

The hog fueled boiler provides steam for the kilns, when the pressure in the lower kilns drops below 35 psi the gas fueled boiler kicks on to supplement the steam.

Energy Application	Quantity	Total Power
Cleaver-Brooks Forced Draft Intake Fan	1	75 hp

General Plant Equipment

Energy Application	Quantity	Total Power
Air Compressors	3	750 hp

Operating Schedule

Area	hrs/day	days/wk	wks/yr	Annual Days	Annual Hours
Sawmill	13.5*	5	52	260	3,510
Planer	13.5*	5	52	260	3,510
Kilns	24	7	52	365	8,760
Boiler	24	7	52	365	8,760

*****The sawmill and planer can both run a second shift, however usually only one or the other is running at a given time.

Utility Summary

Oregon State University OSU Energy Efficiency Center

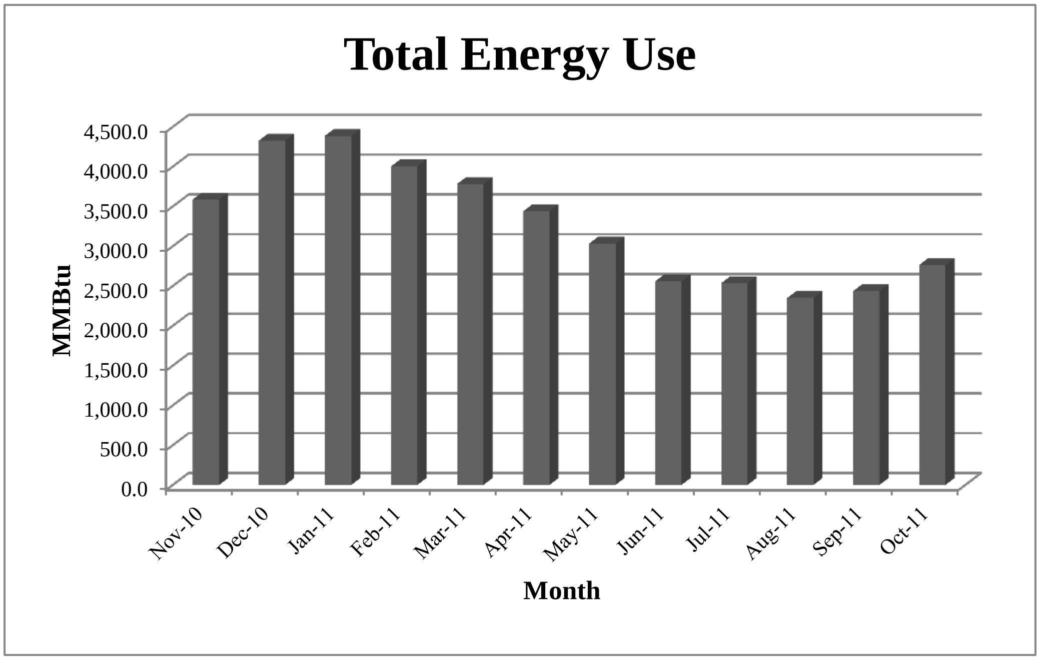
Electricity Summary				
Meter	Meter Description	Rate Schedule	Incremental Electricity Cost **($/kWh)**	Incremental Demand Cost **($/kW-mo)**
1	Paint Shop	83S	**$0.0730**	**$4.80**
2	Paint Shop	32	**$0.1061**	**--**
3	Main	32	**$0.1061**	**--**
4	Molding/ Cleanroom	32	**$0.1061**	**--**
5	Molding/ Cleanroom	85S	**$0.0667**	**$4.95**
6	N. Warehouse	83S	**$0.0730**	**$4.80**
7	Controls Engineering	32	**$0.1061**	**--**
8	L. Casting/ Production	83S	**$0.0730**	**$4.80**
9	L. Casting/ Production	83S	**$0.0730**	**$4.80**
10	Control Warehouse	83S	**$0.0730**	**$4.80**
11	Upper Casting 240V	83S	**$0.0730**	**$4.80**
12	Upper Casting 480V	83S	**$0.0730**	**$4.80**
13	Assembly/S. Warehouse	83S	**$0.0730**	**$4.80**

Natural Gas Summary			
Meter	Meter Description	Incremental Natural Gas Cost **($/therm)**	Incremental Natural Gas Cost **($/MMBtu)**
1	East Plant	**$0.8570**	**$8.57**
2	North Plant	**$1.0524**	**$10.52**
3	West Plant	**$0.6806**	**$6.81**

Utility Summary

Combined Meters/Utilities								
	Electricity							
Month	kWh	kWh$	kW	kW$	kVAR	kVAR$	PF %	Total$
Nov-10	360,780	$25,449	1,069	$4,985	639	$170	66.9%	$32,793
Dec-10	372,220	$26,260	1,067	$4,968	569	$143	70.2%	$33,602
Jan-11	382,800	$26,685	1,054	$4,964	566	$140	70.2%	$34,045
Feb-11	329,200	$23,004	1,003	$4,909	555	$136	70.4%	$30,098
Mar-11	388,240	$27,078	1,046	$4,948	570	$141	70.0%	$34,445
Apr-11	409,780	$28,544	1,099	$5,112	614	$157	69.1%	$36,181
May-11	381,560	$26,608	1,057	$4,960	575	$144	71.1%	$33,963
Jun-11	362,800	$25,369	1,099	$5,087	621	$158	67.5%	$32,803
Jul-11	376,380	$26,245	1,104	$5,109	612	$151	69.1%	$33,744
Aug-11	352,200	$24,604	1,075	$5,017	536	$117	70.4%	$31,879
Sep-11	387,520	$27,000	1,115	$5,098	585	$136	68.7%	$34,514
Oct-11	367,164	$25,652	1,126	$5,146	604	$144	67.7%	$33,254
Totals	4,470,644	$312,497	12,914	$60,302	7,046	$1,736	-	$401,321
Avg/mo.	372,554	$26,041	1,076	$5,025	587	$145	69.3%	$33,443

Combined Meters/Utilities				
	Natural Gas		Combined	
Month	Therms	$	MMBtu	Total $
Nov-10	23,560	$20,341	3,587.3	$53,134
Dec-10	30,558	$26,047	4,326.1	$59,648
Jan-11	30,797	$26,545	4,386.2	$60,591
Feb-11	28,788	$24,735	4,002.3	$54,833
Mar-11	24,563	$21,652	3,781.4	$56,096
Apr-11	20,393	$18,135	3,437.9	$54,316
May-11	17,314	$15,433	3,033.6	$49,396
Jun-11	13,199	$8,302	2,558.2	$41,106
Jul-11	12,501	$11,202	2,534.7	$44,946
Aug-11	11,463	$10,473	2,348.4	$42,352
Sep-11	11,126	$10,251	2,435.2	$44,765
Oct-11	15,100	$13,456	2,763.1	$46,710
Totals	239,361	$206,572	39,194.4	$607,893
Avg/mo.	19,947	$17,214	3,266.2	$50,658


Total Energy Use
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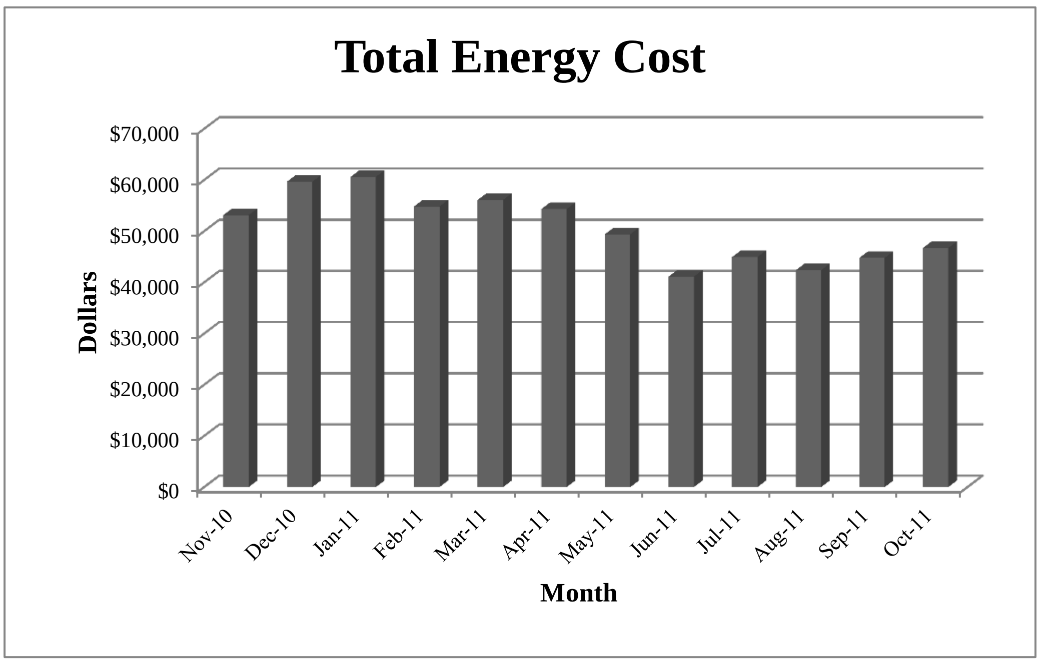
4,000.0
3,500.0
3,000.0
2,500.0
2,000.0
1,500.0
1,000.0
500.0
0.0
MMBtu
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Total Energy Cost
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
Dollars
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 1)

Facility Information

Meter Description	Paint Shop	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)	

Demand Cost

Demand Charge	$1.76	/kW-mo	
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30 kW
	$2.08	/kW-mo over	30 kW
Transmission Charge	$0.82	/kW-mo	

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40% kW

Taxes and Fees

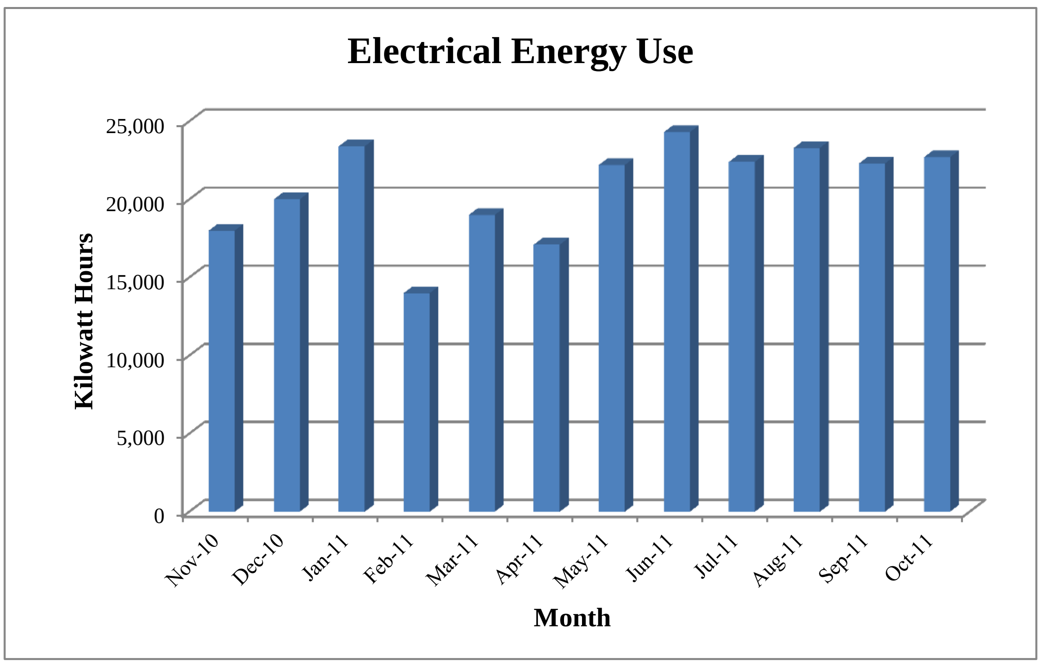
Basic Charge	$30	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
City Tax	1.5%		
County Tax	0.335%		
Public Purpose Charge	3.0%		

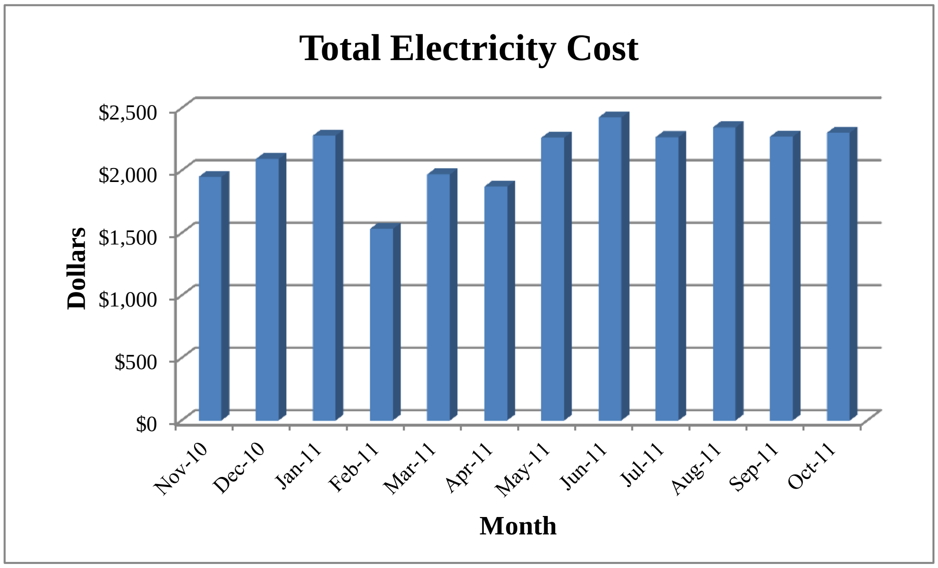
Meter Summary

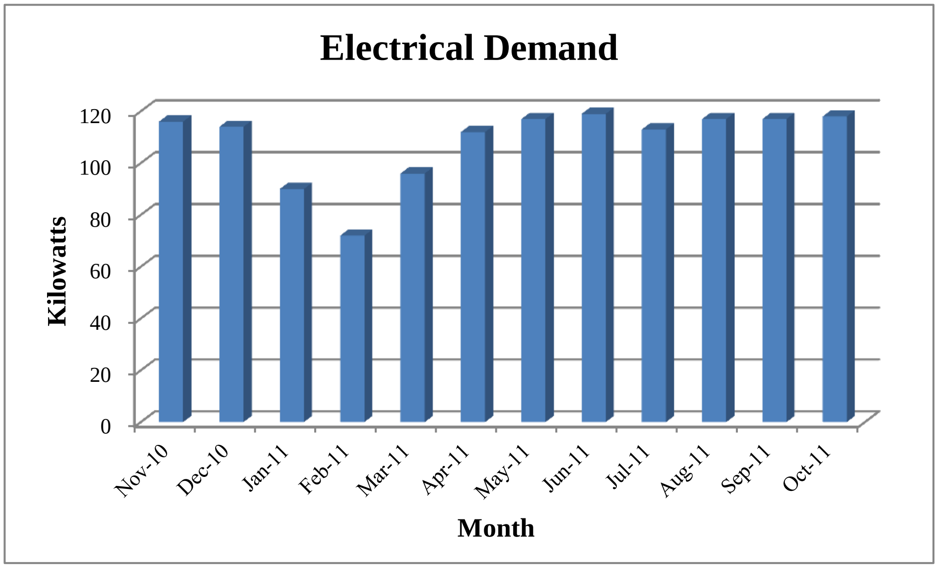
Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.1028	/kWh
Average Power Factor	-	

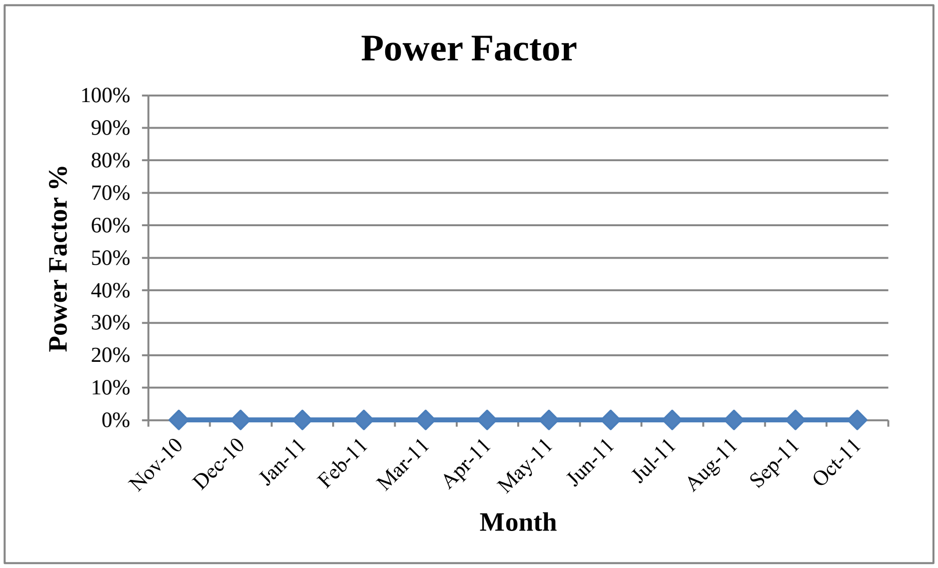
Electricity (Meter 1)

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	18,000	$1,266	116	$556		$0	-	$127	$1,949
Dec-10	20,000	$1,407	114	$551		$0	-	$135	$2,093
Jan-11	23,400	$1,646	90	$489		$0	-	$145	$2,280
Feb-11	14,000	$985	72	$442		$0	-	$106	$1,533
Mar-11	19,000	$1,337	96	$504		$0	-	$129	$1,970
Apr-11	17,100	$1,203	112	$545		$0	-	$123	$1,872
May-11	22,200	$1,562	117	$558		$0	-	$144	$2,264
Jun-11	24,300	$1,710	119	$564		$0	-	$152	$2,425
Jul-11	22,400	$1,576	113	$548		$0	-	$144	$2,268
Aug-11	23,300	$1,639	117	$558		$0	-	$148	$2,346
Sep-11	22,300	$1,569	117	$558		$0	-	$144	$2,271
Oct-11	22,700	$1,597	118	$561		$0	-	$146	$2,304
Totals	248,700	$17,499	1,301	$6,435	0	$0	-	$1,642	$25,575
Avg/mo.	20,725	$1,458	108	$536	-	$0	-	$137	$2,131




Total Electricity Cost
Dollars
$2,500
$2,000
$1,500
$1,000
$500
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
120
100
80
60
40
20
0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 2)

Oregon State University OSU Energy Efficiency Center

Facility Information

Meter Description	Paint Shop		
Rate Schedule	32		

Energy Cost

Base Electricity Cost	$0.10249	/kWh up to	5,000 kWh
	$0.07737	/kWh over	5,000 kWh

Taxes and Fees

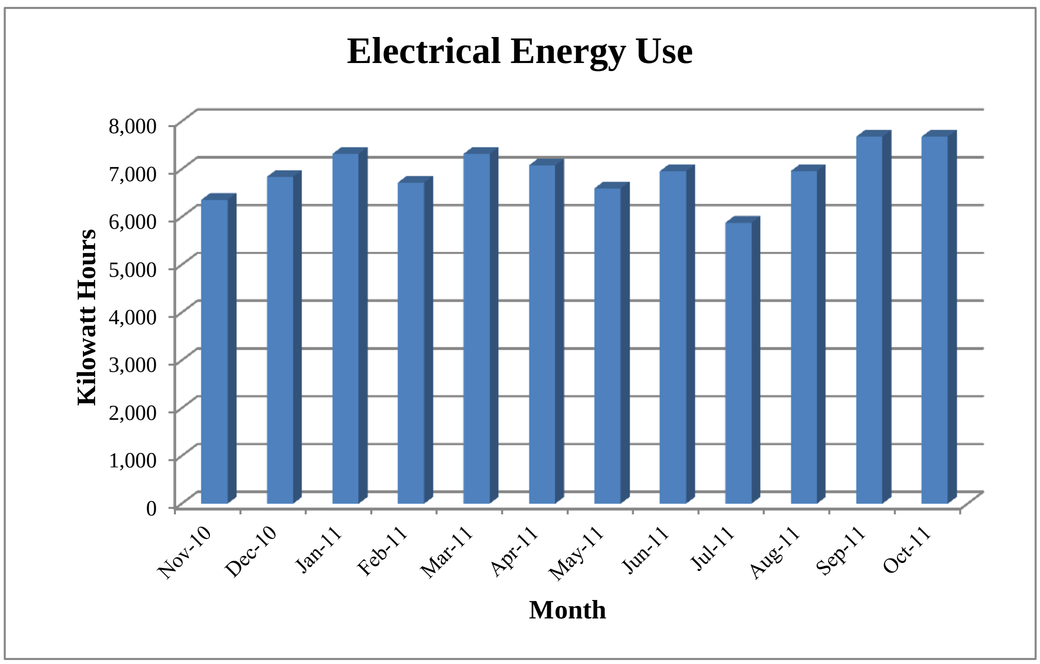
Basic Charge	$16	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
Public Purpose Charge	3.0%		
County Tax	0.335%		
City Tax	1.5%		

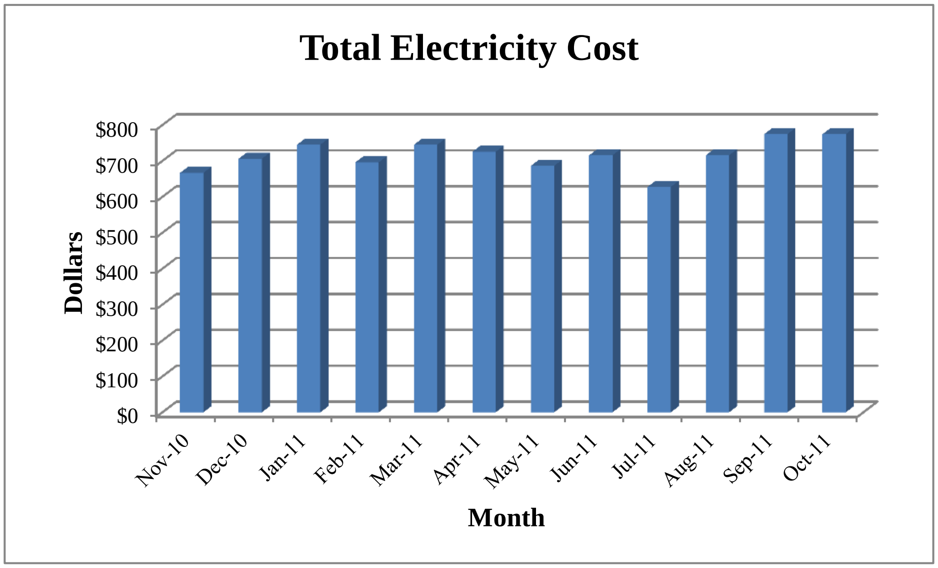
Meter Summary

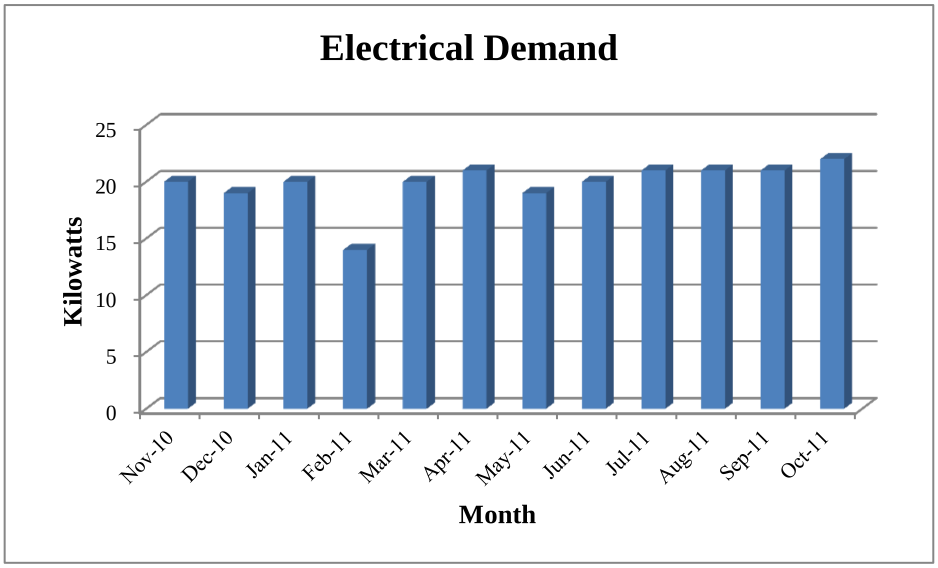
Incremental Electricity Cost	**$0.10608**	/kWh (with taxes and fees)
Incremental Demand Cost	**--**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.1029	/kWh
Average Power Factor	--	

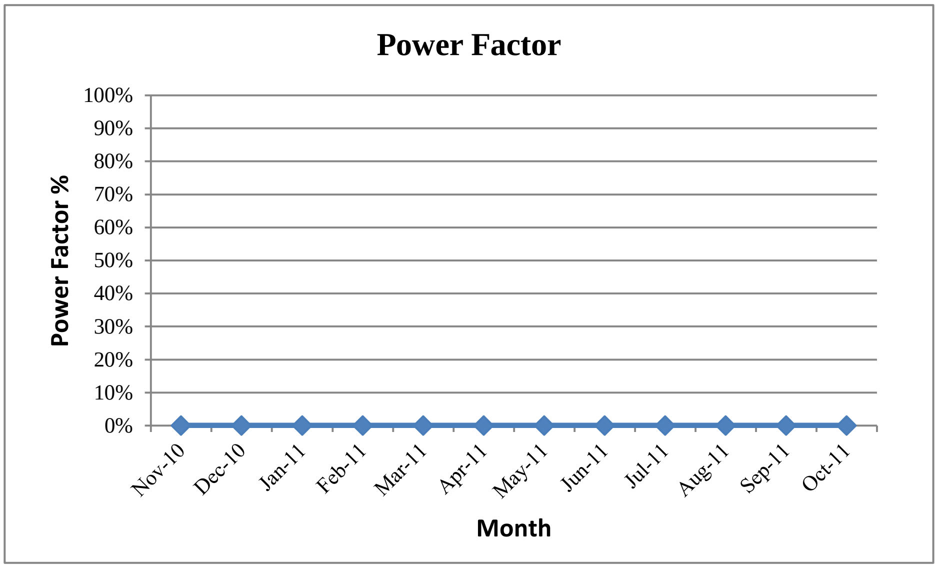
Electricity (Meter 2)

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	6,360	$618	20	$0		$0	-	$49	$667
Dec-10	6,840	$655	19	$0		$0	-	$51	$706
Jan-11	7,320	$692	20	$0		$0	-	$53	$745
Feb-11	6,720	$646	14	$0		$0	-	$51	$696
Mar-11	7,320	$692	20	$0		$0	-	$53	$745
Apr-11	7,080	$673	21	$0		$0	-	$52	$725
May-11	6,600	$636	19	$0		$0	-	$50	$686
Jun-11	6,960	$664	20	$0		$0	-	$52	$716
Jul-11	5,880	$581	21	$0		$0	-	$47	$628
Aug-11	6,960	$664	21	$0		$0	-	$52	$716
Sep-11	7,680	$720	21	$0		$0	-	$55	$774
Oct-11	7,680	$720	22	$0		$0	-	$55	$774
Totals	83,400	$7,960	238	$0	0	$0	-	$619	$8,578
Avg/mo.	6,950	$663	20	$0	-	$0	-	$52	$715




Total Electricity Cost
Dollars
$800
$700
$600
$500
$400
$300
$200
$100
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
25
20
15
10
5
0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 3)

Facility Information

Meter Description	Main	
Rate Schedule	32	

Energy Cost

Base Electricity Cost	$0.10249	/kWh up to	5,000	kWh
	$0.07737	/kWh over	5,000	kWh

Taxes and Fees

Basic Charge	$106	/month		
Low Income Assistance	$0.00050	/kWh up to	1,000,000	kWh
Public Purpose Charge	3.0%			
County Tax	0.335%			
City Tax	1.5%			

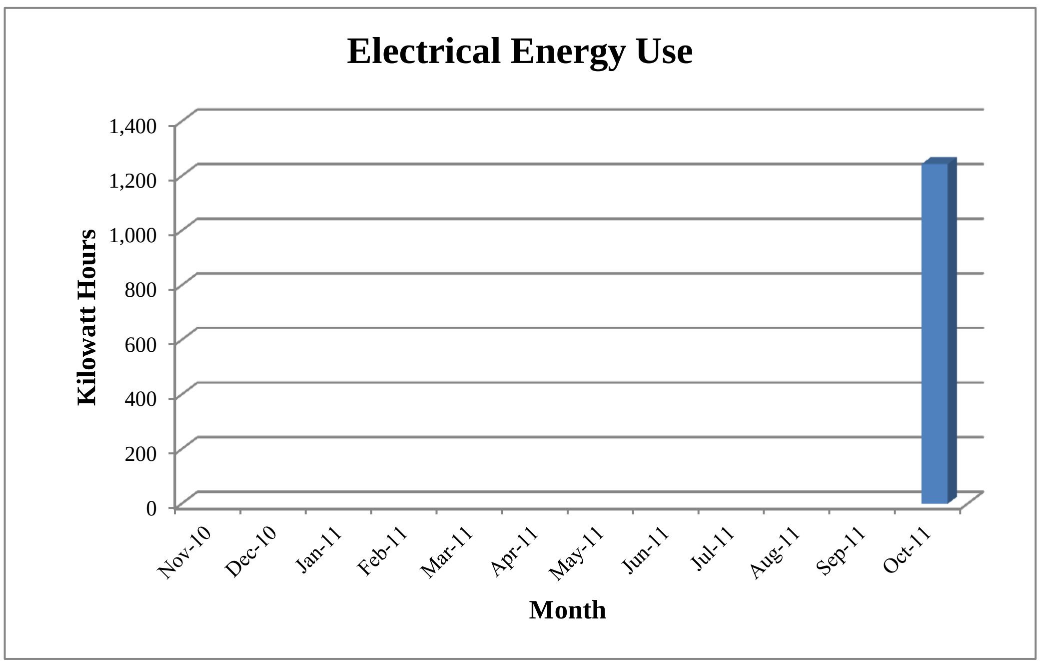
Meter Summary

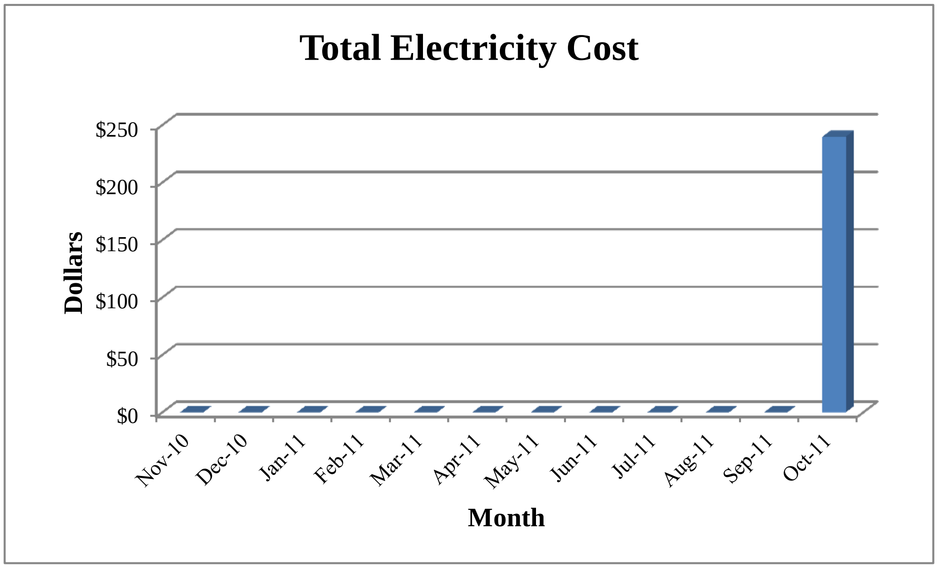
Incremental Electricity Cost	**$0.10608**	/kWh (with taxes and fees)
Incremental Demand Cost	**--**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.1928	/kWh
Average Power Factor	--	

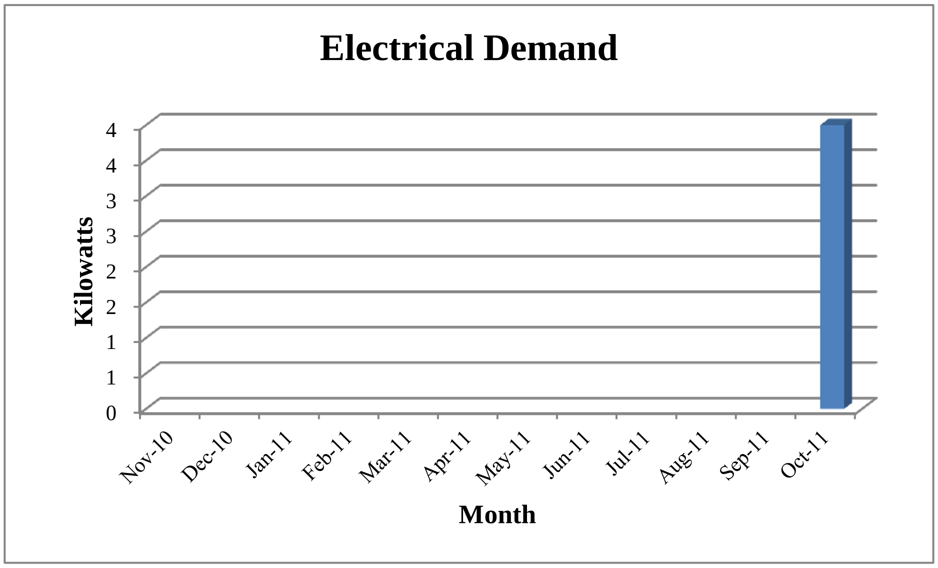
Electricity (Meter 3)

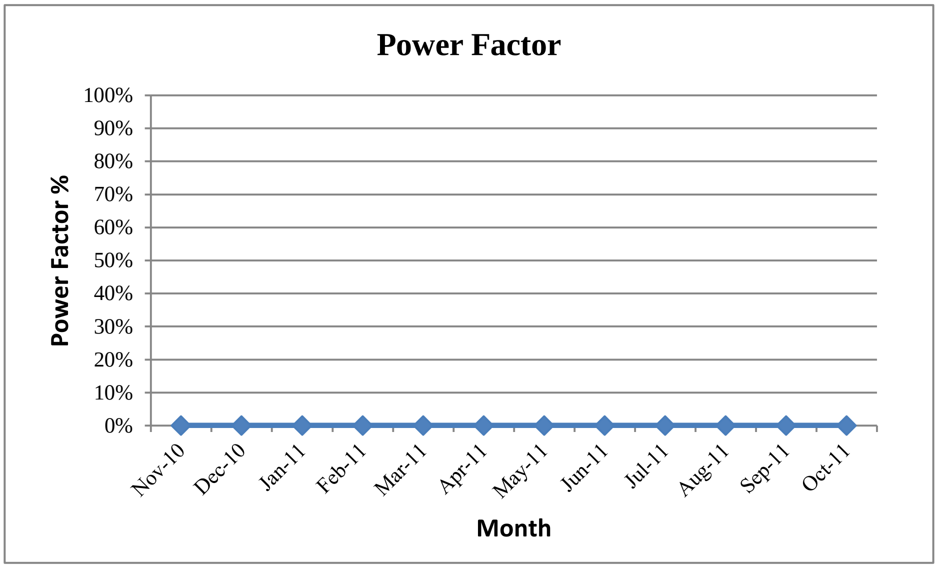
Month	kWh	kWh$	kW	kW$	kVAR	kVAR$	PF %	Taxes/Fees	Total$
Meter Use Summary									
Nov-10		$0		$0		$0	-	$0	$0
Dec-10		$0		$0		$0	-	$0	$0
Jan-11		$0		$0		$0	-	$0	$0
Feb-11		$0		$0		$0	-	$0	$0
Mar-11		$0		$0		$0	-	$0	$0
Apr-11		$0		$0		$0	-	$0	$0
May-11		$0		$0		$0	-	$0	$0
Jun-11		$0		$0		$0	-	$0	$0
Jul-11		$0		$0		$0	-	$0	$0
Aug-11		$0		$0		$0	-	$0	$0
Sep-11		$0		$0		$0	-	$0	$0
Oct-11	1,244	$127	4	$0		$0	-	$112	$240
Totals	1,244	$127	4	$0	0	$0	-	$112	$240
Avg/mo.	1,244	$11	4	$0	-	$0	-	$9	$20

Meter was read once for last six months of service. Bills show no usage from 2/2009 to 3/2011




Total Electricity Cost
Dollars
$250
$200
$150
$100
$50
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
4
4
3
3
2
2
1
1
0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 4)

Facility Information

Meter Description	Molding/ Cleanroom	
Rate Schedule	32	

Energy Cost

Base Electricity Cost	$0.10249	/kWh up to	5,000	kWh
	$0.07737	/kWh over	5,000	kWh

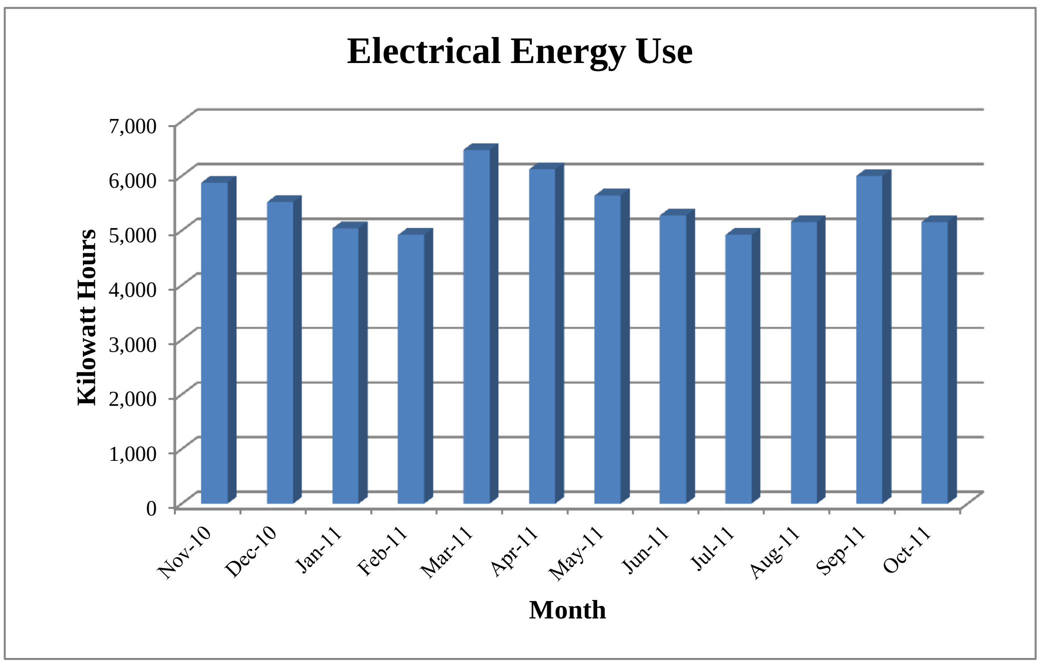
Taxes and Fees

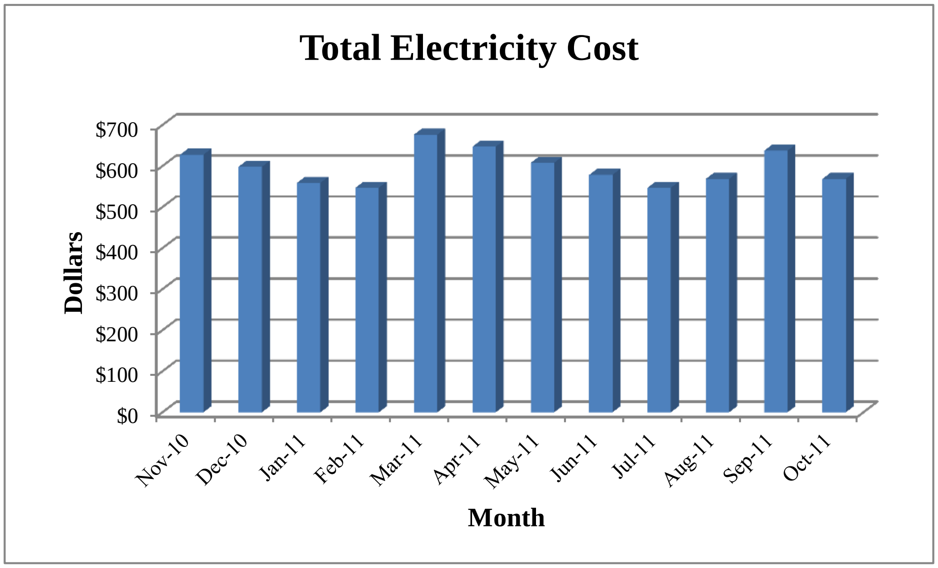
Basic Charge	$16	/month		
Low Income Assistance	$0.00050	/kWh up to	1,000,000	kWh
Public Purpose Charge	3.0%			
County Tax	0.335%			
City Tax	1.5%			

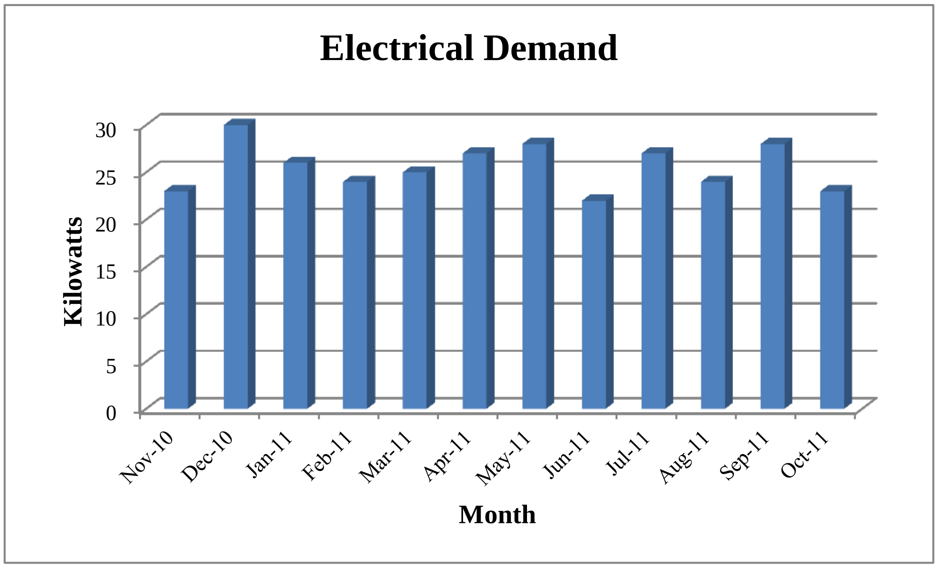
Meter Summary

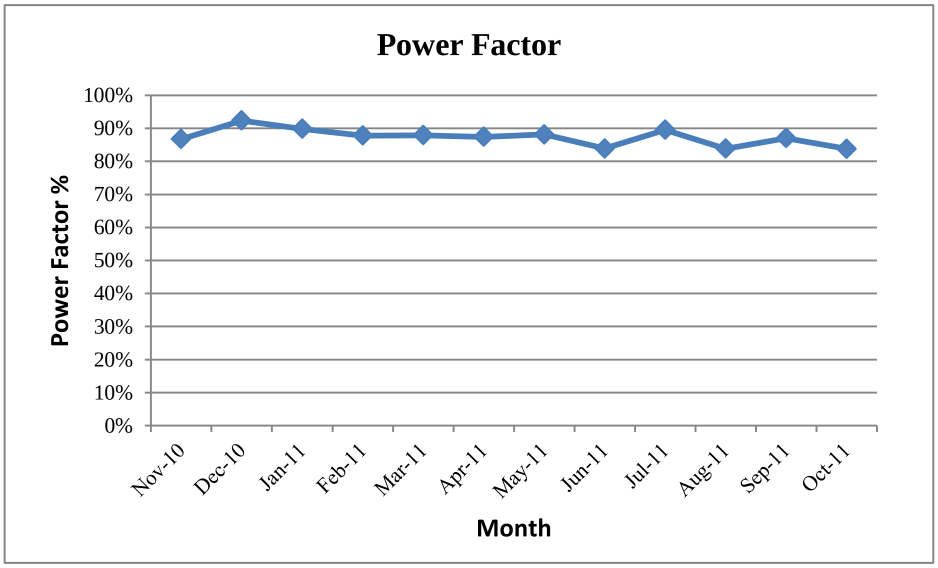
Incremental Electricity Cost	**$0.10608**	/kWh (with taxes and fees)
Incremental Demand Cost	**--**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.1083	/kWh
Average Power Factor	--	

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	5,880	$581	23	$0	13	$0	86.7%	$47	$628
Dec-10	5,520	$553	30	$0	12	$0	92.3%	$45	$598
Jan-11	5,040	$516	26	$0	13	$0	89.8%	$43	$559
Feb-11	4,920	$504	24	$0	13	$0	87.8%	$43	$547
Mar-11	6,480	$627	25	$0	14	$0	87.9%	$50	$677
Apr-11	6,120	$599	27	$0	15	$0	87.4%	$48	$647
May-11	5,640	$562	28	$0	15	$0	88.1%	$46	$608
Jun-11	5,280	$534	22	$0	14	$0	83.9%	$44	$579
Jul-11	4,920	$504	27	$0	13	$0	89.5%	$43	$547
Aug-11	5,160	$525	24	$0	16	$0	83.8%	$44	$569
Sep-11	6,000	$590	28	$0	16	$0	87.0%	$48	$637
Oct-11	5,160	$525	23	$0	15	$0	83.8%	$44	$569
Totals	66,120	$6,619	307	$0	169	$0	-	$545	$7,164
Avg/mo.	5,510	$552	26	$0	14	$0	87.4%	$45	$597




Total Electricity Cost
Dollars
$700
$600
$500
$400
$300
$200
$100
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
30
25
20
15
10
5
0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Facility Information

Meter Description	Molding/ Cleanroom	
Rate Schedule	85S	

Energy Cost

On-Peak Electricity Charge	$0.06662	/kWh
Off-Peak Electricity Charge	$0.05905	/kWh

Demand Cost

Demand Charge	$1.85	/kW-mo	
Variable Electrical Distribution Charge	$2.41	/kW-mo up to	200 kW
	$2.14	/kW-mo over	200 kW
Transmission Charge	$0.82	/kW-mo	

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40% kW

Taxes and Fees

Basic Charge	$240	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
City Tax	1.5%		
County Tax	0.335%		
Public Purpose Charge	3.0%		

Meter Summary

Incremental Electricity Cost	**$0.06672**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.95**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.0828	/kWh
Average Power Factor	72.46%	

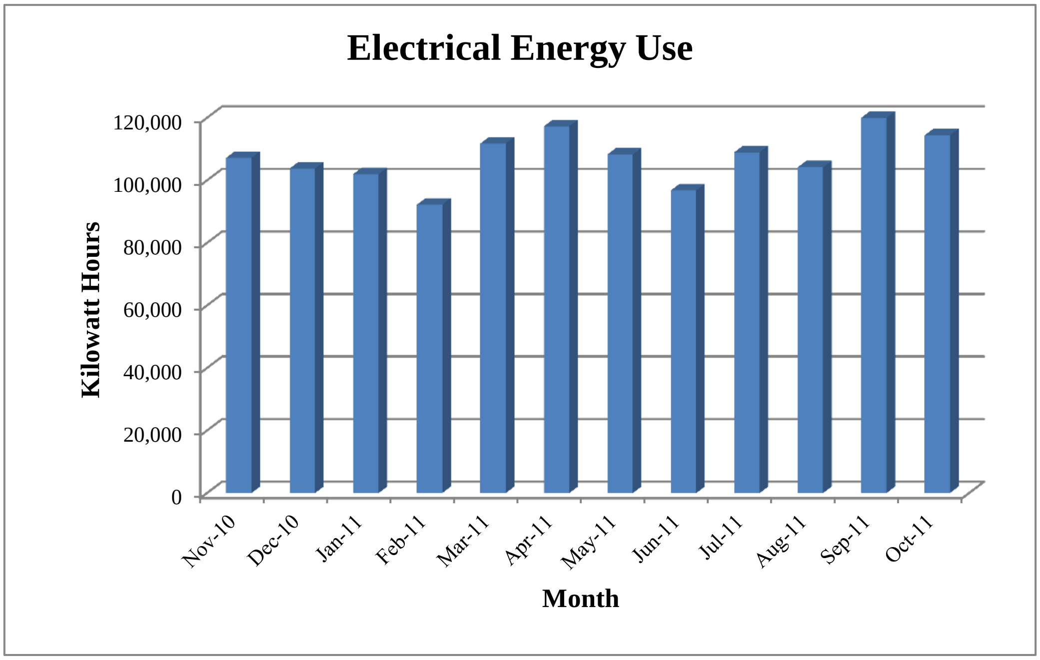
Electricity (Meter 5)

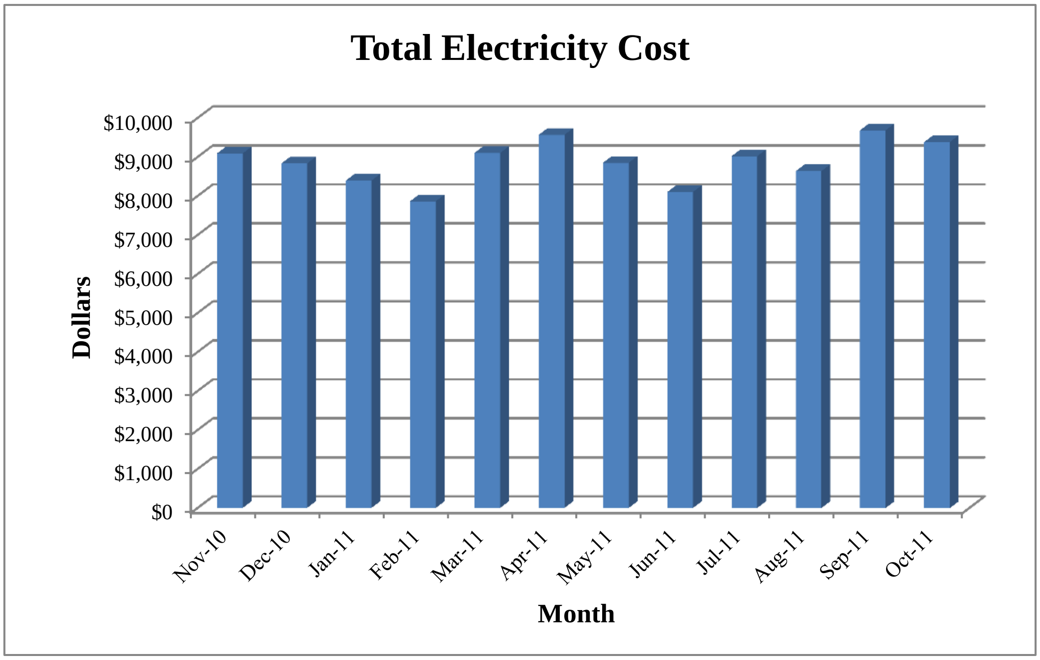
Meter Usage Summary								
Month	On-Peak kWh*	Off-Peak kWh*	Total kWh	kWh$	On-Peak kW*	Off-Peak kW*	kW$	Subtotal$
Nov-10	107,200		107,200	$7,142	234		$1,180	$8,321
Dec-10	103,800		103,800	$6,915	231		$1,165	$8,080
Jan-11	59,500	42,500	102,000	$6,474	236	236	$1,189	$7,663
Feb-11	58,400	33,800	92,200	$5,886	254	247	$1,276	$7,162
Mar-11	70,400	41,400	111,800	$7,135	238	241	$1,199	$8,333
Apr-11	74,100	43,200	117,300	$7,488	255	256	$1,281	$8,768
May-11	68,400	39,900	108,300	$6,913	234	234	$1,180	$8,092
Jun-11	61,400	35,400	96,800	$6,181	239	222	$1,204	$7,384
Jul-11	69,600	39,400	109,000	$6,963	258	228	$1,295	$8,258
Aug-11	66,300	37,900	104,200	$6,655	247	244	$1,242	$7,897
Sep-11	75,700	44,300	120,000	$7,659	244	231	$1,228	$8,887
Oct-11	74,100	40,300	114,400	$7,316	255	236	$1,281	$8,597
Totals	888,900	398,100	1,287,000	$82,726	2,925	2,375	$14,717	$97,444
Avg/mo.	74,075	39,810	107,250	$6,894	244	238	$1,226	$8,120

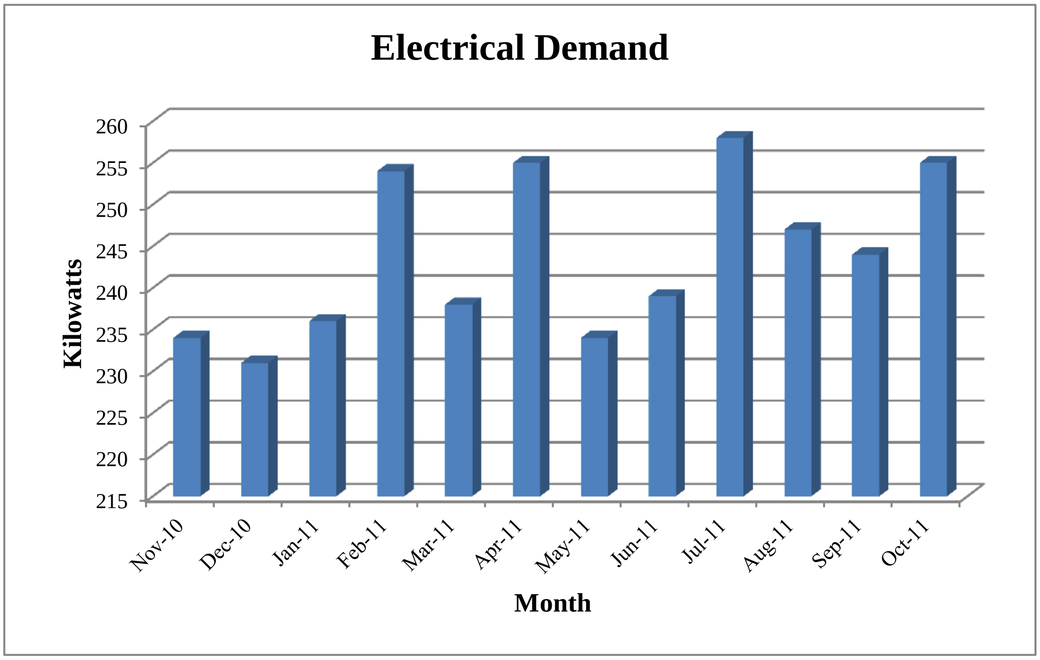
*On-Peak refers to the hours between 6:00 a.m. and 10:00 p.m. Monday - Saturday.

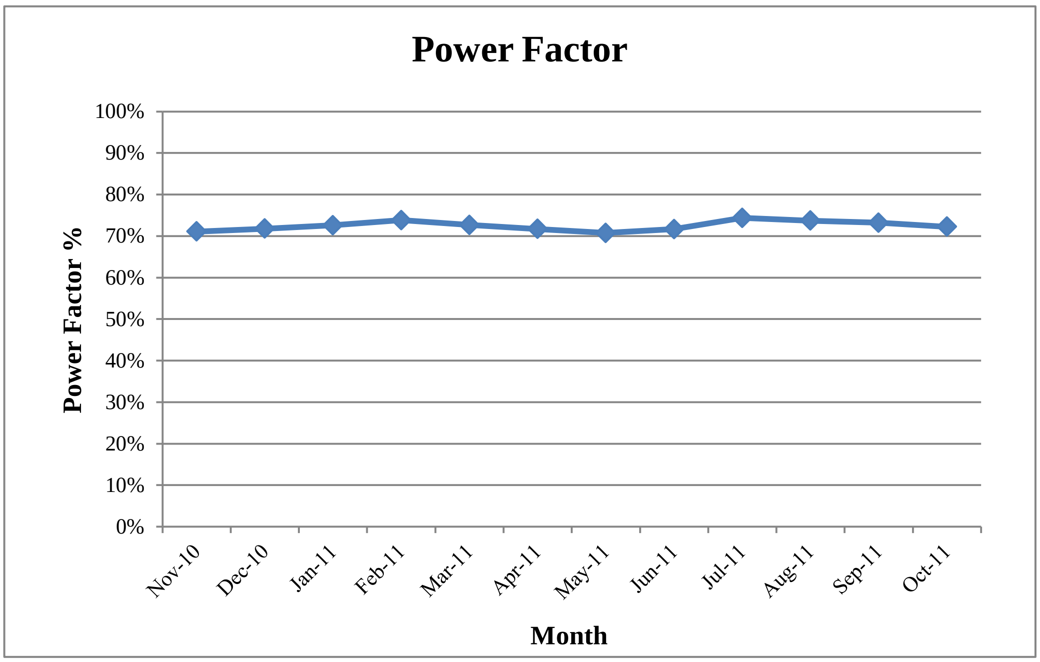
** Before Jan 2011, this meter was on a different rate schedule that did not break down charges between on-peak and off-peak.

Meter Usage Summary Continued						
Month	kVAR	kVAR$	PF %	Taxes/ Fees	Subtotal$	Total$
Nov-10	232	$69	71.1%	$699	$768	$9,089
Dec-10	224	$66	71.8%	$686	$752	$8,832
Jan-11	224	$65	72.6%	$665	$729	$8,392
Feb-11	232	$65	73.8%	$636	$701	$7,863
Mar-11	228	$66	72.7%	$702	$768	$9,102
Apr-11	249	$73	71.7%	$726	$800	$9,568
May-11	234	$70	70.7%	$689	$759	$8,851
Jun-11	233	$69	71.6%	$649	$717	$8,102
Jul-11	232	$64	74.4%	$697	$761	$9,020
Aug-11	226	$64	73.7%	$677	$741	$8,638
Sep-11	227	$65	73.2%	$733	$798	$9,684
Oct-11	244	$71	72.2%	$716	$787	$9,384
Totals	2,784	$807	-	$8,274	$9,081	$106,525
Avg/mo.	232	$67	72.5%	$689	$757	$8,877


Electrical Energy Use
Kilowatt Hours
120,000
100,000
80,000
60,000
40,000
20,000
0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Total Electricity Cost
Dollars
$10,000
$9,000
$8,000
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
260
255
250
245
240
235
230
225
220
215
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Facility Information

Meter Description	N. Warehouse	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)	

Demand Cost

Demand Charge	$1.76	/kW-mo	
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30 kW
	$2.08	/kW-mo over	30 kW
Transmission Charge	$0.82	/kW-mo	

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40% kW

Taxes and Fees

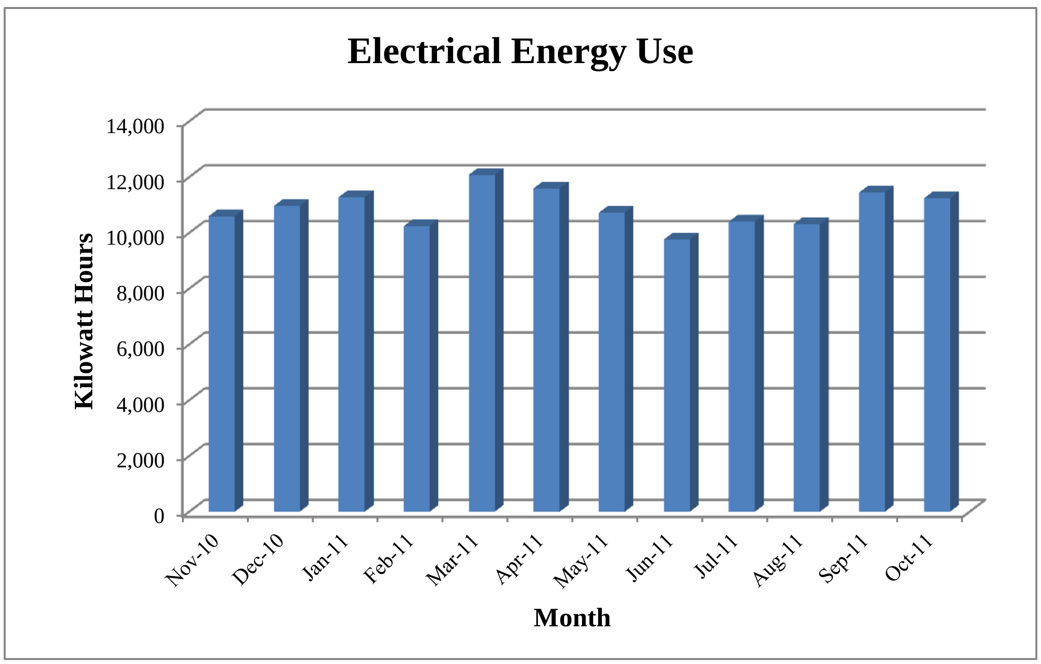
Basic Charge	$30	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
City Tax	1.5%		
County Tax	0.335%		
Public Purpose Charge	3.0%		

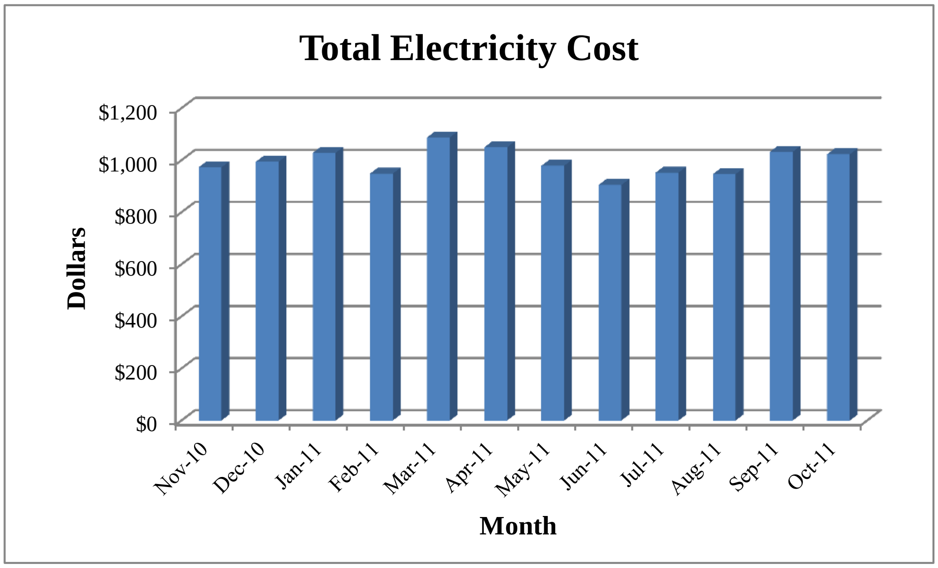
Meter Summary

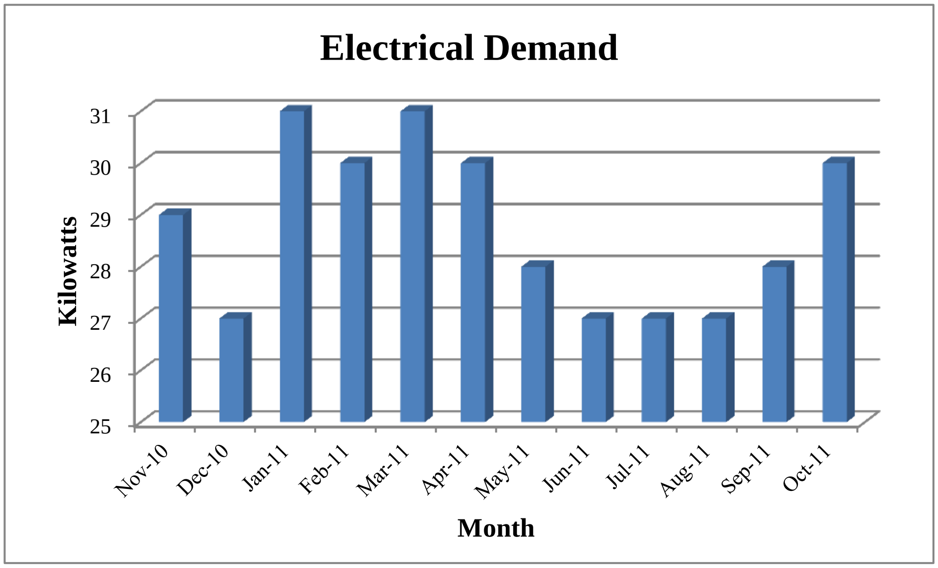
Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.0912	/kWh
Average Power Factor	-	

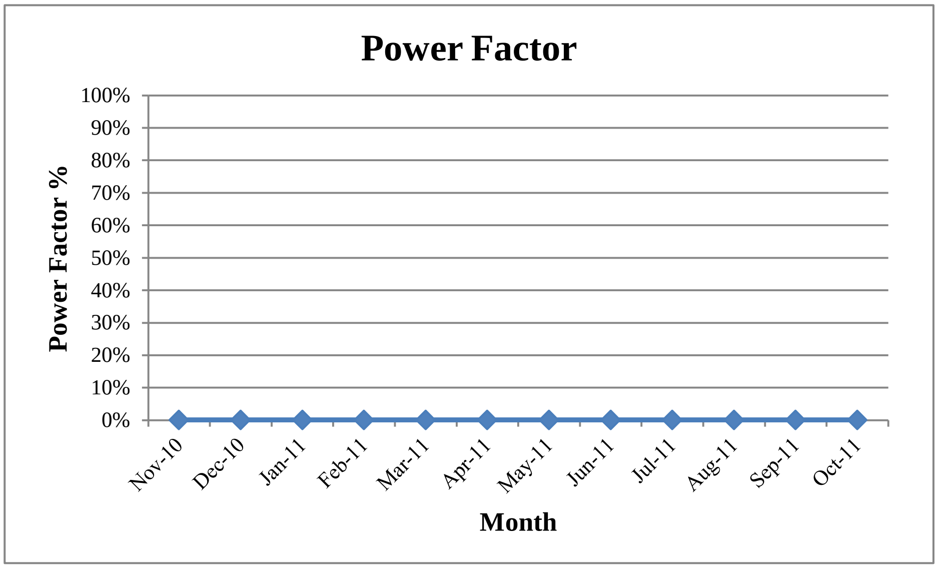
Electricity (Meter 6)

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	10,600	$746	29	$148		$0	-	$79	$973
Dec-10	10,960	$771	27	$143		$0	-	$80	$994
Jan-11	11,280	$794	31	$153		$0	-	$81	$1,029
Feb-11	10,240	$720	30	$151		$0	-	$77	$949
Mar-11	12,080	$850	31	$153		$0	-	$85	$1,088
Apr-11	11,600	$816	30	$151		$0	-	$83	$1,050
May-11	10,720	$754	28	$146		$0	-	$79	$979
Jun-11	9,760	$687	27	$143		$0	-	$75	$905
Jul-11	10,400	$732	27	$143		$0	-	$78	$952
Aug-11	10,320	$726	27	$143		$0	-	$77	$946
Sep-11	11,440	$805	28	$146		$0	-	$82	$1,032
Oct-11	11,240	$791	30	$151		$0	-	$81	$1,023
Totals	130,640	$9,192	345	$1,772	0	$0	-	$955	$11,919
Avg/mo.	10,887	$766	29	$148	-	$0	-	$80	$993




Total Electricity Cost
Dollars
$1,200
$1,000
$800
$600
$400
$200
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
31
30
29
28
27
26
25
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 7)

Oregon State University OSU Energy Efficiency Center

Facility Information

Meter Description	Controls Engineering	
Rate Schedule	32	

Energy Cost

Base Electricity Cost	$0.10249	/kWh up to	5,000	kWh
	$0.07737	/kWh over	5,000	kWh

Taxes and Fees

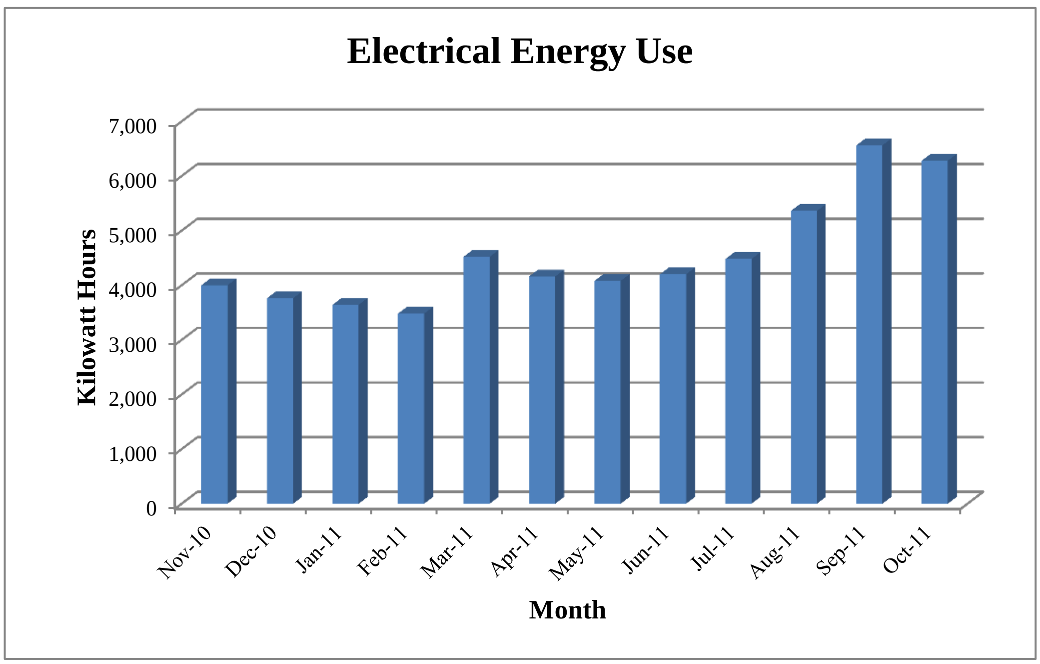
Basic Charge	$16	/month		
Low Income Assistance	$0.00050	/kWh up to	1,000,000	kWh
Public Purpose Charge	3.0%			
County Tax	0.335%			
City Tax	1.5%			

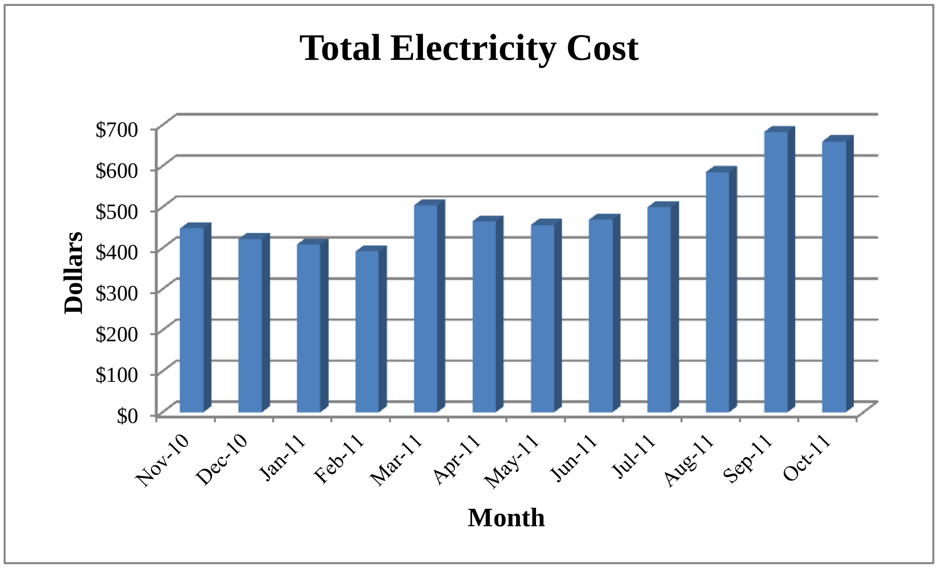
Meter Summary

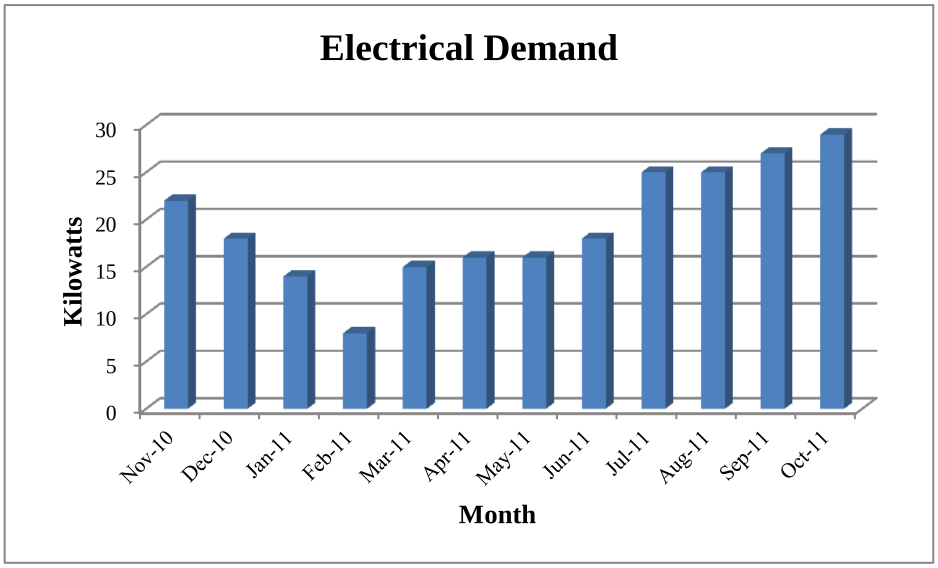
Incremental Electricity Cost	**$0.10608**	/kWh (with taxes and fees)
Incremental Demand Cost	**--**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.1099	/kWh
Average Power Factor	--	

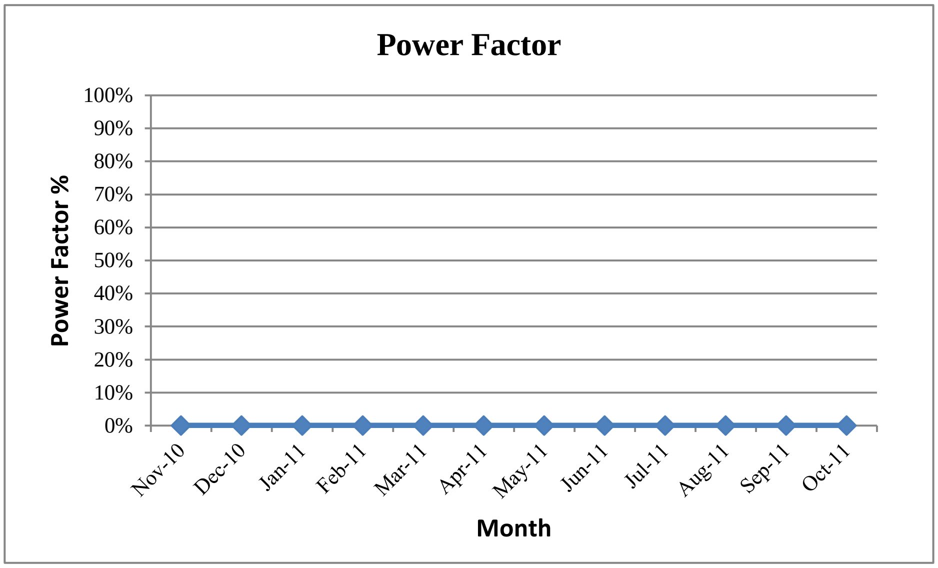
Electricity (Meter 7)

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	4,000	$410	22	$0		$0	-	$38	$448
Dec-10	3,760	$385	18	$0		$0	-	$37	$422
Jan-11	3,640	$373	14	$0		$0	-	$36	$409
Feb-11	3,480	$357	8	$0		$0	-	$35	$392
Mar-11	4,520	$463	15	$0		$0	-	$41	$504
Apr-11	4,160	$426	16	$0		$0	-	$39	$465
May-11	4,080	$418	16	$0		$0	-	$38	$456
Jun-11	4,200	$430	18	$0		$0	-	$39	$469
Jul-11	4,480	$459	25	$0		$0	-	$40	$500
Aug-11	5,360	$540	25	$0		$0	-	$45	$585
Sep-11	6,560	$633	27	$0		$0	-	$50	$683
Oct-11	6,280	$611	29	$0		$0	-	$49	$660
Totals	54,520	$5,507	233	$0	0	$0	-	$486	$5,993
Avg/mo.	4,543	$459	19	$0	-	$0	-	$40	$499




Total Electricity Cost
Dollars
$700
$600
$500
$400
$300
$200
$100
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
30
25
20
15
10
5
0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 8)

Oregon State University OSU Energy Efficiency Center

Facility Information

Meter Description	L. Casting/ Production	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)

Demand Cost

Demand Charge	$1.76	/kW-mo	
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30 kW
	$2.08	/kW-mo over	30 kW
Transmission Charge	$0.82	/kW-mo	

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40% kW

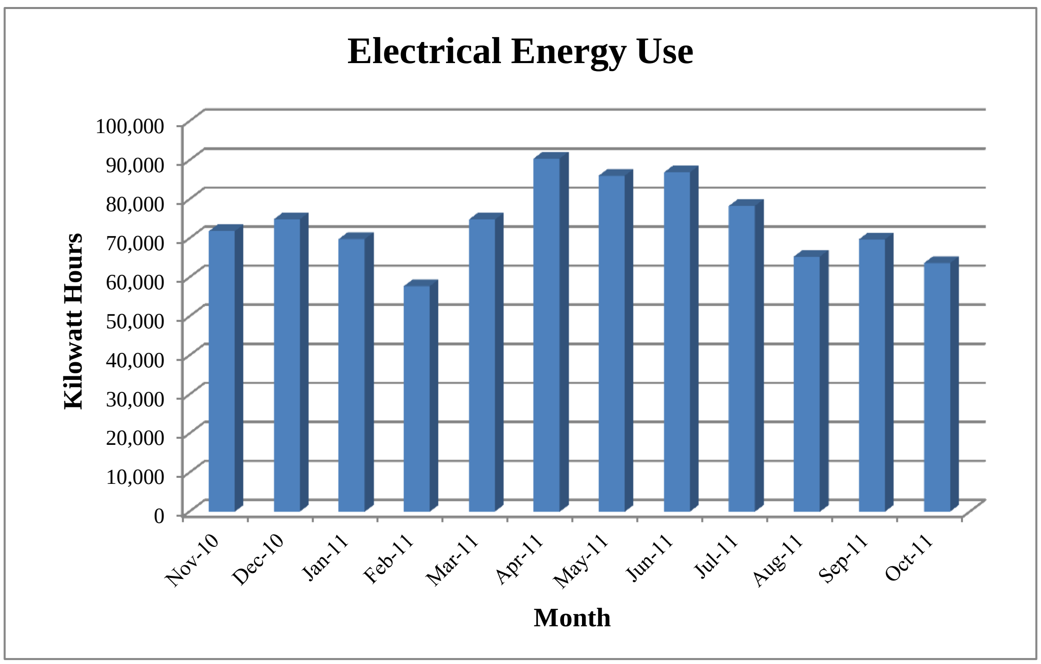
Taxes and Fees

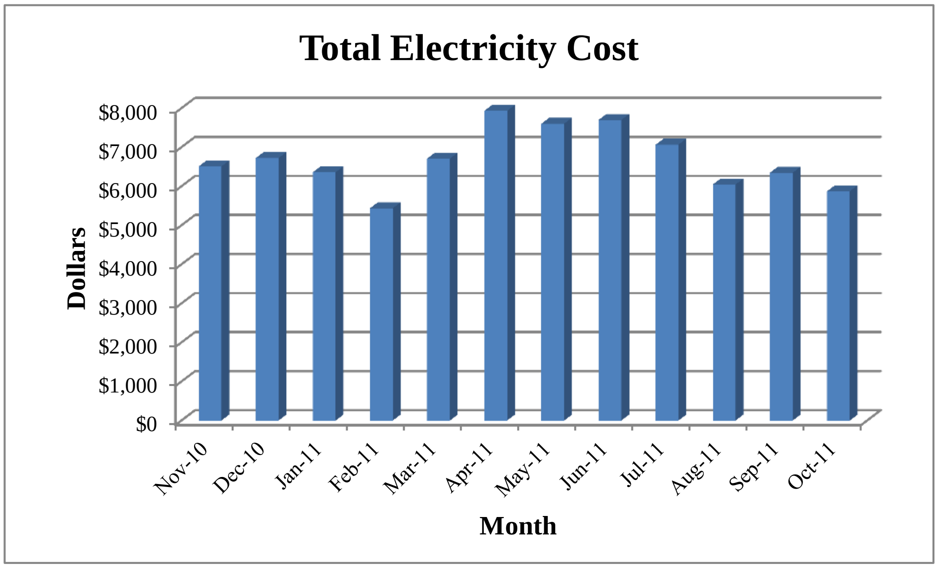
Basic Charge	$30	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
City Tax	1.5%		
County Tax	0.335%		
Public Purpose Charge	3.0%		

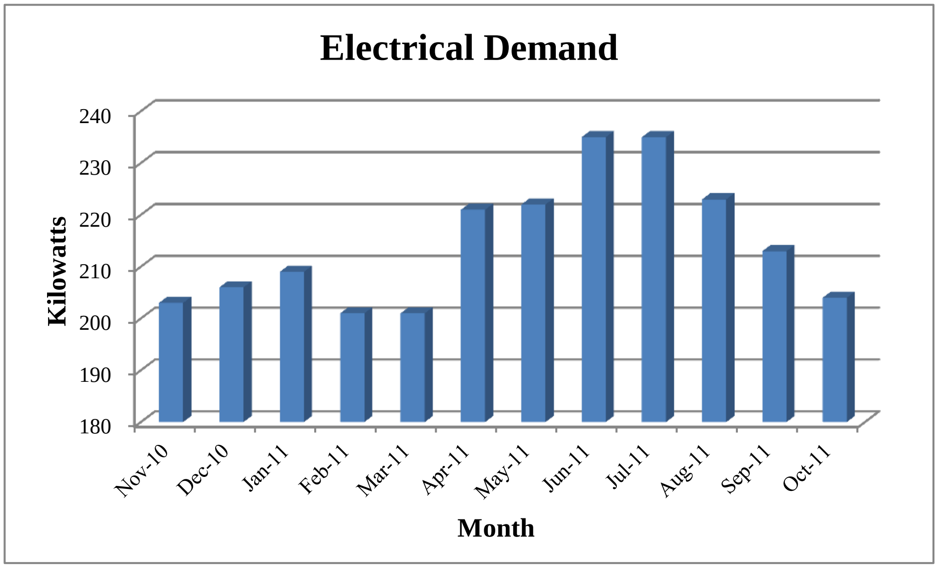
Meter Summary

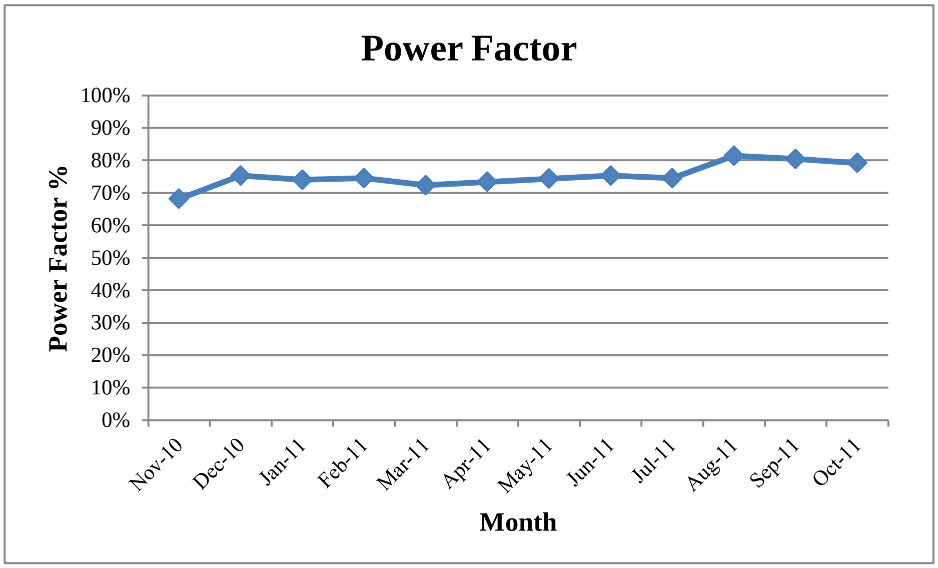
Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.0902	/kWh
Average Power Factor	75.2%	

Meter Use Summary									
Month	kWh	kWh$	kW	kW$	kVAR	kVAR$	PF %	Taxes/Fees	Total$
Nov-10	71,840	$5,055	203	$1,022	218	$68	68.1%	$363	$6,508
Dec-10	74,880	$5,269	206	$1,029	180	$49	75.3%	$374	$6,721
Jan-11	69,840	$4,914	209	$1,037	190	$53	74.0%	$355	$6,359
Feb-11	57,760	$4,064	201	$1,016	180	$50	74.5%	$307	$5,437
Mar-11	74,800	$5,263	201	$1,016	192	$56	72.3%	$374	$6,709
Apr-11	90,480	$6,366	221	$1,068	205	$58	73.4%	$437	$7,930
May-11	86,080	$6,057	222	$1,071	200	$55	74.4%	$420	$7,603
Jun-11	86,880	$6,113	235	$1,104	205	$56	75.3%	$425	$7,698
Jul-11	78,320	$5,511	235	$1,104	210	$58	74.5%	$392	$7,065
Aug-11	65,360	$4,599	223	$1,073	159	$35	81.4%	$339	$6,045
Sep-11	69,760	$4,908	213	$1,047	158	$36	80.4%	$355	$6,346
Oct-11	63,680	$4,481	204	$1,024	157	$38	79.2%	$330	$5,872
Totals	889,680	$62,598	2,573	$12,612	2,254	$612	-	$4,471	$80,293
Avg/mo.	74,140	$5,216	214	$1,051	188	$51	75.2%	$373	$6,691




Total Electricity Cost
Dollars
$8,000
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
240
230
220
210
200
190
180
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 9)

Oregon State University OSU Energy Efficiency Center

Facility Information

Meter Description	L. Casting/ Production	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)

Demand Cost

Demand Charge	$1.76	/kW-mo	
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30 kW
	$2.08	/kW-mo over	30 kW
Transmission Charge	$0.82	/kW-mo	

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40% kW

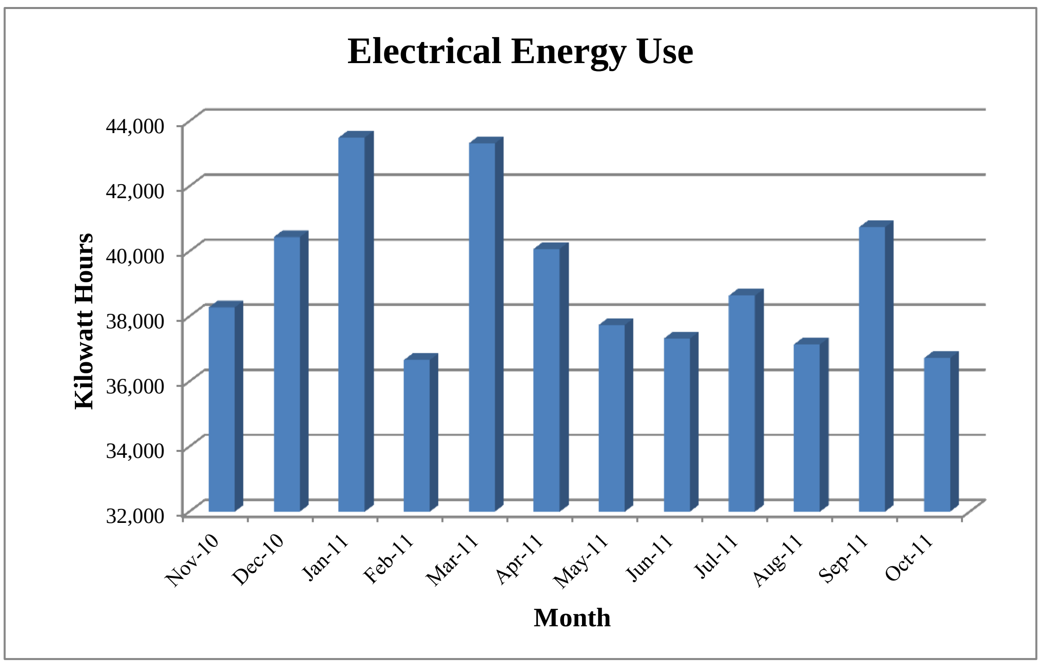
Taxes and Fees

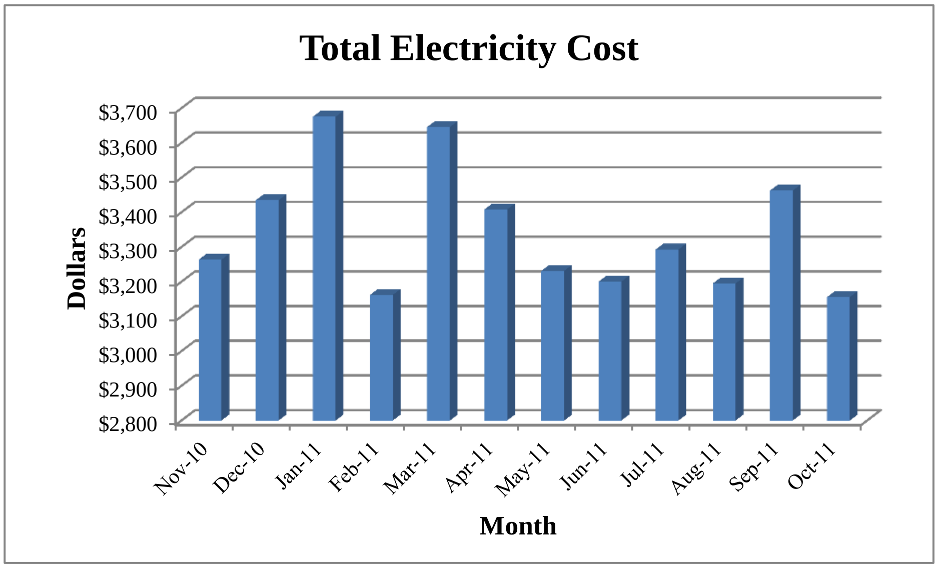
Basic Charge	$30	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
City Tax	1.5%		
County Tax	0.335%		
Public Purpose Charge	3.0%		

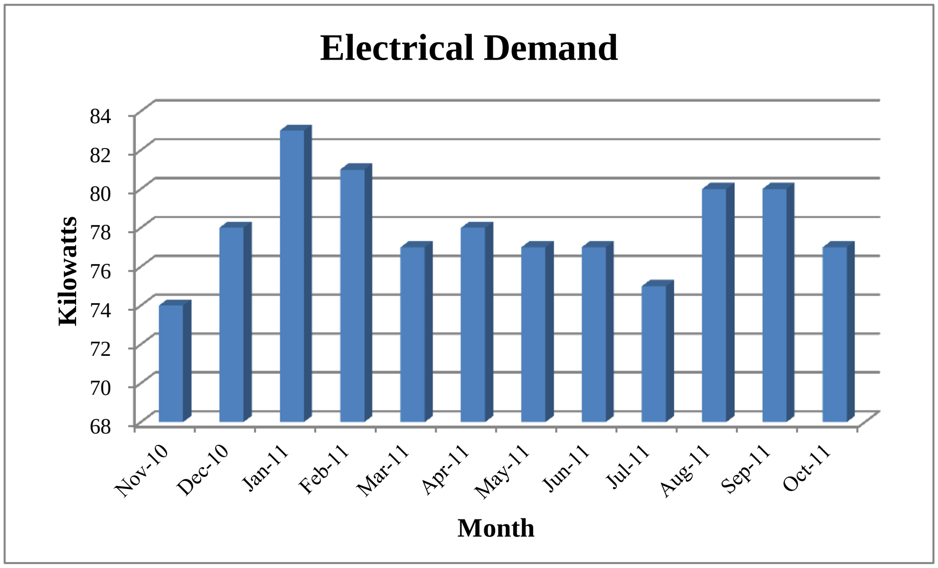
Meter Summary

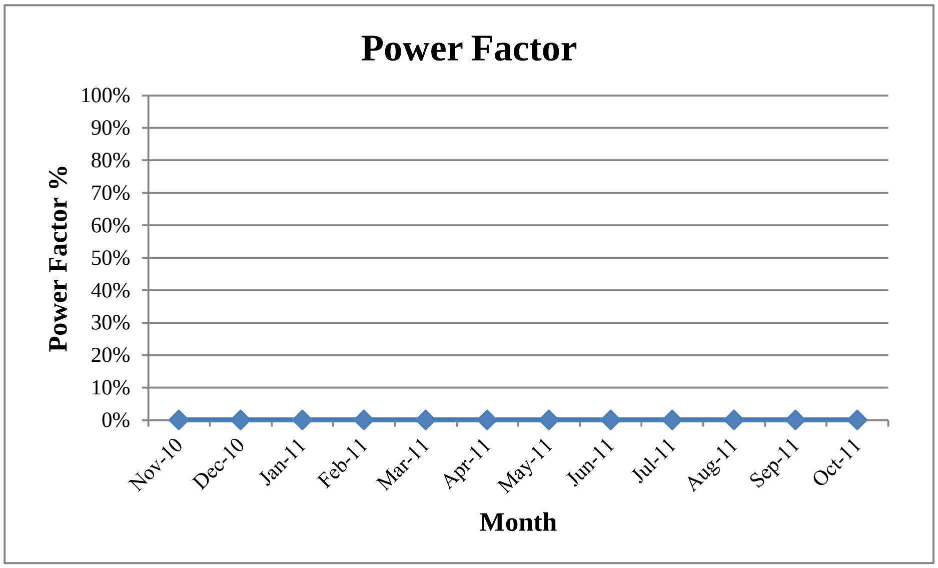
Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.0853	/kWh
Average Power Factor	-	

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	38,280	$2,693	74	$373		$0	-	$197	$3,263
Dec-10	40,440	$2,845	78	$383		$0	-	$206	$3,435
Jan-11	43,500	$3,061	83	$396		$0	-	$219	$3,675
Feb-11	36,660	$2,579	81	$391		$0	-	$192	$3,162
Mar-11	43,320	$3,048	77	$380		$0	-	$217	$3,646
Apr-11	40,080	$2,820	78	$383		$0	-	$205	$3,408
May-11	37,740	$2,655	77	$380		$0	-	$196	$3,231
Jun-11	37,320	$2,626	77	$380		$0	-	$194	$3,200
Jul-11	38,640	$2,719	75	$375		$0	-	$199	$3,293
Aug-11	37,140	$2,613	80	$388		$0	-	$194	$3,195
Sep-11	40,740	$2,866	80	$388		$0	-	$208	$3,462
Oct-11	36,720	$2,584	77	$380		$0	-	$192	$3,156
Totals	470,580	$33,110	937	$4,597	0	$0	-	$2,418	$40,126
Avg/mo.	39,215	$2,759	78	$383	-	$0	-	$202	$3,344




Total Electricity Cost
Dollars
$3,700
$3,600
$3,500
$3,400
$3,300
$3,200
$3,100
$3,000
$2,900
$2,800
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
84
82
80
78
76
74
72
70
68
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 10)

Facility Information

Meter Description	Control Warehouse	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)	

Demand Cost

Demand Charge	$1.76	/kW-mo		
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30	kW
	$2.08	/kW-mo over	30	kW
Transmission Charge	$0.82	/kW-mo		

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40%	kW

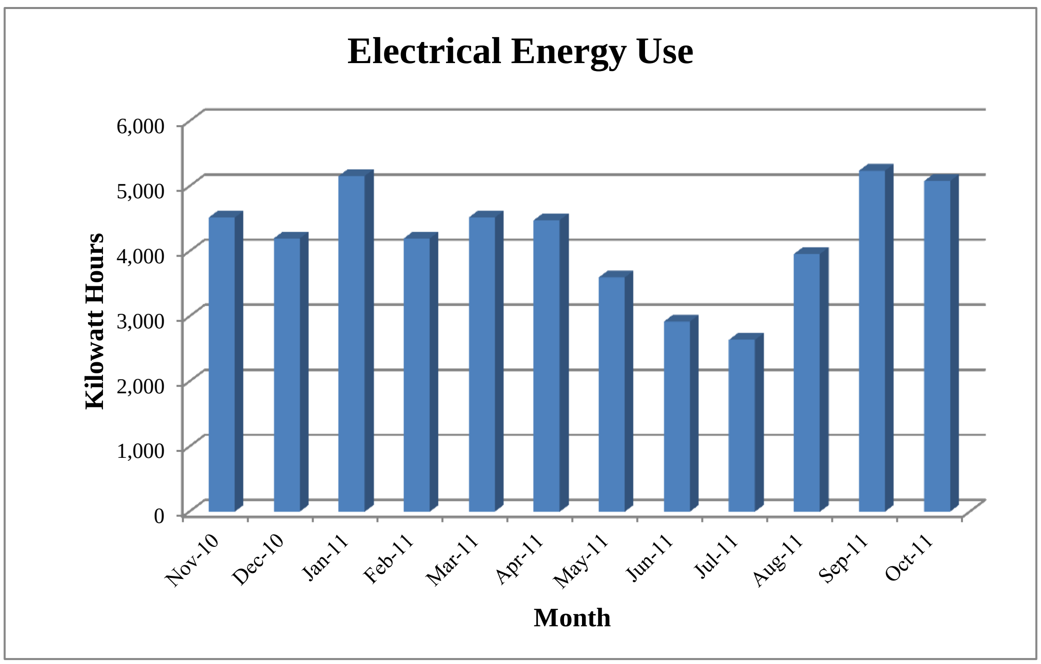
Taxes and Fees

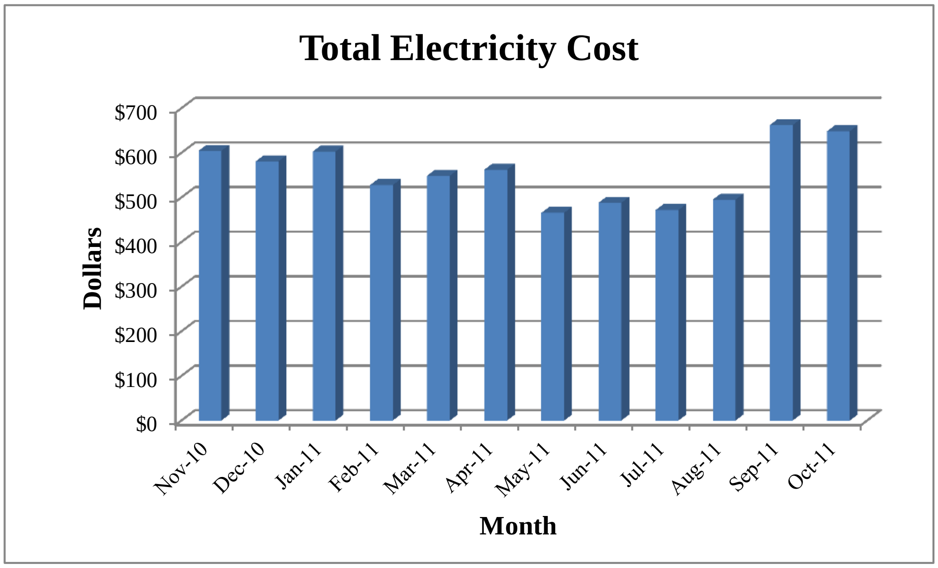
Basic Charge	$30	/month		
Low Income Assistance	$0.00050	/kWh up to	1,000,000	kWh
City Tax	1.5%			
County Tax	0.335%			
Public Purpose Charge	3.0%			

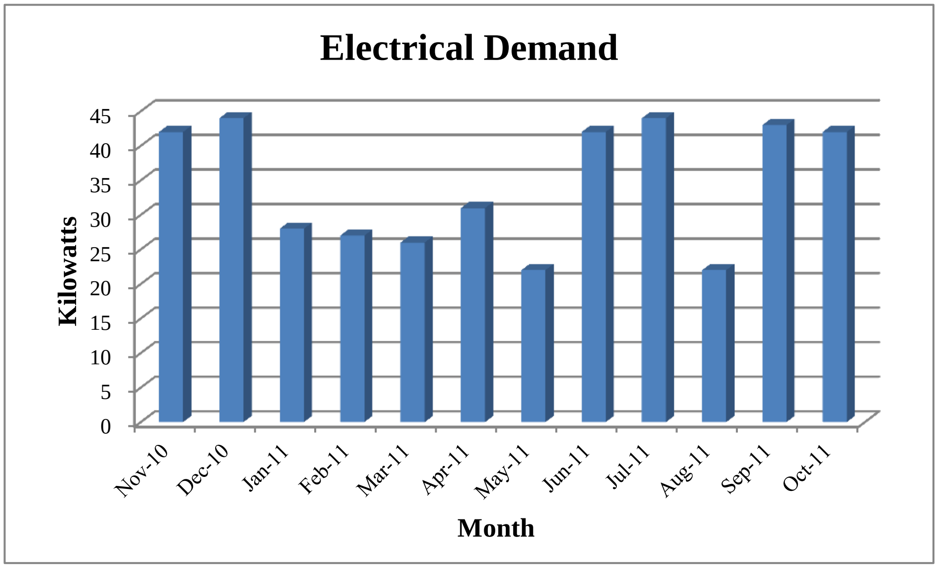
Meter Summary

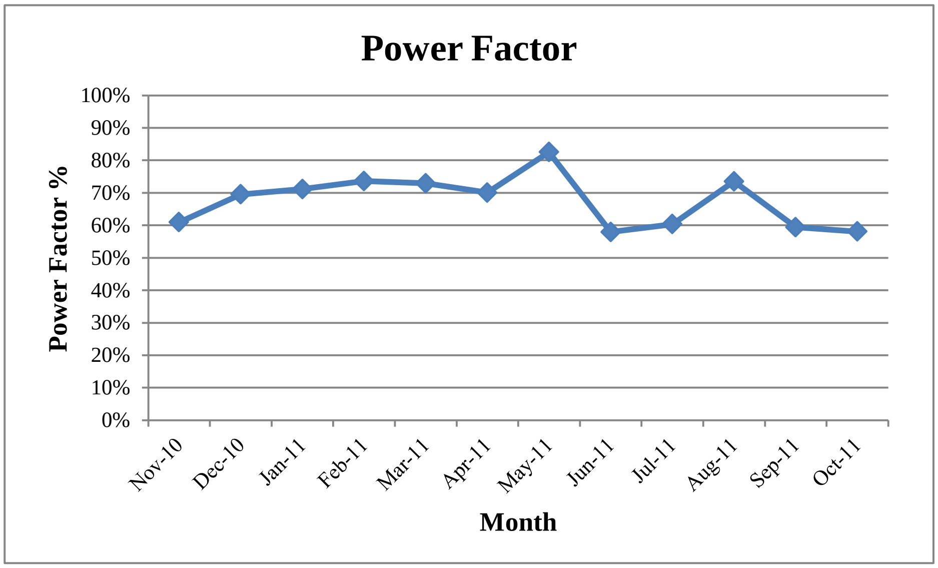
Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.1318	/kWh
Average Power Factor	67.5%	

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	4,520	$318	42	$209	55	$19	60.9%	$59	$604
Dec-10	4,200	$296	44	$214	45	$14	69.5%	$57	$581
Jan-11	5,160	$363	28	$173	28	$8	71.2%	$59	$603
Feb-11	4,200	$296	27	$170	25	$7	73.6%	$55	$528
Mar-11	4,520	$318	26	$168	24	$7	72.9%	$56	$549
Apr-11	4,480	$315	31	$181	32	$10	70.1%	$57	$562
May-11	3,600	$253	22	$157	15	$3	82.6%	$52	$465
Jun-11	2,920	$205	42	$209	59	$21	57.9%	$53	$488
Jul-11	2,640	$186	44	$214	58	$20	60.4%	$52	$472
Aug-11	3,960	$279	22	$157	20	$6	73.5%	$53	$495
Sep-11	5,240	$369	43	$211	58	$21	59.4%	$62	$662
Oct-11	5,080	$357	42	$209	59	$21	58.1%	$61	$648
Totals	50,520	$3,555	413	$2,272	478	$157	-	$675	$6,657
Avg/mo.	4,210	$296	34	$189	40	$13	67.5%	$56	$555




Total Electricity Cost
Dollars
$700
$600
$500
$400
$300
$200
$100
$0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
45
40
35
30
25
20
15
10
5
0
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 11)

Oregon State University OSU Energy Efficiency Center

Facility Information

Meter Description	Upper Casting 240V	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)		

Demand Cost

Demand Charge	$1.76	/kW-mo		
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30	kW
	$2.08	/kW-mo over	30	kW
Transmission Charge	$0.82	/kW-mo		

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40%	kW

Taxes and Fees

Basic Charge	$30	/month		
Low Income Assistance	$0.00050	/kWh up to	1,000,000	kWh
City Tax	1.5%			
County Tax	0.335%			
Public Purpose Charge	3.0%			

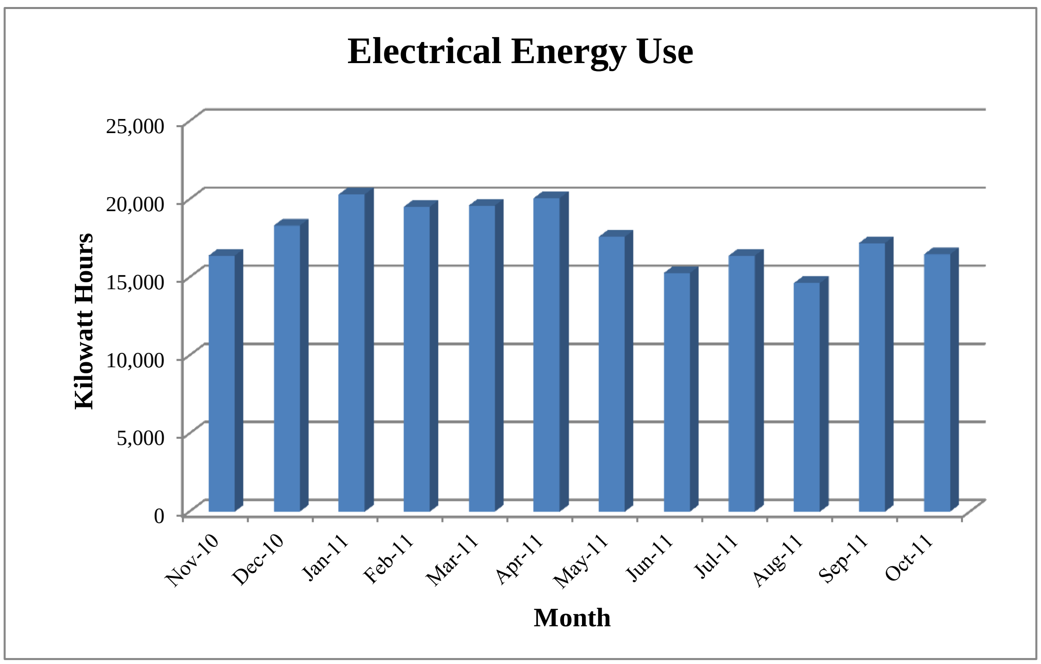
Meter Summary

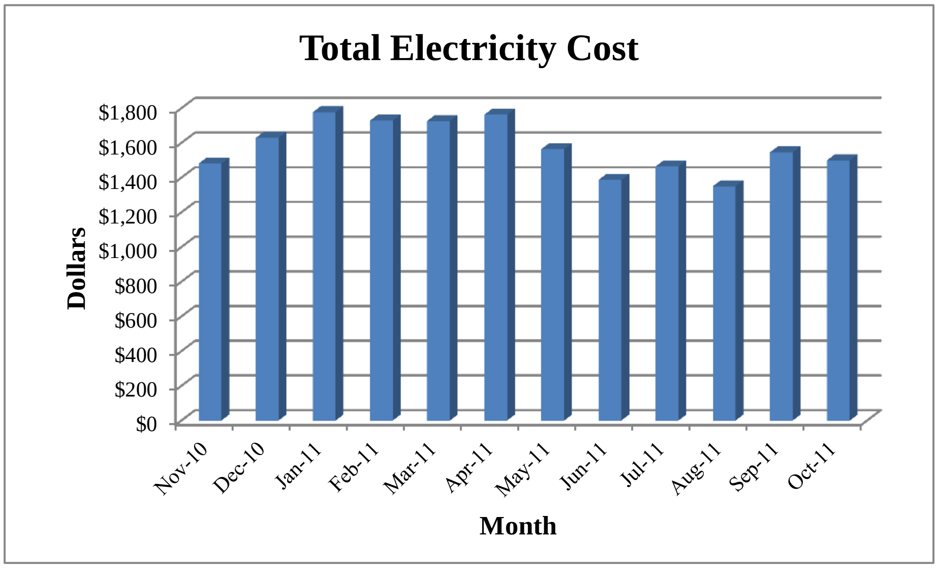
Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.0893	/kWh
Average Power Factor	-	

Electricity (Meter 11)

Oregon State University OSU Energy Efficiency Center

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	16,400	$1,154	43	$222		$0	-	$105	$1,480
Dec-10	18,320	$1,289	45	$227		$0	-	$112	$1,628
Jan-11	20,320	$1,430	45	$227		$0	-	$120	$1,777
Feb-11	19,520	$1,373	49	$237		$0	-	$118	$1,728
Mar-11	19,600	$1,379	46	$230		$0	-	$118	$1,726
Apr-11	20,080	$1,413	46	$230		$0	-	$119	$1,762
May-11	17,600	$1,238	41	$217		$0	-	$109	$1,564
Jun-11	15,280	$1,075	39	$212		$0	-	$100	$1,386
Jul-11	16,400	$1,154	37	$206		$0	-	$104	$1,464
Aug-11	14,640	$1,030	43	$222		$0	-	$98	$1,350
Sep-11	17,200	$1,210	45	$227		$0	-	$108	$1,545
Oct-11	16,480	$1,160	48	$235		$0	-	$106	$1,500
Totals	211,840	$14,905	527	$2,691	0	$0	-	$1,317	$18,912
Avg/mo.	17,653	$1,242	44	$224	-	$0	-	$110	$1,576




Total Electricity Cost
Dollars
$0
$200
$400
$600
$800
$1,000
$1,200
$1,400
$1,600
$1,800
Nov-10
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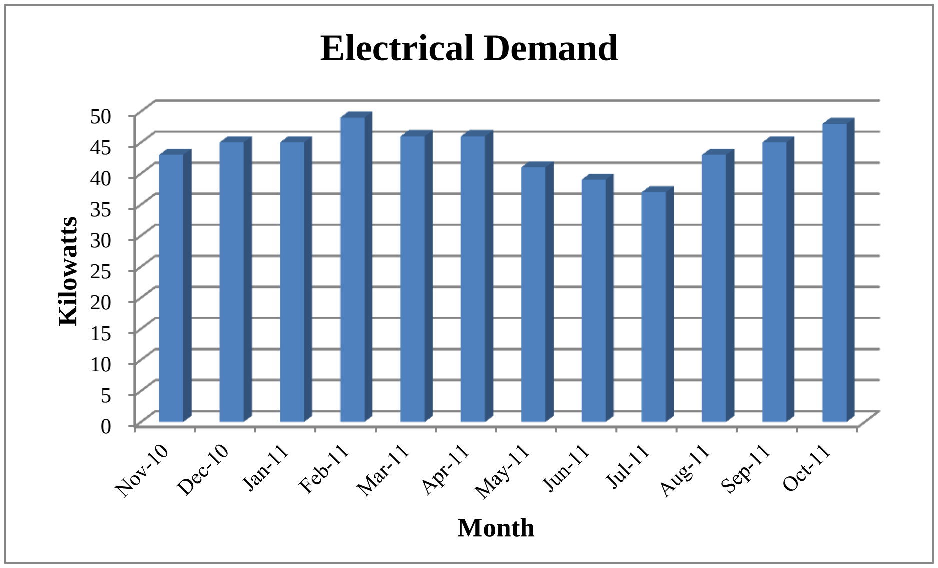
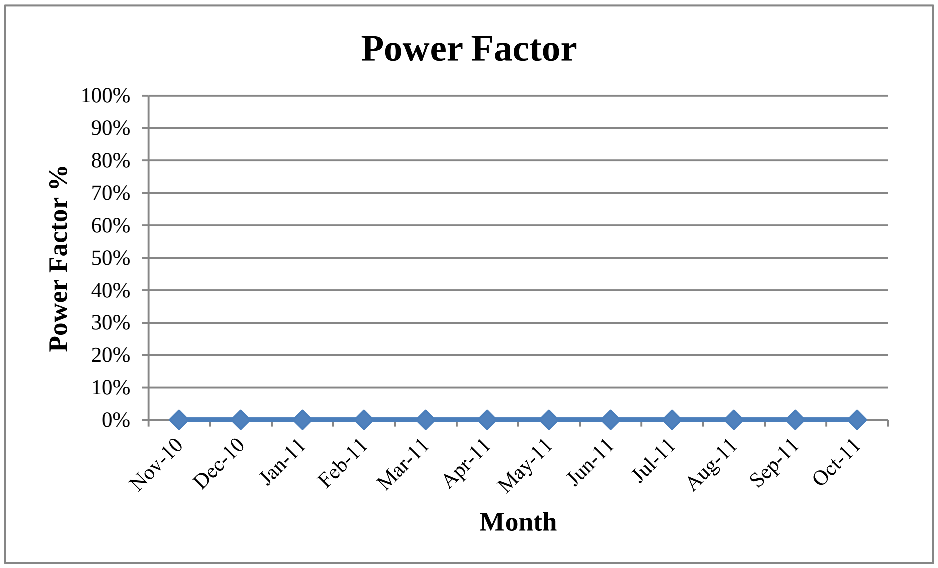
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
Kilowatts
0
5
10
15
20
25
30
35
40
45
50
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
Power Factor %
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Facility Information

Meter Description	Upper Casting 480V	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)	

Demand Cost

Demand Charge	$1.76	/kW-mo	
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30 kW
	$2.08	/kW-mo over	30 kW
Transmission Charge	$0.82	/kW-mo	

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40% kW

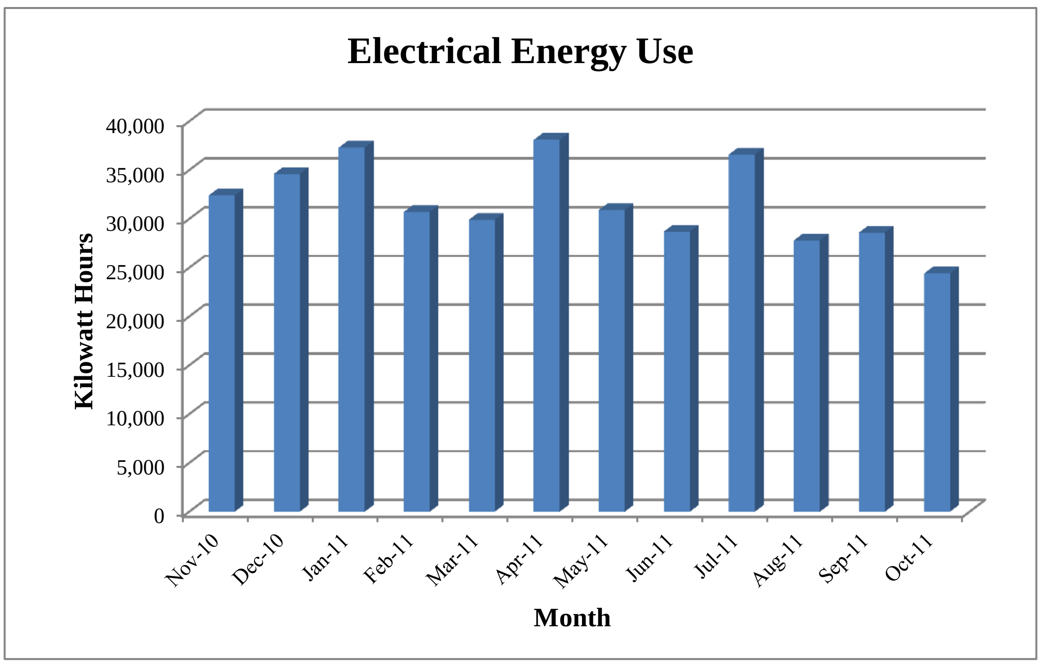
Taxes and Fees

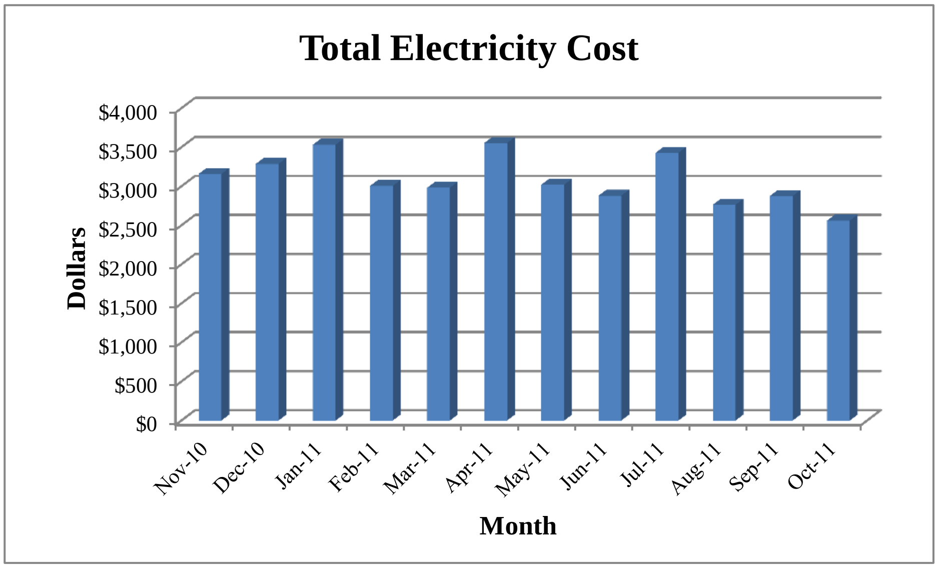
Basic Charge	$30	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
City Tax	1.5%		
County Tax	0.335%		
Public Purpose Charge	3.0%		

Meter Summary

Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.0975	/kWh
Average Power Factor	85.8%	

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	32,400	$2,280	141	$674	84	$14	85.9%	$190	$3,158
Dec-10	34,600	$2,434	128	$641	79	$14	85.0%	$197	$3,286
Jan-11	37,300	$2,624	145	$685	85	$14	86.2%	$209	$3,532
Feb-11	30,700	$2,160	131	$649	80	$14	85.3%	$182	$3,004
Mar-11	29,900	$2,104	145	$685	82	$12	87.0%	$180	$2,981
Apr-11	38,100	$2,681	130	$646	84	$16	84.0%	$211	$3,553
May-11	30,900	$2,174	131	$649	83	$15	84.4%	$183	$3,021
Jun-11	28,700	$2,019	140	$672	82	$13	86.3%	$175	$2,879
Jul-11	36,600	$2,575	128	$641	68	$8	88.3%	$204	$3,429
Aug-11	27,800	$1,956	122	$625	73	$12	85.7%	$169	$2,763
Sep-11	28,600	$2,012	141	$674	85	$14	85.6%	$175	$2,876
Oct-11	24,400	$1,717	140	$672	83	$14	85.9%	$158	$2,561
Totals	380,000	$26,737	1,622	$7,912	969	$160	-	$2,233	$37,042
Avg/mo.	31,667	$2,228	135	$659	81	$13	85.8%	$186	$3,087




Total Electricity Cost
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Dollars
Nov-10
Dec-10
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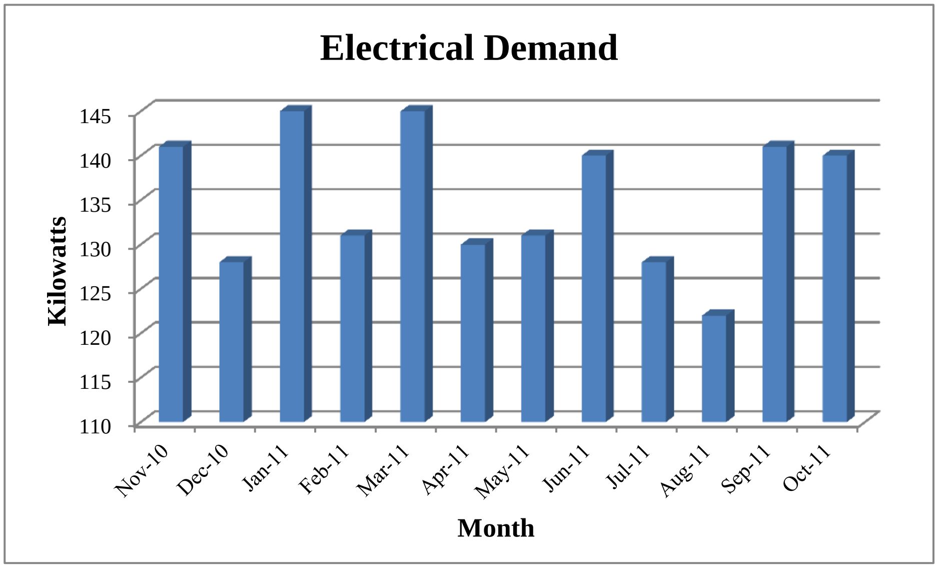
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
145
140
135
130
125
120
115
110
Kilowatts
Nov-10
Dec-10
Jan-11
Feb-11
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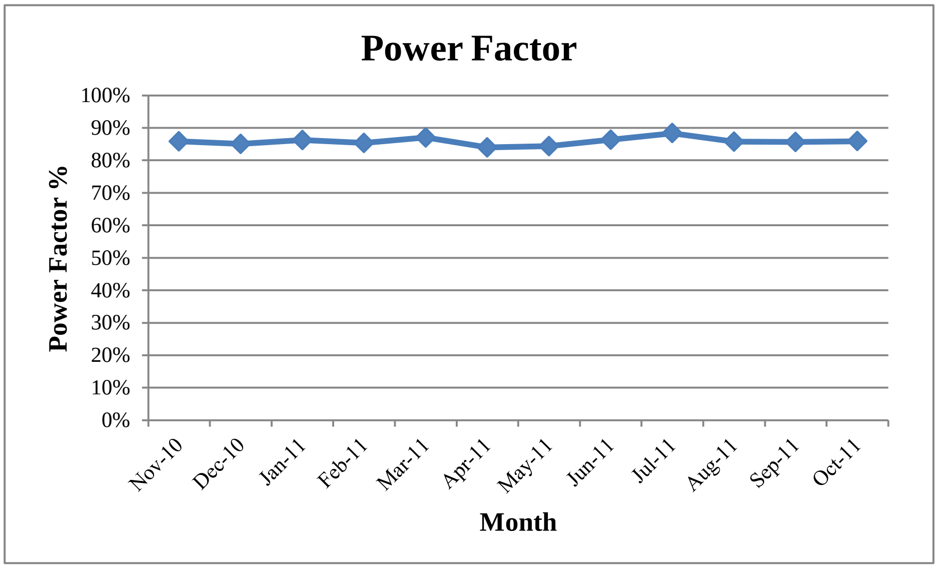
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Power Factor %
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Electricity (Meter 13)

Facility Information

Meter Description	Assembly/S. Warehouse	
Rate Schedule	83S	

Energy Cost

Base Electricity Cost	$0.07036	/kWh (before taxes or fees)	

Demand Cost

Demand Charge	$1.76	/kW-mo	
Variable Electrical Distribution Charge	$2.38	/kW-mo up to	30 kW
	$2.08	/kW-mo over	30 kW
Transmission Charge	$0.82	/kW-mo	

Reactive Power Cost

Reactive Power Charge	$0.50	/kVAR in excess of	40% kW

Taxes and Fees

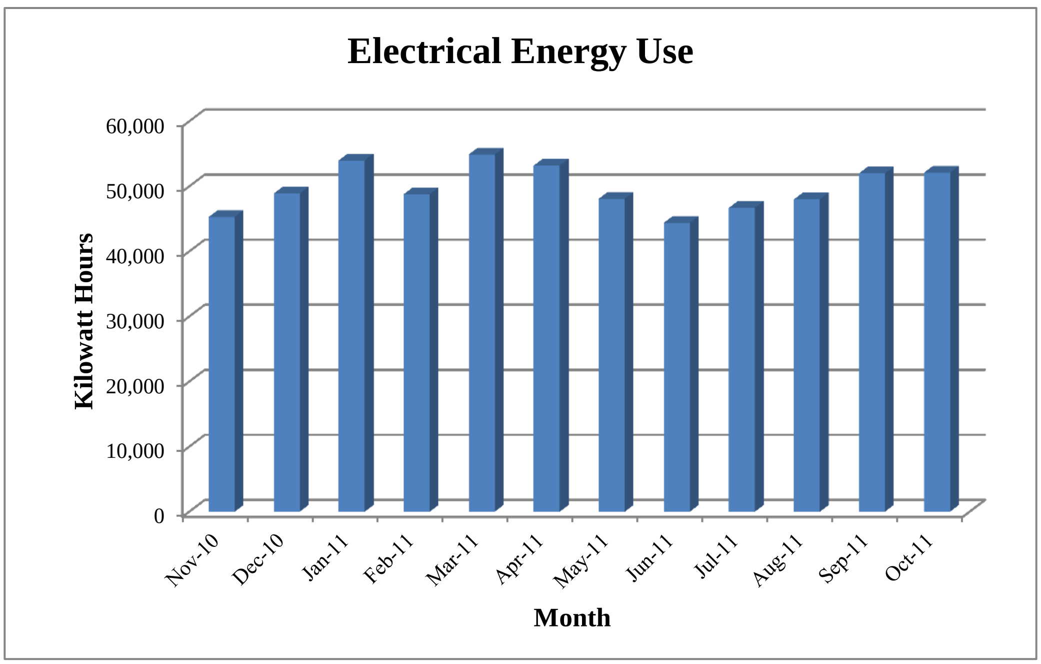
Basic Charge	$30	/month	
Low Income Assistance	$0.00050	/kWh up to	1,000,000 kWh
City Tax	1.5%		
County Tax	0.335%		
Public Purpose Charge	3.0%		

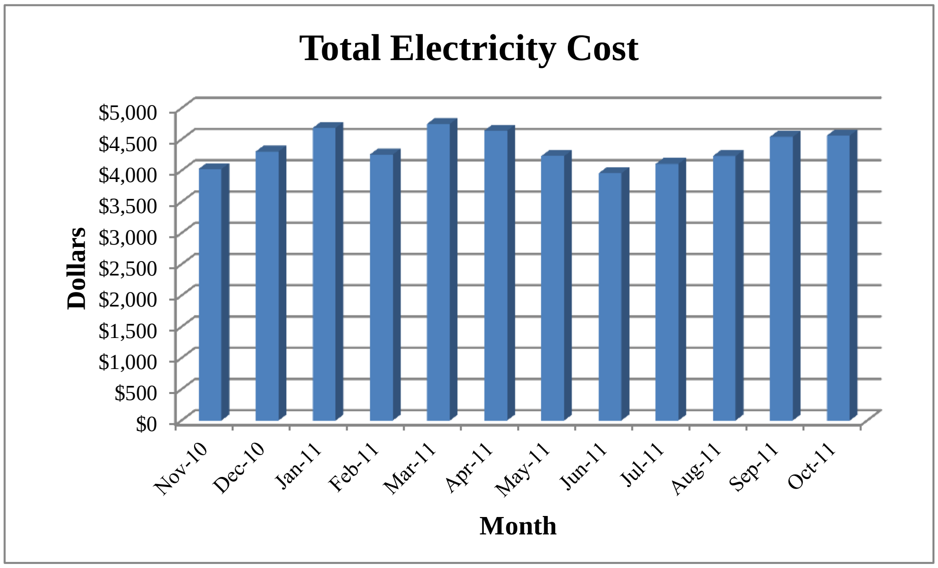
Meter Summary

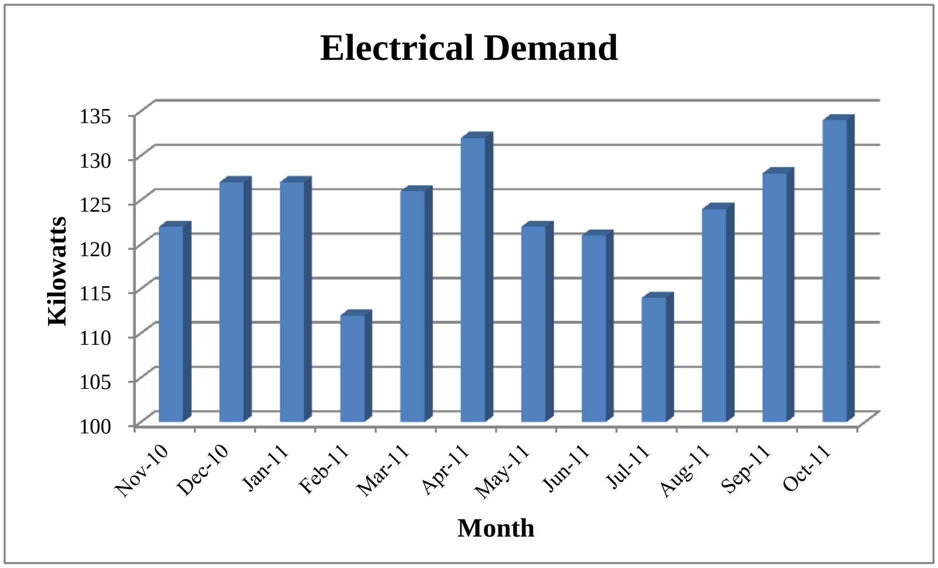
Incremental Electricity Cost	**$0.07299**	/kWh (with taxes and fees)
Incremental Demand Cost	**$4.80**	/kW-mo (with taxes and fees)
Average Electricity Cost	$0.0877	/kWh
Average Power Factor	96.7%	

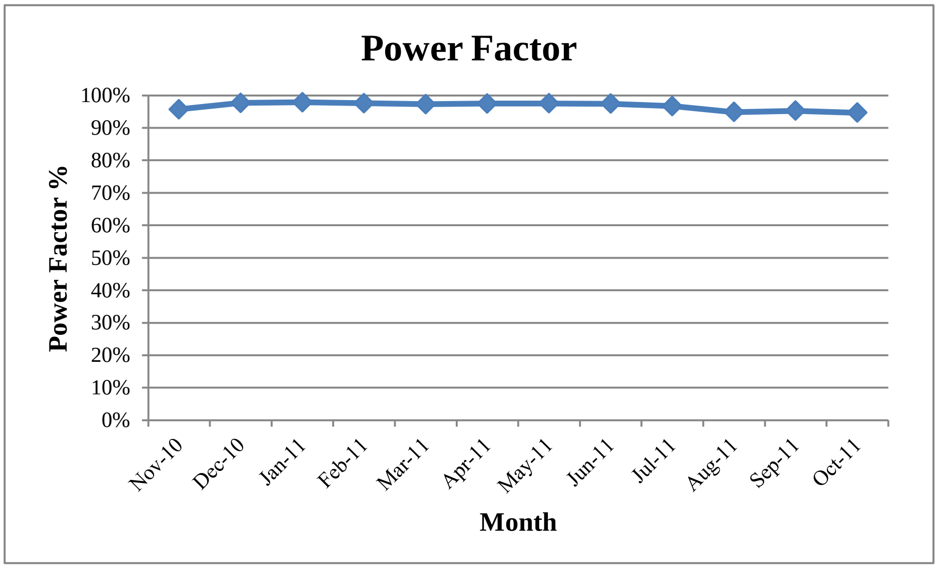
Electricity (Meter 13)

Meter Use Summary									
Month	**kWh**	**kWh$**	**kW**	**kW$**	**kVAR**	**kVAR$**	**PF %**	**Taxes/Fees**	**Total$**
Nov-10	45,300	$3,187	122	$602	37	$0	95.7%	$236	$4,026
Dec-10	48,900	$3,441	127	$615	28	$0	97.7%	$251	$4,307
Jan-11	54,000	$3,799	127	$615	27	$0	97.9%	$270	$4,685
Feb-11	48,800	$3,434	112	$577	25	$0	97.6%	$248	$4,259
Mar-11	54,900	$3,863	126	$613	30	$0	97.3%	$274	$4,749
Apr-11	53,200	$3,743	132	$628	30	$0	97.5%	$268	$4,639
May-11	48,100	$3,384	122	$602	28	$0	97.5%	$247	$4,234
Jun-11	44,400	$3,124	121	$600	28	$0	97.4%	$232	$3,956
Jul-11	46,700	$3,286	114	$582	30	$0	96.7%	$240	$4,108
Aug-11	48,000	$3,377	124	$608	41	$0	94.9%	$247	$4,232
Sep-11	52,000	$3,659	128	$618	41	$0	95.3%	$263	$4,539
Oct-11	52,100	$3,666	134	$633	46	$0	94.7%	$264	$4,563
Totals	596,400	$41,963	1,489	$7,294	391	$0	-	$3,040	$52,297
Avg/mo.	49,700	$3,497	124	$608	33	$0	96.7%	$253	$4,358




Total Electricity Cost
$5,000
$4,500
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Dollars
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Electrical Demand
135
130
125
120
115
110
105
100
Kilowatts
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month


Power Factor
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Power Factor %
Nov-10
Dec-10
Jan-11
Feb-11
Mar-11
Apr-11
May-11
Jun-11
Jul-11
Aug-11
Sep-11
Oct-11
Month

Natural Gas (Meter 1)

Oregon State University OSU Energy Efficiency Center

Facility Information

Meter Description	East Plant	

Natural Gas Cost

Natural Gas Cost	$0.70380	/Therm up to	2,000	Therms
	$0.68423	/Therm over	2,000	Therms

Taxes and Fees

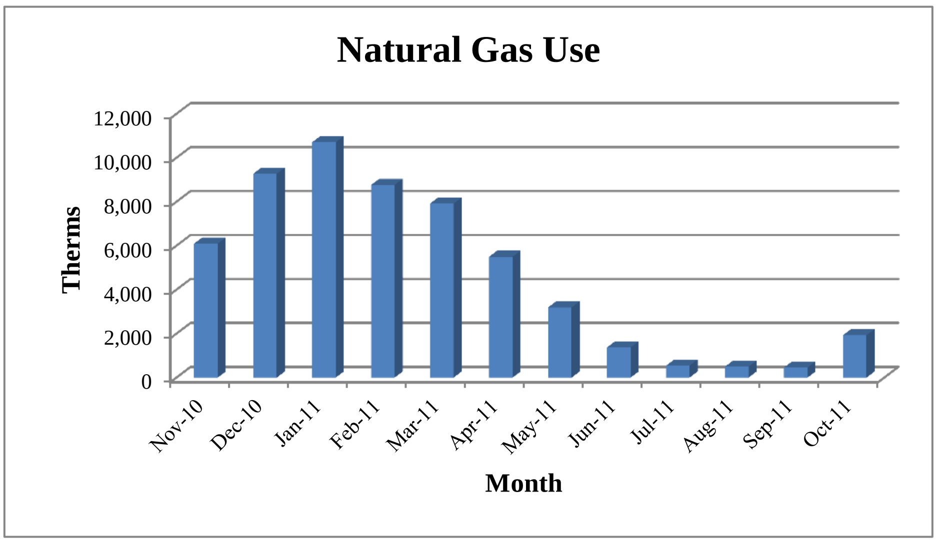
Pipeline Capacity Charge (Volumetric)	$0.13101	/Therm
Basic Charge	$325	/month
City Franchise Fee	2.0%	
County Tax	0.125%	
Puplic Purpose Charge	3.0%	
Gas Optimization Credit	$937	applied only in June

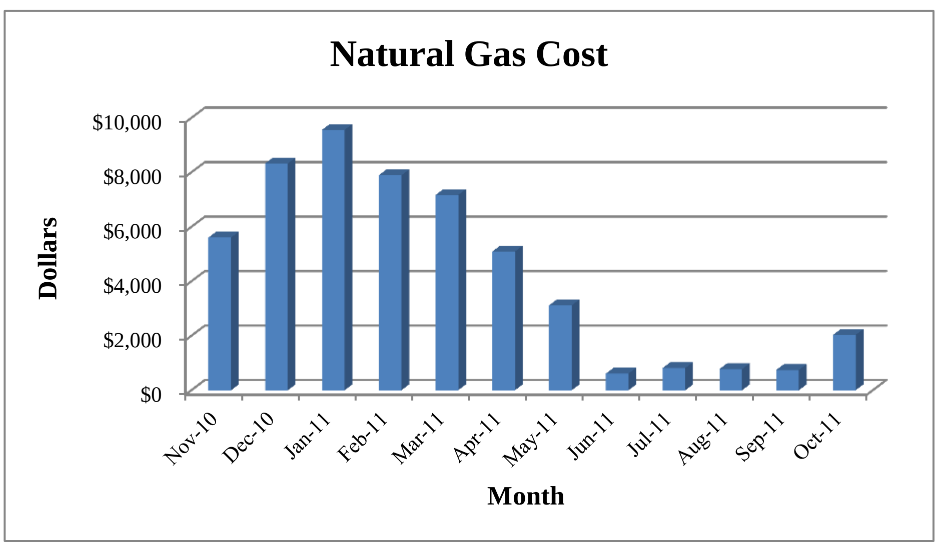
Meter Summary

Incremental Natural Gas Cost	**$0.85702**	/Therm (with taxes and fees)
	$8.57	/MMBtu

Natural Gas (Meter 1)

Meter Use Summary					
Month	**Therms**	**Therm$**	**Taxes/Fees**	**MMBtu**	**Total**
Nov-10	6,096	$5,009	$598	610	$5,607
Dec-10	9,270	$7,596	$731	927	$8,327
Jan-11	10,705	$8,766	$791	1,071	$9,557
Feb-11	8,763	$7,183	$710	876	$7,893
Mar-11	7,917	$6,494	$674	792	$7,168
Apr-11	5,496	$4,520	$573	550	$5,093
May-11	3,191	$2,641	$477	319	$3,118
Jun-11	1,374	$1,147	($536)	137	$610
Jul-11	541	$452	$365	54	$816
Aug-11	497	$415	$363	50	$778
Sep-11	459	$383	$361	46	$744
Oct-11	1,927	$1,609	$424	193	$2,033
Totals	56,236	$46,214	$5,531	5,624	$51,745
Avg/mo.	4,686	$3,851	$461	469	$4,312





Natural Gas (Meter 2)

Oregon State University OSU Energy Efficiency Center

Facility Information

Meter Description	North Plant	

Natural Gas Cost

Natural Gas Cost	$1.00107	/Therm

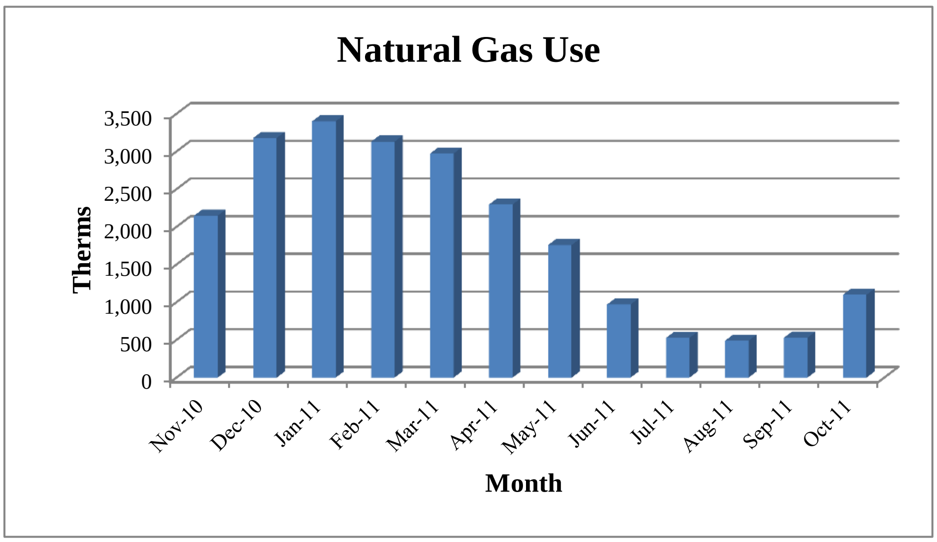
Taxes and Fees

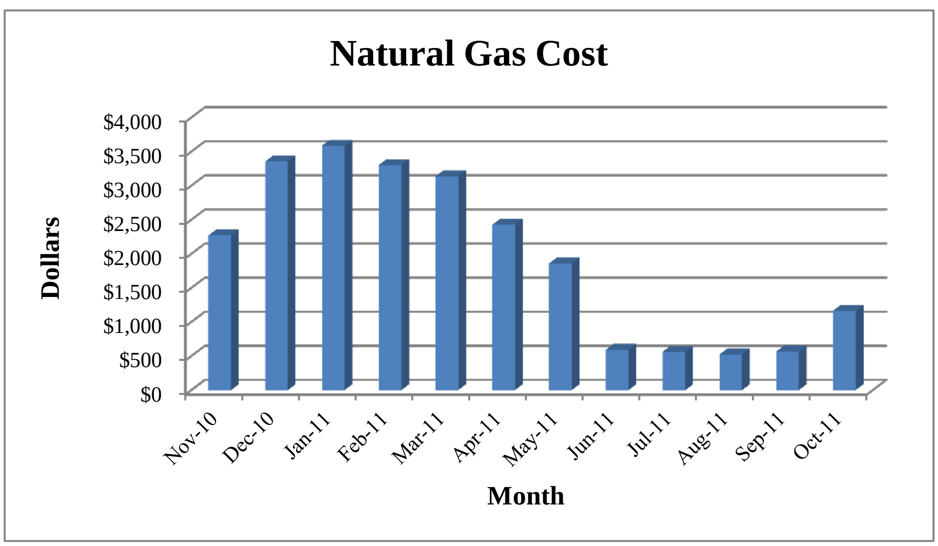
Basic Charge	$8	/month
City Franchise Fee	2.0%	
County Tax	0.125%	
Puplic Purpose Charge	3.0%	
Gas Optimization Credit	$436	applied only in June

Meter Summary

Incremental Natural Gas Cost	**$1.05237**	/Therm (with taxes and fees)
	$10.52	/MMBtu

Meter Use Summary					
Month	**Therms**	**Therm$**	**Taxes/Fees**	**MMBtu**	**Total**
Nov-10	2,149	$2,151	$119	215	$2,270
Dec-10	3,178	$3,182	$171	318	$3,353
Jan-11	3,400	$3,404	$183	340	$3,587
Feb-11	3,131	$3,134	$169	313	$3,303
Mar-11	2,973	$2,976	$161	297	$3,137
Apr-11	2,297	$2,300	$126	230	$2,426
May-11	1,759	$1,760	$99	176	$1,859
Jun-11	970	$971	($378)	97	$593
Jul-11	527	$528	$35	53	$563
Aug-11	489	$489	$33	49	$523
Sep-11	530	$530	$36	53	$566
Oct-11	1,098	$1,099	$65	110	$1,164
Totals	22,500	$22,524	$819	2,250	$23,343
Avg/mo.	1,875	$1,877	$68	188	$1,945





Natural Gas (Meter 3)

Oregon State University Energy Efficiency Center

Facility Information

Meter Description	West Plant	

Natural Gas Cost

Natural Gas Cost	$0.68364	/Therm up to	2,000	Therms
	$0.66644	/Therm over	2,000	Therms

Taxes and Fees

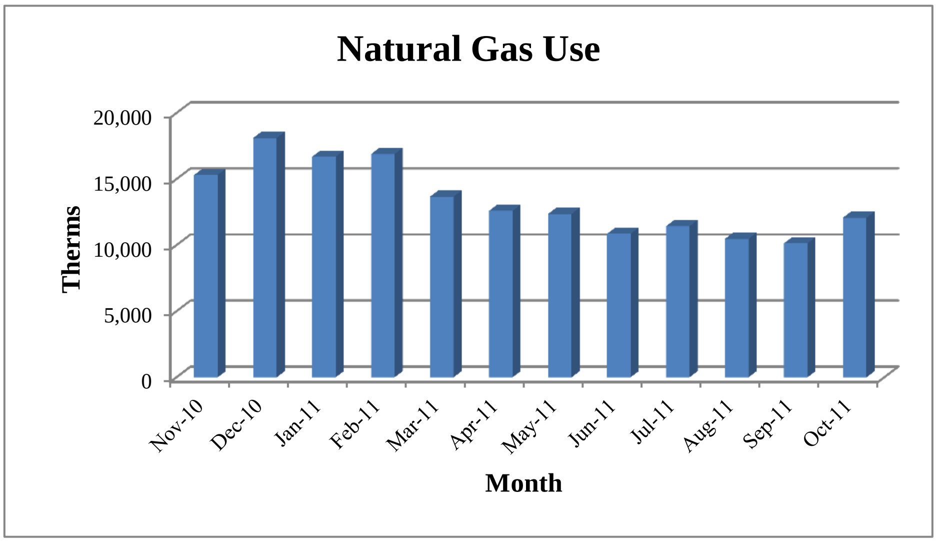
Pipeline Capacity Charge (MDDV)	$1.95	/Therm for	862	Therms
Basic Charge	$325	/month		
City Franchise Fee	2.0%			
County Tax	0.125%			
Gas Optimization Credit	$2,330	applied only in June		

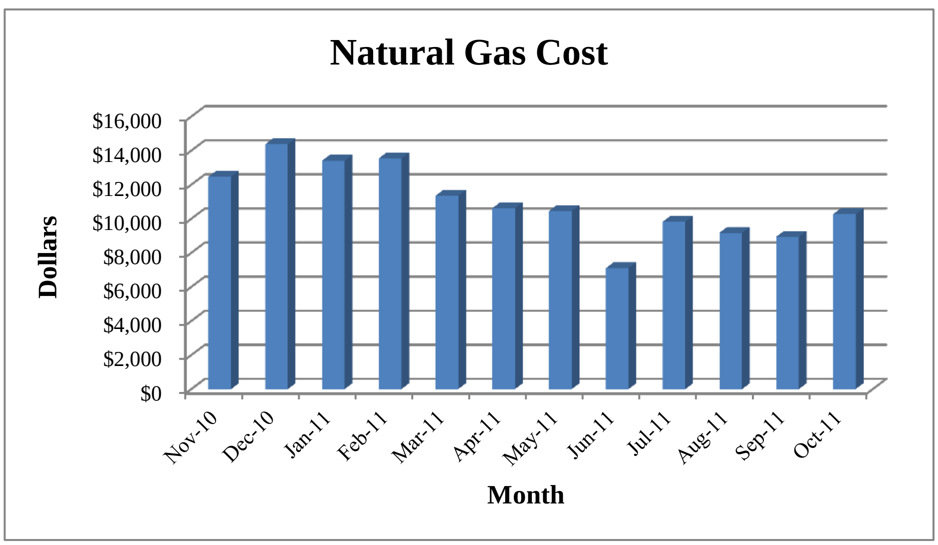
Meter Summary

Incremental Natural Gas Cost	**$0.68060**	/Therm (with taxes and fees)
	$6.81	/MMBtu

Natural Gas (Meter 3)

Meter Use Summary					
Month	**Therms**	**Therm$**	**Taxes/Fees**	**MMBtu**	**Total**
Nov-10	15,315	$10,241	$2,224	1,531	$12,464
Dec-10	18,109	$12,103	$2,263	1,811	$14,366
Jan-11	16,691	$11,158	$2,243	1,669	$13,401
Feb-11	16,894	$11,293	$2,246	1,689	$13,539
Mar-11	13,673	$9,147	$2,200	1,367	$11,347
Apr-11	12,599	$8,431	$2,185	1,260	$10,616
May-11	12,364	$8,274	$2,182	1,236	$10,456
Jun-11	10,856	$7,269	($170)	1,086	$7,099
Jul-11	11,433	$7,654	$2,169	1,143	$9,822
Aug-11	10,478	$7,017	$2,155	1,048	$9,172
Sep-11	10,138	$6,791	$2,150	1,014	$8,941
Oct-11	12,075	$8,082	$2,178	1,208	$10,259
Totals	160,625	$107,460	$24,024	16,063	$131,484
Avg/mo.	13,385	$8,955	$2,002	1,339	$10,957





End Use Summary

Oregon State University OSU Energy Efficiency Center

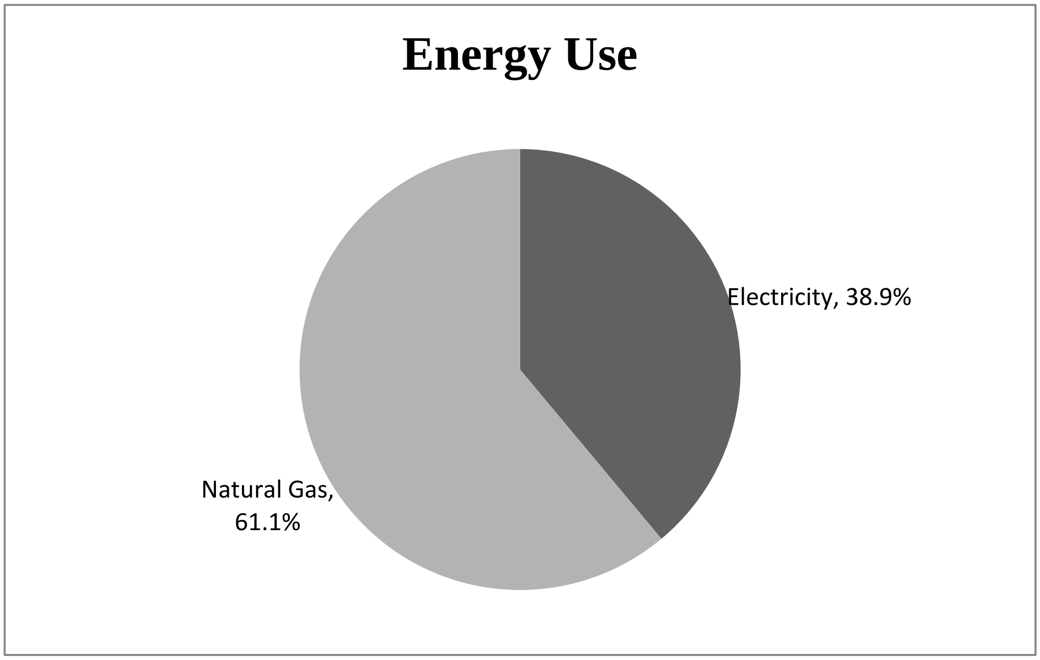
Average Energy Costs

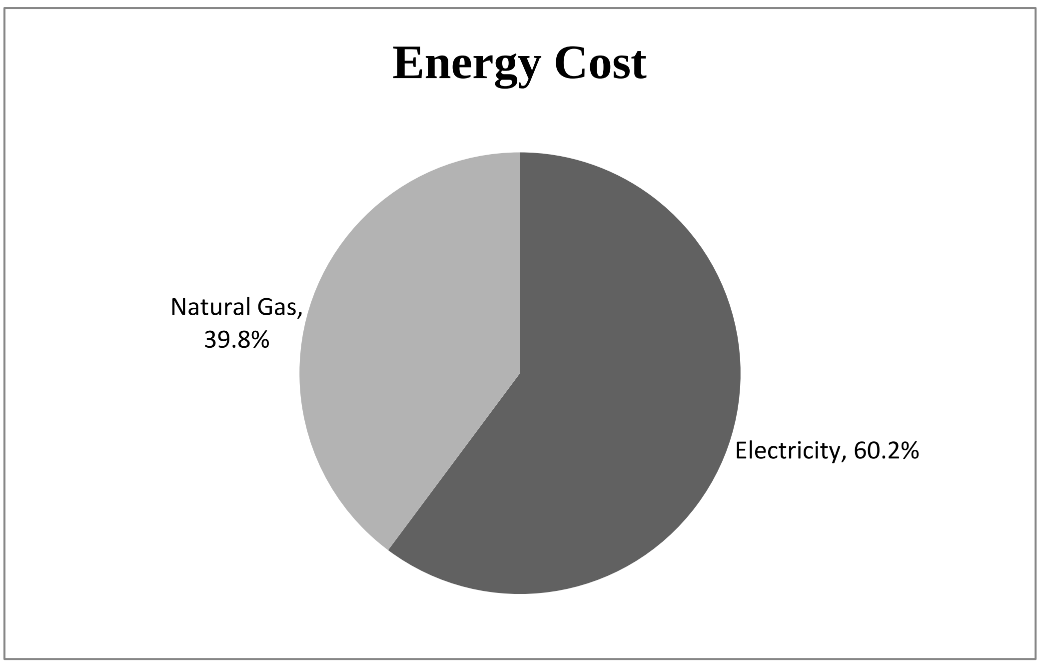
Average Electricity Cost	$0.06990	/kWh
Average Natural Gas Cost	$0.86301	/Therm

Electricity					
Area/System	**kWh**	**MMBtu**	**Energy %**	**Cost**	**Cost %**
Paint Shop	248,700	849	7.5%	$17,384	7.5%
Paint Shop	83,400	285	2.5%	$5,830	2.5%
Main	1,244	4	0.0%	$87	0.0%
Molding/ Cleanroom	66,120	226	2.0%	$4,622	2.0%
Molding/ Cleanroom	114,400	390	3.5%	$7,997	3.5%
N. Warehouse	130,640	446	4.0%	$9,132	4.0%
Controls Engineering	54,520	186	1.7%	$3,811	1.7%
L. Casting/ Production	889,680	3,036	27.0%	$62,188	27.0%
L. Casting/ Production	470,580	1,606	14.3%	$32,893	14.3%
Control Warehouse	50,520	172	1.5%	$3,531	1.5%
Upper Casting 240V	211,840	723	6.4%	$14,808	6.4%
Upper Casting 480V	380,000	1,297	11.5%	$26,562	11.5%
Assembly/S. Warehouse	596,400	2,036	18.1%	$41,688	18.1%
Totals	4,470,644	11,256	100.0%	$230,533	100.0%

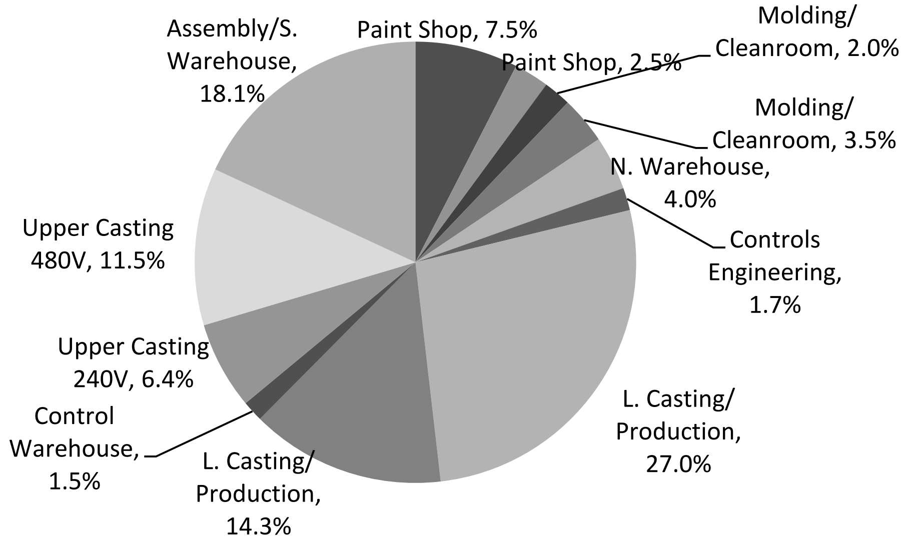
Natural Gas					
Area/System	**Therms**	**MMBtu**	**Energy %**	**Cost**	**Cost %**
East Plant	56,236	5,624	23.5%	$48,532	23.5%
North Plant	22,500	2,250	9.4%	$19,418	9.4%
West Plant	160,625	16,063	67.1%	$138,622	67.1%
Totals	239,361	23,936	100.0%	$206,572	100.0%

Energy Summary					
Utility	**Use**	**MMBtu**	**Energy %**	**Cost**	**Cost %**
Electricity (kWh)	4,470,644	15,258	38.9%	$312,497	60.2%
Natural Gas (Therms)	239,361	23,936	61.1%	$206,572	39.8%
Totals		39,194	100.0%	$519,069	100.0%

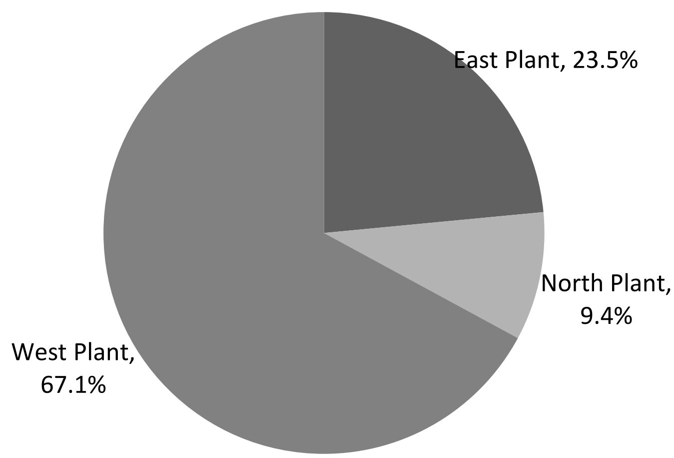

Energy Use
Electricity, 38.9%
Natural Gas,
61.1%


Energy Cost
Natural Gas,
39.8%
Electricity, 60.2%

Electricity Use



Natural Gas Use



NAIMA 3E Plus 4.0

Oregon State University

Item Description	=	Press Enclosure (Line 2) Lines
Calculation Type	=	Heat Flow Limitation Report
Geometry Description	=	Steel Pipe - Horizontal
System Units	=	ASTM C585
Bare Surface Emittance	=	0.8
Nominal Pipe Size	=	4 in.
Process Temperature	=	335 °F
Ave. Ambient Temperature	=	70 °F
Ave. Wind Speed	=	0 mph
Relative Humidity	=	N/A
Dew Point	=	N/A
Condensation Control Thickness	=	N/A
Outer Jacket Material	=	Aluminum, oxidized, in service
Outer Surface Emittance	=	0.1
Insulation Layer 1	=	MF Insulating CEMENT, C195-00, Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	334.5	775.70	
0.5	204.7	165.10	78.72
1.0	161.1	99.28	87.20
1.5	139.9	70.34	90.93
2.0	126.8	53.55	93.10
2.5	117.8	42.71	94.49
3.0	110.6	34.39	95.57
3.5	105.7	29.12	96.25
4.0	101.9	25.12	96.76
4.5	98.2	21.31	97.25
5.0	95.8	18.93	97.56
5.5	93.7	16.98	97.81
6.0	92.0	15.35	98.02
6.5	90.5	13.98	98.20
7.0	89.1	12.82	98.35
7.5	88.0	11.81	98.48
8.0	87.0	10.93	98.59
8.5	86.0	10.16	98.69
9.0	85.2	9.49	98.78
9.5	84.5	8.89	98.85
10.0	83.8	8.35	98.92

NAIMA 3E Plus 4.0

Oregon State University

Item Description	=	Press Enclosure (Line 2) Lines
Calculation Type	=	Heat Flow Limitation Report
Geometry Description	=	Steel Pipe - Horizontal
System Units	=	ASTM C585
Bare Surface Emittance	=	0.8
Nominal Pipe Size	=	4 in.
Process Temperature	=	308 °F
Ave. Ambient Temperature	=	70 °F
Ave. Wind Speed	=	0 mph
Relative Humidity	=	N/A
Dew Point	=	N/A
Condensation Control Thickness	=	N/A
Outer Jacket Material	=	Aluminum, oxidized, in service
Outer Surface Emittance	=	0.1
Insulation Layer 1	=	MF Insulating CEMENT, C195-00, Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	307.6	664.50	
0.5	192.0	145.80	78.06
1.0	152.8	88.04	86.75
1.5	133.7	62.50	90.60
2.0	121.8	47.64	92.83
2.5	113.6	38.02	94.28
3.0	107.0	30.64	95.39
3.5	102.6	25.96	96.09
4.0	99.2	22.39	96.63
4.5	95.7	19.00	97.14
5.0	93.5	16.89	97.46
5.5	91.7	15.15	97.72
6.0	90.1	13.70	97.94
6.5	88.7	12.48	98.12
7.0	87.5	11.44	98.28
7.5	86.4	10.54	98.41
8.0	85.5	9.76	98.53
8.5	84.7	9.08	98.63
9.0	83.9	8.47	98.73
9.5	83.2	7.93	98.81
10.0	82.6	7.46	98.88

NAIMA 3E Plus 4.0

Oregon State University

Item Description = Press Enclosure (Line 2) Lines
Calculation Type = Heat Flow Limitation Report
Geometry Description = Steel Pipe - Horizontal
System Units = ASTM C585
Bare Surface Emittance = 0.8
Nominal Pipe Size = 4 in.
Process Temperature = 306 °F
Ave. Ambient Temperature = 70 °F
Ave. Wind Speed = 0 mph
Relative Humidity = N/A
Dew Point = N/A
Condensation Control Thickness = N/A

Outer Jacket Material = Aluminum, oxidized, in service
Outer Surface Emittance = 0.1
Insulation Layer 1 = MF Insulating CEMENT, C195-00, Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	305.6	656.60	
0.5	191.1	144.40	78.01
1.0	152.1	87.22	86.72
1.5	133.2	61.92	90.57
2.0	121.4	47.20	92.81
2.5	113.3	37.68	94.26
3.0	106.7	30.36	95.38
3.5	102.4	25.72	96.08
4.0	98.9	22.19	96.62
4.5	95.6	18.83	97.13
5.0	93.4	16.74	97.45
5.5	91.5	15.01	97.71
6.0	89.9	13.58	97.93
6.5	88.6	12.37	98.12
7.0	87.4	11.34	98.27
7.5	86.3	10.45	98.41
8.0	85.4	9.67	98.53
8.5	84.6	9.00	98.63
9.0	83.8	8.40	98.72
9.5	83.1	7.86	98.80
10.0	82.5	7.39	98.87

Oregon State University

Item Description = Press Enclosure (Line 2) Lines
Calculation Type = Heat Flow Limitation Report
Geometry Description = Steel Pipe - Horizontal
System Units = ASTM C585
Bare Surface Emittance = 0.8
Nominal Pipe Size = 6 in.
Process Temperature = 196 °F
Ave. Ambient Temperature = 70 °F
Ave. Wind Speed = 0 mph
Relative Humidity = N/A
Dew Point = N/A
Condensation Control Thickness = N/A

Outer Jacket Material = Aluminum, oxidized, in service
Outer Surface Emittance = 0.1
Insulation Layer 1 = MF Insulating CEMENT, C195-00, Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	195.8	276.00	
0.5	143.2	74.50	73.01
1.0	121.8	47.71	82.72
1.5	110.2	34.38	87.54
2.0	102.2	25.73	90.68
2.5	97.4	20.82	92.46
3.0	93.8	17.35	93.71
3.5	90.5	14.24	94.84
4.0	88.4	12.39	95.51
4.5	86.7	10.92	96.04
5.0	85.3	9.73	96.47
5.5	84.1	8.75	96.83
6.0	83.1	7.93	97.13
6.5	82.2	7.24	97.38
7.0	81.4	6.64	97.59
7.5	80.7	6.13	97.78
8.0	80.1	5.68	97.94
8.5	79.6	5.29	98.08
9.0	79.1	4.94	98.21
9.5	78.6	4.63	98.32
10.0	78.2	4.35	98.42

NAIMA 3E Plus 4.0

Oregon State University

Item Description = Press Enclosure (Line 2) Lines
Calculation Type = Heat Flow Limitation Report
Geometry Description = Steel Pipe - Horizontal
System Units = ASTM C585
Bare Surface Emittance = 0.8
Nominal Pipe Size = 3 in.
Process Temperature = 185 °F
Ave. Ambient Temperature = 70 °F
Ave. Wind Speed = 0 mph
Relative Humidity = N/A
Dew Point = N/A
Condensation Control Thickness = N/A

Outer Jacket Material = Aluminum, oxidized, in service
Outer Surface Emittance = 0.1
Insulation Layer 1 = MF Insulating CEMENT, C195-00, Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	184.9	254.60	
0.5	133.5	65.77	74.17
1.0	113.2	39.62	84.44
1.5	102.8	27.51	89.20
2.0	96.7	20.96	91.77
2.5	92.5	16.72	93.43
3.0	89.4	13.78	94.59
3.5	86.8	11.40	95.52
4.0	85.1	9.84	96.14
4.5	83.6	8.61	96.62
5.0	82.2	7.41	97.09
5.5	81.2	6.65	97.39
6.0	80.4	6.02	97.64
6.5	79.7	5.48	97.85
7.0	79.0	5.02	98.03
7.5	78.5	4.63	98.18
8.0	78.0	4.29	98.32
8.5	77.6	3.99	98.43
9.0	77.2	3.72	98.54
9.5	76.8	3.49	98.63
10.0	76.5	3.28	98.71

Oregon State University

Item Description = Press Enclosure (Line 2) Lines
Calculation Type = Heat Flow Limitation Report
Geometry Description = Steel Pipe - Horizontal
System Units = ASTM C585
Bare Surface Emittance = 0.8
Nominal Pipe Size = 2 in.
Process Temperature = 120 °F
Ave. Ambient Temperature = 70 °F
Ave. Wind Speed = 0 mph
Relative Humidity = N/A
Dew Point = N/A
Condensation Control Thickness = N/A

Outer Jacket Material = Aluminum, oxidized, in service
Outer Surface Emittance = 0.1
Insulation Layer 1 = MF Insulating CEMENT, C195-00, Varied

Variable Insulation Thickness	Surface Temp (°F)	Heat Loss (BTU/hr/ft^2)	Efficiency (%)
Bare	120.0	93.99	
0.5	97.5	23.86	74.61
1.0	89.5	15.03	84.01
1.5	84.9	10.45	88.88
2.0	82.0	7.85	91.64
2.5	80.2	6.28	93.32
3.0	78.8	5.19	94.48
3.5	77.8	4.39	95.33
4.0	76.8	3.71	96.05
4.5	76.2	3.25	96.54
5.0	75.7	2.89	96.93
5.5	75.1	2.52	97.32
6.0	74.7	2.28	97.57
6.5	74.4	2.08	97.79
7.0	74.1	1.91	97.97
7.5	73.9	1.76	98.13
8.0	73.7	1.63	98.26
8.5	73.5	1.52	98.38
9.0	73.3	1.42	98.49
9.5	73.1	1.33	98.58
10.0	73.0	1.25	98.67

5. SECTOR BEST PRACTICES

Following is a narrative outlining general Best Practices associated with achieving optimum energy efficiency in the Agricultural Sector.

Efficient Irrigation

Irrigation commonly accounts for approximately 30 percent of a farm's overall electricity usage. Following these recommendations can help reduce your water consumption, electricity and labor costs while improving crop yields and reliability.

Recommendations

- When purchasing motors, buy Premium Efficiency (PE) models. PE motors are between 2 and 10 percent more efficient than standard efficiency motors, and the savings commonly justify the greater initial cost. Also, consider purchasing a new PE motor instead of rewinding an older motor. If choosing to rewind, investigate the ability of your rewind shop to maintain motor efficiency in the rewind process.

- Testing pump efficiency every two to three years can help make sure that pumps are performing properly and that no significant losses are occurring. Depending on the required head and flow, pumps can feasibly reach efficiencies as high as 70%. Unfortunately they are able to get the job done at abysmal efficiencies (as low as 20% efficiency) with little outward sign of inefficient operation. Guidelines for given efficiencies follow.

    - *Efficiencies Above 60%* - No action is necessary, although efficiency may be improved by adjusting impeller clearances.

    - *Efficiencies Between 50% and 60%* - Adjusting the impeller to housing clearance is recommend as efficiency may increase by up to 10-15%

    - *Efficiencies Between 50% and 55%* - Damage to the impeller is likely and repair is recommended as efficiency may increase by up to 20%

    - *Efficiencies Below 50%* - Replacement is recommended in most cases, it may be caused by an improperly sized motor for the application. Consider resizing components for optimum efficiency.

    - In some combinations of flow and head, max possible efficiency may be below these minimal values.

  The Pumping System Assessment Tool is free software is available through the U.S.DOE that can help the user identify the best possible efficiency for an application and evaluate the efficiency of a currently installed pump and the best efficiency that is possible. It can be downloaded from: *http://www1.eere.energy.gov/industry/bestpractices/software_psat.html*.

- Using the correct pipe size for the desired flow rate can significantly reduce energy consumption. Using 6 inch mainlines can consume 4 times as much energy as 8 inch mainlines in some cases. When expanding or replacing mainlines we recommend consulting a professional to help analyze which sizes may be most cost effective.

- Using proper diffusers, fitting, meters, and valves can significantly increase overall system efficiency. We recommend reviewing Energy Saving Tips for Irrigators[1], published by the ATTRA.

Low Pressure Irrigation

Most irrigation systems utilize a high pressure sprinkler system to deliver water to the field. These systems typically operate from 70 - 100 psi. This is a very inefficient method for delivering water to a field. A more energy efficient system uses low pressure drop down nozzles that require less pressure to operate at the same flow rate as conventional sprinklers. These low pressure systems can operate at pressures as low as 15 - 20 psi without reducing flow rate. By installing a variable speed drive (VSD), the pump can operate efficiently at these low pressures to reduce energy consumption.

Recommendations

- Linear or center pivot irrigation systems are easily retrofitted to run at 15 psi and yield very quick paybacks. Larger systems will be more cost effective.

- Hand lines can be converted to a lower pressure (35 psi and sometimes lower), but are not as cost effective because it reduces the flow rate thus increasing pumping time.

- Moving guns can be retrofitted to a moving boom system and can be very cost effective, but will suffer from limited mobility and increased chance of operator caused damage.

VSD Irrigation Pump

Most irrigation pumps run at full speed no matter the load on the system. This is very inefficient, particularly when a wide range of flow rates and pressures are needed throughout the season. A more energy efficient system uses a variable speed drive (VSD) to slow the motor speed to match the end use requirements. This will maintain the same pressure while reducing the flow rate and energy consumption of the pump. A VSD will also allow pumps to "soft start", by slowly ramping up the motor instead of trying to do so instantaneously. This will also reduce motor wear and damage caused by hard starting as well as maintenance cost associated with water surge/hammer damage.

- Systems where VSD irrigation pumps usually payoff:

[1] http://attra.ncat.org/attra-pub/PDF/energytips_irrig.pdf

- Pumping systems implementing bypass or throttling control valves.
- Pumping systems that draw from a well with a depth that varies significantly.
- Pivot and linear systems that have an end gun that turns on and off at varying locations in the field.
- Pivot and linear systems located on terrain that has elevation changes.
- Pumps that service multiple systems that may not all be on at once.

Premium Efficiency Motors

Depending on horsepower, high efficiency motors operate from 1% to 10% more efficiently than standard motors. The savings are larger on more powerful motors and on motors that operate for long periods. We recommend replacing only motors for which the size and operating conditions yield favorable payback periods. When a motor fails consider replacing it with premium efficiency motor instead of another standard motor or rewinding. If choosing to rewind, investigate the ability of your rewind shop to maintain motor efficiency in the rewind process. Upgrading current working motors, however, is typically not cost effective and will not yield a favorable payback period.

Notched V-Belts

A notched belt reduces slip and allows the belt to bend around pulleys with less energy. Motor speed and efficiency losses occur when a standard V-belt slips within the groove of the pulley. The friction between the standard V-belt and pulley generates heat within the belt, resulting in an energy loss and a shortening of belt life. Notched V-belts can improve efficiency by approximately 2% to 4% over standard V-belts. We recommend replacing belts with notched V-belts as they wear out.

Fuel Storage

Fuel tanks can lose a considerable amount of fuel due to evaporation and unnoticed leaks. In extreme cases up to 40 percent of the tank capacity can be lost per year through evaporation in above ground tanks while many leaks continue to go unnoticed in underground tanks. This is not only wasteful and costly, but also harmful to the surrounding environment. It is important to recognize these problems quickly and take measures to correct them.

Recommendations

- Fuel in tanks slowly evaporates to atmosphere when exposed to higher temperatures. Darker colors absorb more radiant heat than lighter colors, which reflect heat. Using aluminum finished or white tanks can significantly decrease the heat absorbed by the tank, lowering its internal temperature. This will help reduce the amount of fuel that vaporizes to atmosphere.

- Tanks should be kept out of direct sunlight to reduce the amount of fuel that vaporizes. Either burying the tank or putting a protective roof over the tank can solve this. However, burying the tank is not recommended because leaks can go unnoticed, increasing fuel loss.

- Older fuel tanks simply vent to atmosphere through a small vertical pipe. Installing vacuum pressure relief caps on the vents can reduce the amount of fuel vapors released from the tank while still allowing air to flow into the tank.

- During inspections, tighten all fittings and check for leaks and properly functioning valves. It is important to keep leaks to a minimum to help protect the environment and reduce fuel costs.

Farm Rewiring

As facilities expand, proper wiring is often ignored and systems become outdated. This could eventually lead to a system overload or complete failure. Many utility companies offer free annual wiring checkups to identify areas that may need upgrading or replacement. Conducting a thorough wiring checkup is recommended at least every two years, according to the Rural Energy Management Council (REMC). Enhancing electrical safety and improving power quality and equipment operation are some key reasons for considering rewiring and upgrades.

Recommendation

- Ensure your wiring systems comply with all safety codes. National and State Electrical Codes are your best aids in developing a wiring system that will operate efficiently and safely for many years.

- Ensure your system is adequately sized. The wiring system must have enough circuits and outlets of the correct size and type and consist of the proper materials to prevent premature corrosion or overload. Also, give careful thought about what equipment will be served by specific circuits and outlets. This information is also valuable when working with your utility to ensure that the transformer serving your farm is sized correctly.

- Create new systems to be expandable. Working with a qualified electrician and your utility on future additions or expansions can save unnecessary costs in the long run. This step becomes important when specifying service panels, sizing conductors, and selecting wiring methods.

- Allow sufficient planning time to work with a qualified electrician and/or your utility to ensure your system is efficient. An efficient system minimizes power losses from voltage drops by using adequately sized conductors and quality components.

Tractor Operation

Operators can obtain a number of speeds by adjusting the transmission gear ratio while maintaining the same engine RPM. Within each gear ratio there is further adjustment available with the idler. In most cases tractor field speeds are determined by the implement and not by the tractor power available. Most operators run tractors at full throttle using the transmission gear ratio to vary speed. Significant increases in fuel efficiency are expected if the governor speed is reduced and a faster gear ratio is selected. This is particularly true in cases where the tractor and equipment are not properly matched and the tractor is operating at less than half load.

Recommendations

- The engine speed should be reduced as far as possible while staying in its designed power range. Check the operator's manual to find the proper engine power range. Operating a tractor outside side of its designed power range will decrease fuel efficiency

- It is important to not overload or 'lug' the tractor. 'Lugging' the tractor causes the engine to generate more than the designed torque at low engine speeds. This can result in engine overheating and in some extreme cases, engine failure. Key indicators to overloading are excessive black smoke, or the sluggish response when throttled up. The tractor should accelerate quickly when throttled up, if it doesn't, the engine RPMs should be increased until the engine becomes responsive to throttle change.

- Only reduce throttle during non-PTO operations unless the tractor is equipped with a variable speed PTO that can maintain PTO speed with reduced engine RPMs.

Tractor Maintenance

Neglecting routine tractor maintenance can lead to premature wear on critical engine components, shortened life and significant losses in fuel efficiency. Tractors should be maintained as specified in the operator manual. This will help increase useful life and fuel efficiency while decreasing the number of costly breakdowns that occur during the operating season. This will also increase the power output while minimizing the amount of harmful exhaust emissions released into the atmosphere.

Recommendations

- Check tire pressures weekly as pressure can change when exposed to work intensive tasks. Check your operator's manual for correct inflation pressures. Under-inflated tires can prematurely wear tires and decrease fuel efficiency by 3 percent. Over inflated tires can cause excessive slip, decreasing fuel efficiency by a similar percentage.

- Check and replace oil and fuel filters seasonally or as recommended by the operator manual. Clogged or dirty filters can not only harm the engine but also decrease fuel efficiency by up to 5 percent. Replace filters as recommended by operator manual.
- Check and clean air filters weekly and replace as needed or as recommended by the operator manual. In extreme cases, a dirty air filter can decrease fuel efficiency by up to 20 percent.

- Check ballast weight when changing implements. Properly ballast the tractor to reduce slip, power hop and weight. Excessive weight can increase fuel consumption so it is important to obtain the correct weight for the implement being used to maintain good traction, balance and handling characteristics. Tire slip should be kept to a minimum, between 5 and 15 percent for work intensive tasks. Check operator manual for details.

- Avoid excessive road use as it can prematurely wear tires, giving them a shorter life. Worn tires also get significantly less traction, reducing fuel efficiency.

- Use correct size tractor for implement. Using an over-sized tractor uses excessive fuel. If the tractor can be throttled down significantly, while still performing the task, it is recommended to use a smaller tractor.

- Upgrade to more efficient tractors when replacing older models. The higher efficiency commonly compensates for the higher initial cost.

- Avoid quick starts. Engines need to warm up to operating temperatures before operation to reduce engine wear. The engine oil needs to be warmed up and circulated throughout the engine to provide proper lubrication.

- Have wheels aligned and balanced regularly to decrease the overall rolling resistance of the tractor, increasing fuel efficiency. Check the operator manual for more details.

Heating and Cooling

Heating and cooling accounts use more energy than any other typical building system. No matter what kind of heating, ventilation, or cooling system you have in your building, significant energy savings and increased comfort can be realized by properly maintaining and/or upgrading your system. Even then, a properly maintained system can waste a considerable amount of energy through improper insulation, air sealing, and thermostat setting. It is important to make sure your system, and any connected systems, are efficient.

Recommendations

- Set your thermostat as cold as you are comfortable with during the winter, and as warm as you are comfortable with during the summer. This reduces the system heating/cooling load, drastically reducing energy costs.

- Make sure that all vents are clear of obstructions as this reduces effectiveness and increases fire hazards.
- Clean ventilation filters on a regular basis to reduce fan load.

Efficient Insulation

Having a properly insulated building can reduce heating and cooling loads thus reducing energy costs. Insulation is measured in R-values, the higher the value, the better the insulator and the more resistant it is to heat loss. The Department of Energy Insulation Fact Sheet[2] shows recommended insulation values based on location. By entering your zip code you can find the recommended R-values for different areas of your building. Places to check for proper insulation are your attic, ceilings, walls, basement walls, floors, and crawl spaces.

Recommendations

- Install attic vents along the entire ceiling cavity to improve ventilation. This will help with moisture control and reduce cooling bills during the summer.

- Use lighting fixtures designed for direct insulation contact to reduce heat loss through and around fixtures.

- Make sure to take into account all building and climate factors before replacing or installing insulation.

- Use higher density insulation on exterior walls and ceilings.

Efficient Windows

Many farm buildings have windows to provide natural lighting, ventilation, and a view to the outside world. Unfortunately, a considerable amount of energy can be lost out windows as well. During cold winter months as much as 25 percent of your heating bill can be lost through windows. If your buildings utilize single pane windows or you are building a new building, consider upgrading to more efficient double or triple pane gas filled windows that will reduce heating costs.

Recommendations

- During Winter
  - Cover windows from the inside with a heavy duty clear plastic to reduce infiltration. Plastic must be sealed around window to work properly.
  - Close curtains during night and open them during the day.
  - Keep windows clean especially on the south side of buildings to let in solar heat.
  - Install interior or exterior storm windows.

[2] http://www.ornl.gov/sci/roofs%2bwalls/insulation/ins_16.html

- During Summer
    - Install white window shades, drapes, or blinds especially on south side of building to reflect solar energy.
    - Keep curtains closed during the day especially on south side of building
    - Apply a reflective film on south facing windows to reduce solar gain.
    - Install awnings on south and west facing windows.

Sealing Air Leaks

Many older buildings develop cracks and air leaks over the years. By sealing cracks, seams, and leaks you can easily and inexpensively decrease your building's heat losses and associated energy costs.

Recommendations

- Check the entire building for potential leaks. This can be done by feel, or you can use lit incense on a windy day to check for any disturbances from the interior. If a leak is near, the smoke will blow horizontally instead of vertically. Check windows, doors, vents, and any visible cracks or seams.

- Use weather stripping on any doors or windows that leak.

- Check for dirty spots on walls, ceiling, and floors, this could be an indicator that an air leak is present.

- When a fireplace is not in use, close the flue stack to reduce heat loss.

Efficient Lighting

Fluorescent lighting fixtures are much more efficient than Metal Halide, Halogen, Incandescent, and Mercury fixtures. Replacement of fixtures can reduce energy costs. Depending on the location, lighting requirements and usage

Recommendations

- Compact fluorescent bulbs can be used in place of incandescent lights. They are extremely efficient and last over 10 times as long as standard incandescent lights.

- T-8 fluorescent bulbs should be used for general task lighting. These are much more efficient than incandescent lights, and the standard T-12 fluorescent lights. They also have the advantage of a quick re-strike time, allowing them to be used with a motion sensor system.

- T-5 fluorescent bulbs should be used in high bay applications, such as warehouses, in place of metal halide, halogen, and mercury lamps. They are extremely efficient and have the advantage of a quick re-strike time, allowing them to be used with a motion sensor system.

Photocell Sensors

Photocell sensors can dim or turn off lights when sufficient day lighting in the area is reached. In some cases this can reduce electricity costs and associated labor and maintenance costs. Photocell sensors can be used for outdoor and indoor lighting next to windows, doors or sky-lights. Typically they are only useful inside a building if lights are located within 15 feet of an outside lighting source.

Refrigeration Tune

Refrigeration systems are very important in all operations to hold low temperatures where needed. They are also very sensitive and can easily decrease in efficiency over time when not well-maintained. An inefficient refrigeration system will cause higher temperatures in the cooling area, overworking the compressor motors, and more wear and tear on the system. These will cause higher operating and maintenance costs because more energy is put into the system than needed. Below is a list of ways to increase the efficiency of your refrigeration system.

Recommendations

- **Increase Suction Pressure** – Suction pressure is the pressure, or corresponding temperature, at which the refrigerant evaporates. Every refrigeration system has low and high suction pressure set points to tell the compressor when to turn on and shut off. If these suction temperatures are too low then the motor is working very hard to lower the refrigerant temperature that far. Increasing the suction pressure set points will decrease the load on the motor. Typically, 2% to 3% of refrigeration compressor energy can be saved for each degree Fahrenheit increase in suction temperature.

- **Reduce Discharge Pressure** – Discharge pressure is the point at which the refrigerant condenses. When this pressure, or corresponding temperature, and approach temperature is above the ambient air temperature, the compressor is doing more work than needed. Compressor power is dependent on the pressure difference across it, so reducing the discharge pressure will reduce the load on the compressor motor. However, it will increase evaporator fan usage, but only approximately 10-30% of compressor energy savings. We can estimate 1% compressor energy savings for every degree Fahrenheit condensing temperature is reduced.

- **Clean Evaporator Fans** – Water evaporates as it absorbs heat from the condensing refrigerant. This can cause corrosion on the heat exchange surfaces, reducing air flow through the evaporator. Regularly cleaning the evaporator surfaces will maximize airflow and increase refrigeration efficiency.

UTILITIES
APPENDIX

1. OVERVIEW

An essential component of any energy management program is tracking energy. We have prepared a utility baseline analysis in the Site Data Section based on information provided by you or your utility companies. They show how energy is used and help identify potential energy savings.

2. GLOSSARY

We use specific terminology in discussing your energy, water, and waste expenses. The following section presents common terms you are likely to encounter along with details.

Average Demand Cost: Total billed demand cost divided by total demand. Average demand cost includes taxes, fees and unit cost.

Average Disposal Cost: Average cost per pickup or ton of waste or other scrap material. This cost is calculated using all annual expenses to obtain a representative cost per unit of disposal.

Average Energy Cost: Total billed cost divided by total energy. Average energy cost includes taxes, fees and unit cost.

Average Load Factor: Average Load Factor expresses the relationship between peak load and average load on a given electrical system. A higher load factor typically results in a lower average energy cost. Defined as the ratio of annual electrical energy use divided by the average demand in kilowatts (kW) and hours in a year.

Basic Charge: A fee a utility can charge each month to cover administrative, facility, or other fixed costs. Some rate schedules have higher energy or power rates that compensate for no or low basic charge.

BOD Charge: Charge levied by a sewer/water treatment utility to cover extra costs for high strength wastewater. High strength wastewater requires more intensive treatment by the utility and extra processing. BOD, biochemical oxygen demand, is a measure of how much oxygen will be used to microbiologically degrade organic matter in the wastewater stream. State agencies such as a Department of Environmental Quality set BOD and other regulations that wastewater treatment facilities must meet to discharge treated water into nearby waterways. Your treatment facility may have ideas that could help lower the strength of your wastewater.

Box Rental Rate: The fee imposed by a waste or recycling utility to cover costs of their receiving containers.

Commodity Rate: The component of the billing rate that represents the annual weighted average commodity cost of natural gas.

Energy: The time-rate of work expressed in kWh for electric energy. Another common unit is million Btu or MMBtu. One MMBtu is equivalent to 293.1 kWh.

Demand: The highest electrical power required by the customer, generally averaged over 15 minute cycling intervals for each month. Demand is usually billed by the kW-mo unit.

Disposal Cost: Incurred by the waste utility for disposing of your waste in a landfill or other facility. These charges increase when hazardous materials are present in the waste.

Incremental Demand Cost: A charge levied by your utility for the capacity to meet your power needs at any given time. Peak demand is the highest demand level required over a set period of time and is calculated by continuously monitoring demand levels. Demand is usually billed based on peak power, but charges such as facility charges and other fees billed per kW can also be included in incremental demand cost. If your utility bills one set rate for all power needs, this value is used as the incremental demand cost.

Incremental Energy Cost: The cost of one more unit of energy, at current use. This cost is usually taken from your utility rate schedule. When all large meters are on the same rate schedule, the incremental energy cost is the cost from the highest energy tier, or tail block. To further clarify this method: if a facility is charged $0.05/kWh up to 100,000 kWh, and $0.03/kWh over 100,000 kWh and they are consistently buying over 100,000 kWh each month, any energy savings will be calculated using the $0.03/kWh cost.

Low Power Factor Charge: Most utilities penalize customers whose power factor is below a set level, typically in the range of 95% - 97%, or kVAR greater than 40% of kW. Improving power factor may reduce both energy and power costs, however these savings are generally much less than savings from real power penalties enforced by electrical utilities.

Minimum Charge: The least amount billed by a utility at the end of the billing period regardless of use.

Power: The rate at which energy is used, expressed as the amount of energy use per unit time, and commonly measured in units of watts and horsepower. Power is specified three ways: real, reactive and total power.

Kilovolt Amperes: Kilovolt amperes are a measure of total electrical power including reactive power associated with power factor. Power is sometimes billed by kVA.

kVAR Charge: A charge based on reactive power. High reactive power or kVAR can reduce the capacity of lines and transformers to supply kilowatts of real power, causing additional expenses for the electrical service provider. Electrical rates may include charges for kVAR that exceed a normal level. These charges allow the supplying utility to recover some of the additional expenses caused by high kVAR conditions, and encourage customers to correct this condition.

Rate Schedules: Another term for tarrifs, specify billing procedures and set forth costs for each service offered. The state public utility commission approves public utility tariffs. For example: an electric utility will set a price or schedule of prices for power and energy and specify basic and PF charges. A natural gas utility will specify cost to supply or transport gas and include costs such as price per therm, basic charge, minimum charges and other costs. Current rate schedules can often be found online at the utility's website. If you think you belong on a different rate schedule, consult your utility representative.

Reactive Power: Reactive power is measured in kilovolt-amps reactive (kVAR). Reactive power can result from the need to excite the magnetic field of an induction motor or other inductive load. This component does no useful work and is not registered on a power meter. However, it does contribute to the heating of generators, transformers, wiring, and transmission lines and constitutes an energy loss for your utility.

Real Power: Real power does useful work and is measured in kilowatts (kW).

Pickup Costs: The cost charged by a waste utility for each pickup of waste or recycling. This charge is usually applied when the utility is working on an "on call" basis. Pickup costs can also be a flat rate for a certain number of pickups per month.

Power Factor: The ratio of real power to total power. Power factor is the cosine of angle θ between total power and real power on the power triangle.

Tariff: See *Rate Schedules*.

Therm: A unit of energy typically used for natural gas. (1 therm = 100,000 Btu)

Transportation: The movement of customer-owned natural gas (typically purchased from a 3rd party) from the pipeline receipt point(s) to a customer site through a natural gas utility's distribution network.

Total Power: Total power is made up of two parts; *real power* and *reactive power*.

MOTORS
APPENDIX

1. OVERVIEW

Motors account for the majority of electrical energy consumption. They are often used to power fans, pumps, and conveyors.

2. GLOSSARY

To evaluate motor systems it is important to understand key terms and concepts. The following section presents common terms you are likely to encounter regarding a motor system.

AC Motor: A type of electric motor that operates using alternating current (AC).

Alternating Current (AC): A current in which polarity and current direction is reversed at regular intervals. In the United States, the standard is 60 cycles per second.

Armature: The part of a motor in which a current is induced by a magnetic field.

Bearing: A device to reduce the friction between two rotating parts.

Brush: A device inside DC motors that transfers power from a rotating object.

Capacitor: A device that stores an electrical charge under high voltage potential and releases it under low voltage potential.

Centrifugal Switch: A type of switch that operates using the centrifugal force created by a rotating object.

Direct Current (DC): A type of current in which polarity remains fixed and current travels through a conductor in a single direction.

Dual Voltage Motor: A type of three-phase motor that operates on multiple voltage levels.

Electric Motor: A device that converts electrical energy into mechanical energy.

Frame: A code given to a specific motor frame size and type.

Full Load Amps: A measure of amps a motor draws under full load.

Generator: A device that converts mechanical energy into electrical energy.

Grounded: When a device is connected to a neutral body such as the earth that can absorb electrical energy.

Horsepower: Horsepower (HP) is a measure of power.

Induction Motor: A type of AC motor that use electrical current to induce rotation in the coils.

Load Factor: A description of actual motor load and output power as a percentage of full load power.

Magnet: A device or object that creates a magnetic field.

Magnetic Flux: The area around a magnet that produce attraction and repulsion forces.

Motor Nameplate: A plate attached to a motor specifying motor characteristics.

NEMA: National Electrical Manufacturers Association

Output Shaft: The part of a electric motor that transfers the mechanical energy from the rotor to the end use.

PE Motors: Premium Efficiency Motors as defined by NEMA.

Phase Displacement: The separation of the phases in a poly-phase motor.

Power Factor: The ratio between real and apparent power.

Reactance: The resistance to flow of alternating current due to inductance.

Resistance: The opposition to current flow.

Rotor: The rotating part of a motor.

RPM: Revolution per Minute

Single Voltage Motor: A type of three-phase motor that operates using one voltage level.

Single-Phase Motor: A type of motor that uses a single phase of alternating current to operate.

Slip: The difference between a motor’s synchronous speed and its speed at any particular load.

Stator: The stationary part of a motor.

Three-Phase Motor: A type of motor that operates using three phases of alternating current.

Torque: A force that produces rotation.

Transformer: A device that increases or decreases voltage in a circuit.

Volts: Volts (V) is a measure of the electrical potential difference between two points.

3. EQUIPMENT

To evaluate motor systems it is important to be able to identify the type of equipment in use, and understand generally how that equipment works. The following section describes common equipment encountered in a motor system along with important details.

3.1 AC Motors

Alternating current motors can broadly be broken down into two categories; single phase and three-phase (poly-phase). Generally, fractional horsepower motors operate on single-phase; motors larger than 7.5 horsepower on three-phase; and motors in the 1.0 to 7.5 horsepower range may be either single or three phase. Usually the three-phase motor is preferred if three-phase electricity is available. They are more efficient, simpler in design, easier to start, less costly to maintain, and have a lower first cost than single-phase motors.

3.1.1 Poly-Phase Motors

The most common type of poly-phase AC is three-phase. Three-phase AC consists of three separate phases of alternating current with equal frequency and amplitude, but differing in phase by one-third of a period. Unlike single-phase motors, this allows a constant torque to be applied during a given period of time, increasing motor and equipment life while reducing maintenance costs. Three-phase AC motor types can be categorized as follows:

- **Squirrel-Cage Induction Motor –** The most common type of three-phase motor is the squirrel-cage induction motor due to its simple construction and ease of maintenance. The squirrel-cage motor is a constant speed motor; the poly-phase current produces a rotating magnetic field in the stator which causes the rotor to spin.

- **Wound Rotor Induction Motor –** Similar to the squirrel-cage motor, the wound rotor motor uses insulated coil rotor windings connected to a slip-ring. Brushes are used to provide a variable resistance to the coils, varying the resistance varies the motor speed making these motors ideal for applications that require varying speeds.

- **Synchronous Motors –** Synchronous motors vary somewhat from induction motors as there is no slip, the motor will operate at the same speed as the rotating stator field which is dependent on the number of poles and AC frequency. A synchronous motor will operate at the same speed until the load increases such that the motor cannot handle the load, at which point the motor speed decreases abruptly. They are difficult to maintain and expensive, hence seldom used in industry.

Three-phase motors can also be divided into four separate NEMA classifications according to starting torque and current. The four NEMA design classifications are as follows:

- **Design A –** These are specific use motors that have a higher than normal starting torque as compared to the other classifications.

- **Design B –** These are general purpose motors that work well with variable speed drives. The design class B induction motor has a normal starting torque and current. They are the most common type of class used in industry.

- **Design C –** These motors have a high starting torque, normal starting current and low slip. They are typically used in applications with high starting loads.

- **Design D -** The design Class D motor also has a higher starting torque than the Class B motor, but it achieves this with very little additional starting current. The price paid is in greatly reduced efficiency.

3.1.2 Single-Phase Motors

Since single-phase induction motors do not employ a rotating magnetic field like three-phase motors, it is necessary to employ some sort of starting device. Because the starting device is designed to operate at 60 Hz, a variable speed drive should not be used as it will cause motor failure. Single-phase induction motors can be classified by the method used to start the motor as follows:

- **Split-Phase Motors -** These have a low starting torque, a high starting current, and tend to be noisy. They have a lower initial cost than other types, but are infrequently used when power requirements exceed 0.5 horsepower.

- **Capacitor-Start Motors -** These have a high starting torque and high efficiency but also tend to be noisy. These are also called capacitor-start, induction-run motors.

- **Permanent-Split Capacitor Motors -** These are quiet, but also have a low starting torque and low efficiency.

- **Capacitor-Start, Capacitor-Run Motors -** These have both good running and starting characteristics, high efficiency, and are relatively quiet. They also have a higher initial cost than other types. Most single-phase motors larger than 1.0 horsepower are of this type.

There are four common types of AC motor enclosures; totally enclosed air over (TEAO), totally enclosed non-ventilated (TENV), totally enclosed fan cooled (TEFC), and open drip proof (ODP).

3.2 AC Motor Controls

AC motors will operate as described by their NEMA characteristics given their design type. In order to instantaneously control motor speed a Variable Speed Drive (VSD) must be used. A VSD works by varying the frequency of alternating current supplied to a motor while maintaining a constant voltage. Because most AC motors operate at a speed relating to the frequency of the current, varying the frequency will also vary the speed. VSDs are particularly useful in applications with varying speed related demands. A VSD can be installed with various sensors and controls so that it can automatically match motor speed to actual demand reducing associated energy consumption.

4. PERFORMANCE RELATIONSHIPS

To evaluate motor systems it is important to be able to understand the relationships affecting the system performance, efficiency and effectiveness. The following section presents common equations and relationships required to evaluate motor systems.

4.1 Load Factor

Motor load factor, also called motor loading, describes output power as a fraction of the nameplate horsepower. A motor with real power output greater than its nameplate power is said to be overloaded. The load factor is greater than 1.0. The service factor expresses a safe overload limit, this is typically around 1.15. If a motor runs overloaded (above the service factor) for a sustained period of time, it will overheat and permanent damage may result. Using input power measurements the motor loading can be expressed as:

$$LF = \frac{P_i}{P_{ir}} \times 100\% \qquad \text{(Eq. 1)}$$

where

LF = Load factor, output power as a percentage of rated power
P_i = Measured power, in kW
P_{ir} = Input power at full-rated load, in kW

Another method for determining load factor when only amperage measurements are available is the current load estimation method. Because the amperage draw of a motor is approximately proportional to the load a simple relationship can be used to relate the two. This method isn't as accurate as the input power method and should only be used if motor load is above 50 percent. Below 50 percent load, due to degrading power factor, the relationship between current and motor load becomes increasingly non linear. Using line current measurements the motor loading can be expressed as:

$$LF = \frac{I}{I_r} \times \frac{V}{V_r} \times 100\% \qquad \text{(Eq. 2)}$$

where

LF = Load factor, output power as a percentage of rated power
I = Measured RMS current, mean of all three-phases in amps
I_r = Nameplate rated current, in amps

V = Measured RMS voltage, mean of all three-phases in volts
V_r = Nameplate rated voltage, in volts

Another method for estimating load factor is the slip method. The synchronous speed of a motor is dependent on the number of poles and frequency of the alternating current. The actual speed of a motor is less than the synchronous speed due to slip. The amount of slip is directly proportional to the motor load. The slip method is only recommended when operational speed is the only available data set. Using the slip method the motor loading can be expressed as:

$$LF = \frac{S_s - S}{S_s - S_r} \times 100\% \qquad \text{(Eq. 3)}$$

where

LF = Load factor, output power as a percentage of rated power
S_s = Synchronous speed, in rpm
S = Measured speed, in rpm
S_r = Nameplate full-load speed, in rpm

The synchronous speed of a motor can be expressed as:

$$S_s = \frac{2 \times f}{Poles} \times \frac{60\,\sec}{1\,\min} \qquad \text{(Eq. 4)}$$

where

S_s = Synchronous speed, in rpm
f = Frequency of the applied voltage, in Hz
$Poles$ = Number of poles in the motor

4.2 Power

Motor input power is the real electrical power delivered to the motor. Note that it does not include reactive power. There are two common methods for measuring input power. The first is to measure it directly with a watt meter, clamp-on type. The second is to measure it indirectly using a power factor meter, voltmeter, and ammeter. Using the second method three-phase motor power can be expressed as:

$$P_i = V \times I \times PF \times \sqrt{3} \times \frac{1kW}{1,000W} \qquad \text{(Eq. 5)}$$

where

P_i = Input power, in kW
V = Measured RMS voltage, mean of all three-phases in volts
I = Measured RMS current, mean of all three-phases in amps
PF = Part-load power factor, as a decimal

For single phase, motor power can be expressed as:

$$P_i = V \times I \times PF \times \frac{1kW}{1,000W} \qquad \text{(Eq. 6)}$$

where

P_i	=	Input power, in kW
V	=	Measured RMS voltage, in volts
I	=	Measured RMS current, in amps
PF	=	Part-load power factor, as a decimal

If input power cannot be obtained from measurement, it can be estimated from the nameplate horsepower for single or three-phase motors. Full-rated load power can be expressed as:

$$P_{ir} = \frac{HP_r}{\eta_{fl}} \times \frac{0.7457kW}{1hp} \quad \text{(Eq. 7)}$$

where

P_{ir}	=	Input power at full-rated load, in kW
HP_r	=	Nameplate rated horsepower, in hp
η_{fl}	=	Efficiency at full-rated load as a decimal

Similarly part-load power can be expressed as:

$$P_i = \frac{HP_r \times LF}{\eta_{fl}} \times \frac{0.7457kW}{1hp} \quad \text{(Eq. 8)}$$

where

P_i	=	Input power, in kW
HP_r	=	Nameplate rated horsepower, in hp
LF	=	Load factor, output power as a percentage of rated power
η_{fl}	=	Efficiency at full-rated load as a decimal

4.3 Efficiency

The function of an electric motor is to convert electrical power to mechanical power. Electric motors generally are very efficient at accomplishing this. However, no electric motor can convert all of the electric power input to rotational mechanical power. The lost electrical power ends up as waste heat due to friction, resistance, etc. Typical motor losses can be categorized as follows:

- **Stator and Rotor Losses (50 – 65%) -** These result from the resistance to current through the windings and/or squirrel cage. These losses in an energy-efficient motor are reduced by increasing the amount of conductor used to make the windings or squirrel cage. New and better insulation has made it possible to increase the amount of conductor without increasing the size of the motor or compromising insulation value.

- **Core Losses (15 – 20%) -** These are due to hysteresis and unwanted eddy currents. Energy-efficient motors are made from more expensive metal alloys with better magnetic properties to reduce hysteresis losses. The cores are more finely laminated to reduce eddy current losses.

- **Stray Load Losses (10 – 15%) -** These result primarily from compromises in the manufacturing process. For example, the width of the air gap between the core and the stator is critical for good motor efficiency. Air makes a poor magnet so the wider the air gap, the greater the losses. Energy-efficient motors generally have narrower air gaps to reduce stray losses; however, it costs more to build motors with tighter tolerances.

- **Friction and Windage Losses (5 – 10%) -** These are due to friction in bearings and the drag of moving air. In an energy efficient motor, low friction bearings are used. In a fan-cooled energy-efficient motor, windage losses are reduced by better fan design.

Motor efficiency is the ratio of the mechanical power output to the electrical power input and can be expressed as:

$$\eta = \frac{P_o}{P_i} \times 100\% \qquad \text{(Eq. 9)}$$

where

η = Efficiency, as a percentage
P_o = Output power, in kW
P_i = Input power, kW

The efficiency of a motor may also be less than its full-load efficiency, particularly if it is over sized. Determining if a motor is over sized requires knowing the power input and either the power output or the motor losses. Unfortunately, both output power and motor losses are difficult, and often impractical, to measure directly in the field. There are two methods to estimating motor efficiency:

An upper limit to motor efficiency can be estimated by measuring the real power input using a power meter. Measure power input first under normal operating load and then under no load. An upper limit to efficiency can then be estimated using the following relation:

$$\eta < \frac{P_i - P_{nl}}{P_i} \times 100\% \qquad \text{(Eq. 10)}$$

where

η = Efficiency, as a percentage
P_i = Input power, kW
P_{nl} = No-load power, in kW

The assumption made is that motor losses are at least equal to the power input under no-load conditions. Losses exceed no-load power at higher loads; therefore this estimate is an upper limit to motor efficiency. Actual efficiency is likely to be less. The error increases with increasing load factor so that this method is more accurate when the load factor is less than 25 percent. In order to measure the input power under no-load conditions, the motor must be disconnected from its load. In some cases this will require only that a belt or coupling be temporarily removed. In other cases it will be too inconvenient or time consuming.

A second method for estimating motor efficiency is from a motor performance curve chart. Different motors will have different curves. The differences occur primarily because of the motor type and nameplate horsepower. Some manufacturers will provide curves on request. However, the curve was probably developed in a test laboratory with nearly ideal rather than field-operating conditions so the actual operating efficiency will usually be less than the rated efficiency. Typically, motors are designed to run at 50% to 100% of rated load with a maximum efficiency around 75% of rated load. Below 50% of rated load, the efficiency tends to drop dramatically.

4.4 Premium Efficiency

In recent years there has been a significant effort by major motor manufacturers to improve motor efficiency. The National Electrical Manufacturers Association (NEMA) has developed and implemented several standards and procedures for defining and testing motor efficiency. The result is that motors may now be specified as premium efficiency motors.

NEMA Standards Publication MG 1-2006 defines two types of efficiency and describes a method for indexing the efficiency on the motor nameplate. The nominal efficiency of a motor is the efficiency that 50 percent of a given manufacturer's motors exceed. The minimum efficiency is the lowest efficiency that could be expected. Further, the nominal efficiency is to be stamped on the motor nameplate.

4.5 Power Factor

Similarly to part-load efficiency, part-load power factor decreases as the load factor decrease. Below 75% of full-rated load, power factor begins to drop dramatically. If part-load power factor cannot be measured or determined from performance curves it can be estimated using the following expression:

$$PF_{pl} = PF_r \times \left(0.728 + \left(\frac{0.4932}{FLA_p} \right) - \left(\frac{0.2249}{FLA_p^{\ 2}} \right) \right) \qquad \text{(Eq. 11)}$$

where

PF_{pl} = Part-load power factor, as a percentage
PF_r = Full-load power factor, as a percentage
FLA_p = Percent of full-load amps, as a decimal

Power factor is related as a function of the percent full-load operating amperage. The expression approximates motor performance data taken from General Electric publication #GEP-500G (3/87).

4.6 Phase Unbalance

The voltage and current of each phase in a three phase system should be of equal magnitudes. Phase unbalances can result in increased distribution losses, decreased motor efficiency and reduced motor life. Voltage unbalance should be less than 1% and never more than 5%. NEMA defines voltage unbalance as 100 times the maximum voltage variation from average divided by the average voltage of the three phases and can be expressed as:

$$V_{un} = \frac{V_{avg} - V}{V_{avg}} \times 100\% \qquad \text{(Eq. 12)}$$

where

V_{un} = Voltage unbalance, as a percentage

V_{avg} = Measured RMS voltage, mean of all three-phases in volts
V = Measured RMS voltage, of single phase in volts

Current unbalance can be caused from voltage unbalance and should not exceed 10%. NEMA defines current unbalance as 100 times the maximum current variation from average divided by the average current of the three phases and can be expressed as:

$$I_{un} = \frac{I_{avg} - I}{I_{avg}} \times 100\% \qquad \text{(Eq. 13)}$$

where
I_{un} = Voltage unbalance, as a percentage
I_{avg} = Measured RMS voltage, mean of all three-phases in volts
I = Measured RMS voltage, of single phase in volts

5. OPPORTUNITIES

In any motor system, opportunities for saving energy arise from either reducing the horsepower required or by increasing the system efficiency.

5.1 Motor and Transmission Efficiency

5.1.1 Replace standard efficiency motors with NEMA premium efficiency motors

NEMA premium efficiency motors operate at higher efficiencies than other motors. This will reduce energy consumption especially in applications with larger motors or high use factors. Even if specific motors have been identified as targets for replacement with efficient motors it may not be economical to replace them immediately. In such cases it is a useful strategy to mark them so it is clear that an efficient motor should be used when replacement is required for other reasons.

5.1.2 Replace oversized motors

Motors consume the least amount of energy when they operate at their highest efficiency. For most motors, this is from 75% to 110% of their rated load. As the motor loading drops below 50%, the efficiency and power factor drops rapidly. It is common for motors to be progressively upsized in a facility as they are replaced. If a motor of the same size is not available, the next size up is installed - just to be on the safe side. If a motor consistently operates at less than half of full load, then it is not operating efficiently and is a candidate for downsizing. Before downsizing a motor verify that if will not be loaded beyond its capacity at some point in it operation.

5.1.3 Replace standard V-belts with notched V-belts

The slightly higher cost of notched V-belts should be offset by an increased life expectancy. Notches on the inside radius of the belt reduce energy loss and heat generation caused by compressing and decompressing the belt as it arcs around the sheave.

5.1.4 Match motor operating speeds

Some applications such as pumps and fans are extremely sensitive to operating speed. Small increases in operating speeds can result in large increases in motor load and energy consumption. To maintain efficiency, match motor full-load operating speeds to equipment.

5.2 Motor Controls

5.2.1 Use variable speed drives where appropriate

If loads vary significantly or another mechanism for control is currently in use, it may be cost effective to install a variable speed drive. This will allow the motor to vary speeds to match demand, reducing energy consumption. Some common instances where VSDs will typically payback include:

- **DC Generator Sets** - Before the advent of relatively inexpensive solid state variable speed drives, DC Generator sets where commonly used to achieve variable speed control and to provide high start up torque on a piece of equipment. Solid state VSD's are typically more efficient and will provide soft starting of equipment.

- **Eddy Current Drives** - Eddy current drives are another older and less efficient method of achieving variable speed control. Eddy current clutches can be high maintenance items, replacement parts are expensive and difficult to locate.

5.2.2 Consider load shedding

Turning motors off while they are not in use can save energy. This can be done manually or through use of controls. The maximum number of on/off cycles allowed per hour should be considered when determining if a motor is a candidate for load shedding. Common instances of load shedding include:

- **Manually reduce equipment operation time** - Turn off equipment during lunch and breaks, or other times when it is not required. This measure is only as reliable as the operator(s)

- **Interlock equipment with a related process -** If a particular piece of equipment is dedicated to a specific process that requires additional equipment, the equipment can be interlocked with the process so all will be turned off when the operator turns off the process.

- **Operate equipment such as a grinder in batches then shut off -** A piece of equipment like a grinder may run continuously although material only runs through it occasionally. An alternative approach with no installation cost is to allow material to collect and assign someone to periodically turn it on to process that material in batches. If material collection is left unmonitored, the collection bin can overflow requiring additional labor for clean up. Jamming problems could also develop. Batch processing also has potential for increasing demand charges if the equipment is more heavily loaded.

- **Automatically control equipment operation time** - Install timers, level sensors, material sensors, or other controls for automatic operation and/or to shut off equipment as required. For example: Install material sensor on equipment such as a grinder. Set it to turn on with appropriate accumulation of material and turn off after allowable idle time. Care must be taken to avoid creating a safety hazard.

5.3 Power Quality

5.3.1 Maintain voltage levels

Take care to operate motors at their designed nameplate voltages. Operating motors at voltages other than they were designed for can reduce efficiency, power factor and service life.

5.3.2 Minimize phase unbalance

An unbalanced three-phase system can increase distribution losses and reduce motor efficiency and service life. Common causes for phase unbalance include excessive single phase loads, different cable sizing, faulty circuits, shorted phases to ground, and cable insulation damage.

5.3.3 Maintain high power factor

Not only does a low power factor commonly incur a charge from utility companies but it can also increase distribution system losses. Low power factor is commonly caused by induction motors operating at less than full capacity. Consider installing capacitor banks at problem areas.

5.3.4 Reduce distribution losses

Poor grounding, shorts to ground and bad connections can induce energy losses while also presenting substantial safety hazards. Undersized cables can increase line resistance resulting in line losses. Facility wiring should be regularly checked and maintained to avoid future complications.

FANS AND BLOWERS
APPENDIX

1. OVERVIEW

Fans and blowers are primarily used for either material handling or ventilation. They are typically powered by electric motors thus some considerations regarding fans and motors may overlap.

2. GLOSSARY

To evaluate fan and blower systems it is important to to understand key terms and concepts. The following section presents common terms you are likely to encounter regarding fan or blower systems.

Absolute Pressure: Atmospheric pressure added to the gauge pressure.

Affinity Laws: A set of relationships that predict revised pump operation with changes in fan speed or dimensions.

Air Horsepower: Air Horsepower typically refers to the total power delivered to air by a fan as a function of flow and change in pressure.

Atmospheric Pressure: Pressure that results from the weight of air in the Earth's atmosphere. At sea level, atmospheric pressure is 14.7 psi.

Backpressure: Typically refers to pressure that must be overcome to induce flow such as the pressure on the discharge side of the fan.

Best Efficiency Point (BEP): The Best Efficiency Point is the operating point on a fan's performance curve that the fan operates most efficiently.

Brake Horsepower (bhp): Brake horsepower typically refers to mechanical power available in a motor's output shaft or required at the input shaft of a fan. (Note: if there is a mechanical loss between the two such as occurs in a belt drive, the motor bhp will need to be greater than the fan bhp in order to overcome this loss.)

Capacity: For fans, capacity is typically defined as Fluid flow measured in volume per unit time.

Close Coupled: A fan impeller mounted directly on the motor shaft.

Deadhead: A condition in which a fan can develop no flow because the pressure required to induce flow is greater than the fan can develop.

Density: A measure of the mass of a unit volume of a fluid often expressed in lb/in^2 or g/cm^2.

Efficiency: The power an energy conversion system such as a fan develops divided by the power it requires.

Free Delivery: The operating condition of maximum fan delivery at which static pressure across the fan is zero.

Fluid: Material that assumes the shape of its container, either liquid or gas.

Gauge Pressure: A measure of pressure using atmospheric pressure as the zero reference.

I.D: Inside Diameter (I.D.)

I.S.O: The International Standards Organization sets pump and seals standards for the metric community.

Impeller: A component in a centrifugal fan that attaches to the end of the shaft to impart energy to the fluid being handled.

O.D: Outside Diameter (O.D.)

Specific Gravity: A measure of the mass of a unit volume of a fluid compared to water.

Standard Air: Air at a temperature of 70^{o}F dry bulb and a barometric pressure of 29.92 in. of mercury and a barometric pressure of 0.075 lbs/cu. ft.

Static Pressure: Apparent fluid pressure that does not include velocity pressure.

System Curve: A curve describing pressure required for any particular flow in a ducting network. The curve will initiate at the static pressure point when there is now flow and increase in proportion to the square of the flow. The fan will operate on the intersection of the system curve and its fan curve.

Tip Speed: The circumference of the fan wheel times the RPM of the fan, expressed in ft/min, also referred to as peripheral velocity.

Total Pressure: The sum of static pressure and velocity pressure.

Vacuum: Any pressure less than atmospheric.

Velocity Pressure: Pressure due to fluid velocity that is measured by stalling fluid flow.

Wheel: The fan wheel is the structure that physically holds the fan blades in place and transfers the mechanical rotational energy from the shaft to the blades.

3. EQUIPMENT

To evaluate fan and blower systems it is important to be able to identify the type of equipment in use, and understand generally how that equipment works. The following section describes common equipment encountered in a fan or blower system along with important details.

3.1 Fans

Despite the wide range of types and sizes, fans can generally be classified into two categories based on the manner in which they introduce energy to the working fluid. Although both centrifugal and axial fans can be used for a number of applications and have overlapping output characteristics, centrifugal fans are more common due to their ability to generate relatively high pressures at high efficiencies.

3.1.1 Centrifugal Fans

Centrifugal fans produce airflow by imparting kinetic energy to a fluid. This is generally done by using a rotating impeller which accelerates the fluid. As the fluid exits the fan housing it goes through a diffuser that converts kinetic energy into a pressure increase. Centrifugal fans have a variable flow/pressure relationship which is described by a fan performance or characteristic curve. Centrifugal fans have the benefit of being able to produce high pressure at high efficiencies while also withstanding the harsh conditions of material handling tasks. Centrifugal fans can be categorized based on their relative fan blade style, common types of centrifugal fans are described below.

- **Forward Curved:** Forward curved fans feature blades that curve in the direction of the wheel rotation. They are typically used in small packaged applications because of their relatively compact size and ability to operate at low impeller speeds resulting in reduced noise levels. The shape of the fan blades lends itself to imparting velocity over pressure to the air stream making them useful in low to medium flow and low pressure applications. Limited to clean side applications, forward curved blades are built lightly and cannot withstand high pressures or harsh environments. Efficiencies commonly range between 45% and 65%, making them undesirable for large applications that would require large power inputs. Forward curved fans also have a power curve that steadily increase with air flow as the fan approaches free delivery; this requires careful motor selection to avoid overloading and damaging the driver.

- **Radial:** Radial fans feature blades that extend radially outward perpendicular from the axis of rotation with no curve or pitch. The simplicity of the blade design allows them to be fabricated locally at a lower cost. This type of fan blades is characteristically rugged, and the flat blade shaped reduces material build up during operation. Because of this, radial fans are typically used in material handling applications with high particulate streams including dust, wood chips, and metal shavings. The ability to develop higher pressures only lends itself further the material handling applications. While not the most efficient type of fan blade, typical efficiencies can be expected to range from 50% to 65% which is acceptable for most applications.

- **Radial Tip:** Radial tip fans have the same basic design as radial blades only with a slight angle of attack between the blades and incoming air. This allows for slightly increased efficiencies ranging from 60% to 75%. As a cost to the increased efficiencies, radial tip fans have slightly reduced material handling characteristics which limit them to small nonabrasive particulates in moderate concentrations.

- **Backward Curved:** Backward curved fans feature fan blade tips that gradually slope backwards, opposite to the direction of the wheel. They can handle some dirty applications although are limited to very small non sticky particulates such as dust. With a peak efficiency of 80%, backward curved fans are very efficient, only out done by airfoil fans.

- **Airfoil:** Airfoil fans feature airfoil shaped blades that slope backward away from the direction of rotation. They represent the highest efficiency of any style centrifugal fans with efficiencies peaking at 85%. They are however strictly limited to clean side air applications and can only be used in dirty settings if protected by a bag-house or filter. They also require careful maintenance due to their tighter clearances and thinner blade construction which makes them susceptible to blade erosion.

3.1.2 Axial Fans

Axial fans produce airflow by imparting kinetic energy to a fluid. Differing from centrifugal fans, this velocity is created axially as air passes through the impeller with no portion of the velocity being created by centrifugal forces. They main advantages to axial fans are their low cost, compactness and ability to operate in the reverse direction. They are typically used in ventilation and exhaust applications for those reasons. Axial fans must rotate at greater speeds than comparable centrifugal fans to develop the same airflow. This generally makes axial fans nosier; however the noise is of a higher pitch so it doesn't travel nearly as far as the lower pitch rumble of centrifugal fans.

- **Propeller:** These are low pressure, high capacity fans that are seldom applied in applications requiring anything but circulatory or ventilation airflow. They are very simple in construction and design making them inexpensive but they are also very inefficient as a result. Unlike most fans their power requirements decrease with increased airflow reaching maximum efficiency near free delivery conditions.

- **Tubeaxial:** A slightly improved and more complex design of a propeller fan is the tubeaxial fan. It is essentially a propeller fan located within a tube or ducting. Due to the improved and more control flow conditions these fans offer slightly improved efficiencies and pressure outputs than standard propeller fans.

- **Vaneaxial:** Refined even further from the tubeaxial is the vaneaxial fan which is a tubeaxial fan with outlet vanes that improve airflow patterns by straightening the airflow, further converting kinetic energy into pressure. While still only operating at low pressures, vaneaxial fans can achieve much higher efficiencies than other types of axial fans.

3.2 Prime Movers

Fans are most commonly driven by AC electric motors due to their low operating cost and high reliability. In some instances, DC electric motors or combustion engines are also used. Correct selection and sizing of the prime mover can have a substantial effect on system performance and operating costs. More information regarding electric motors and control strategies can be found in the Motors Appendix.

3.3 Ducting

Ducting is used to transfer the working fluid from the fan to the end uses and vice-versa. Flow resistance and duct diameter are inversely related such that an increase in duct size will reduce flow resistance and pressure losses. Correctly sizing the distribution system components can greatly reduce lost energy due to these added resistances and friction losses. Larger ducts are more expensive and take up more space so there is a trade off that must be considered when sizing ducting.

3.4 Dampers

Dampers are devices that control airflow by blocking the ducting passage. They are commonly located at either the inlet or outlet of a fan. Typical styles include but are not limited to parallel dampers, opposed dampers and variable inlet vane dampers. They are typically used in applications were variable flow is sometimes required although they are often misapplied and used to correct for an oversized fan. A damper that is partly or mostly closed in most situations is often an indicator that energy savings may be available.

4. PERFORMANCE RELATIONSHIPS

To evaluate fan and blower systems it is important to understand the relationships affecting the system performance, efficiency and effectiveness. The following section presents common equations and relationships required to evaluate fan and blower systems.

4.1 Pressure

The pressure of a fluid can be thought of as being equivalent to a vertical column of water which, due to its weight, exerts a force equal to the pressure in question. In fan systems, the height of this column is commonly expressed in terms of inches of water. The height of a column of fluid corresponding to any specific pressure is dependent on the weight of the fluid and can thus be expressed as:

$$H = \frac{p_s \times g_c}{\rho \times g} \qquad \text{(Eq. 1)}$$

where

H = Static head, in feet
p_s = Static pressure, in lb_f/ft^2
g_c = Dimensional constant ($32.2\ lb_m\text{-}ft/lb_f\text{-}sec^2$)

ρ = Fluid density, lb_m/ft^3
g = Acceleration of gravity (32.16 ft/sec^2)

Static pressure is related to back pressure due to flow resistance in the ducting network and end of line pressure.

Velocity pressure is related to the energy of a fluid that can be attributed its motion at some velocity. Velocity pressure can be expressed using the following formula:

$$p_V = \rho \left(\frac{V}{1,096.2} \right)^2 \quad \text{(Eq. 2)}$$

where

p_v = Velocity pressure, in inches of water
V = Fluid velocity, in fpm
ρ = Fluid density, lb_m/ft^3

Total pressure (p_t) is the sum of static pressure and velocity pressure. Total pressure can be expressed using the following formula:

$$p_t = p_s + p_V \quad \text{(Eq. 3)}$$

where

p_t = Total pressure, in inches of water
p_s = Static pressure, in inches of water
p_v = Velocity pressure, in inches of water

Friction pressure loss is the pressure required to overcome the resistance to flow in ducting and fitting. It is dependent on the size and type of duct, flow rate, and fluid properties. The Darcy equation represents these friction losses and can be expressed through the following formula:

$$\Delta p_f = \frac{12\, fL}{D_h} \rho \left(\frac{V}{1,096.2} \right)^2 \quad \text{(Eq. 4)}$$

where

p_f = Friction pressure loss, in inches of water
f = Friction factor, dimensionless
L = Duct length, in feet
D_h = Hydraulic diameter, in inches
V = Fluid velocity, in fpm
ρ = Fluid density, lb_m/ft^3

Hydraulic diameter is a representation of the diameter of non circular ducts, it can be expressed through the following formula:

$$D_h = 4A / P \quad \text{(Eq. 5)}$$

where

D_h = Hydraulic diameter, in inches

A = Duct area, in inches^2
P = Perimeter of cross section, in inches

4.2 Capacity
The capacity of a fan is usually expressed in cubic feet per minute (cfm). The relationship between capacity, duct size and velocity are directly proportional. Capacity or flow rate can be expressed as:

$$Q = V \times \pi \times \left(\frac{ID}{2}\right)^2 \qquad \text{(Eq. 6)}$$

where
Q = Capacity, in cfm
V = Fluid velocity, in fpm
ID = Inside diameter of duct, in feet

4.3 Power
The work performed by a fan is referred to as the air horsepower and is a function of the total pressure and the weight of the fluid being moved during a time period. The air horsepower can be expressed as:

$$ahp = \frac{Q \times p_t \times K_P}{6{,}356} \qquad \text{(Eq. 7)}$$

where
ahp = Air horsepower
Q = Capacity, in cfm
p_v = Total pressure, in inches of water
K_p = Compressibility factor, dimensionless

The constant 6,356 is derived by dividing the number of foot-pounds for one horsepower (33,013) by the weight of one cubic foot of water divided by 12 inches per foot (5.192 pounds).

4.4 Efficiency
Brake horsepower or input power to a fan is greater than the air horsepower or output power due to mechanical and friction losses that occur in the fan. Fan efficiency is the ratio of input power to output power and can be expressed as:

$$\eta_f = \frac{ahp}{bhp} \times 100\% \qquad \text{(Eq. 8)}$$

where
η_f = Fan efficiency, as a percentage
ahp = Air horsepower
bhp = Brake horsepower

4.5 Affinity Laws
Affinity laws are relationships between several variables involved in fan performance that apply to all types of centrifugal fans. With impeller diameter held constant they can be expressed as:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \quad \text{(Eq. 9)}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \quad \text{(Eq. 10)}$$

$$\frac{ahp_1}{ahp_2} = \left(\frac{N_1}{N_2}\right)^3 \quad \text{(Eq. 11)}$$

where

Q	=	Capacity, in cfm
N	=	Fan speed, in RPM
H	=	Total head, in feet of water
ahp	=	Air horsepower

With fan speed held constant they can be expressed as:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \quad \text{(Eq. 12)}$$

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2 \quad \text{(Eq. 13)}$$

$$\frac{ahp_1}{ahp_2} = \left(\frac{D_1}{D_2}\right)^3 \quad \text{(Eq. 14)}$$

where

Q	=	Capacity, in cfm
D	=	Impeller diameter, in feet
H	=	Total head, in feet of water
ahp	=	Air horsepower

Note: affinity laws tend to bear out more reliably for speed changes than for dimensional changes.

4.6 Fan Performance Curves

A fan performance or characteristic curve graphically shows how total pressure, brake horsepower, and efficiency relate over the capacity range of the fan. They can be used to estimate unknown operating parameters or to compare a fan's theoretical performance against its actual performance.

4.7 Systems Curves

A system characteristic curve shows the relationship between flow (fan capacity) and an increasing friction and total head associated with that flow in a ducting system. Friction losses vary as a square of flow rate and the system curve forms graphically as a parabolic shape. If plotted together with the fan characteristic curve, it can be determined where the fan will operate on its curve by finding the intersection point of the two curves.

5. OPPORTUNITIES

Opportunities for energy savings in fan or blower operations are often overlooked because fans can work at abysmal efficiencies without any apparent signs of sub-optimal operation. In any fan system, opportunities for saving energy arise from either reducing the horsepower required or by increasing the system efficiency.

5.1 Fan and Distribution Efficiency

5.1.1 Operate fan at BEP

Fan and blower efficiency is very dependent upon flow and pressure, and the fan or blower's operating characteristics. For a given rpm there is one optimal operating point of flow and pressure. As the pressure changes, flow changes and operating efficiency is also affected. If system conditions have changed since the initial fan or blower selection, they may be operating at a higher rpm than is required, using more energy than optimally required. An oversized fan or blower often works continuously against a throttle or damper causing even greater inefficiencies.

- **Adjust fan speed**
  It may be possible to tune the speed of a fan or blower so it can operate more efficiently in a given system. If the fan or blower is belt driven the sheaves can be modified in order to change the rpm. A motor that operates at a different rpm may also be installed, particularly if it is oversized. Installing a VSD could also be an option. Reducing the speed of the blower or fan will not only reduce energy consumption and therefore costs but also reduce the wear and tear on the distribution piping and the fan itself by reducing the velocity of the particulates.

- **Replace fan**
  It may not be possible to achieve an acceptable efficiency on a system with a given fan or blower. New equipment that is properly selected for the task may be the best option.

5.1.2 Use higher efficiency blade type

Switching to more efficient blade type is occasional a cost effective method to increase efficiency. Sometimes other modifications to the system must be made in order to accommodate a blade upgrade. A common example is switching from a standard radial fan wheel to a radial tip fan wheel reducing energy consumption.

5.1.3 Eliminate blowers

Conveying material using air flow is convenient but not always efficient. In some cases pneumatic chip transfer can be replaced with mechanical conveyors or vibrating transfer systems. These are more efficient alternatives and work well with larger particulates.

5.1.4 Correctly size distribution system

Often as a facility expands and additional lines are needed, additional loads are placed on the distribution system. Ducts that are undersized for current capacity will result in increased pressure losses due to friction, using excessive energy.

5.1.5 Reduce load

Often a system can be modified to reduce the load placed on a fan. An example would be using different bag house filter material to reduce pressure drop across the medium increasing efficiency.

5.2 Fan Controls

5.2.1 Use variable speed drive where appropriate

One of the most common and inefficient methods to control a fan or blower is to restrict its flow. As pressure is increased flow is reduced. However, work required to deliver the reduced flow is greater than would otherwise be required. Variable Speed Drives can provide significant energy savings. Quick savings estimates vary greatly with conditions; however VSDs frequently pay off in a year or two if they replace a throttle control that operates at 60-70 percent of full flow or less most of the time. The impact on the fan or blower system due to variations in speed should be evaluated when considering this measure.

5.2.2 Use inlet vane control where appropriate

Inlet vanes are a good option for applications like dust collection systems where the air volume required changes, while the air velocity and associated pressure drop must remain relatively constant. By pre-spinning inlet air, inert guide vanes can reduce airflow without affecting the pressure the fan must overcome. They are not as efficient as VSDs in applications where system pressure can be allowed to drop with reductions in airflow. At extreme reductions in airflow (less than 30 percent) an inlet vane acts like a throttle and its efficiency drops off significantly.

5.2.3 Gate off requirements not in use

Often times dust collection systems provide suction to operations that are not in always on use. This unnecessarily increases the load on the fan , increasing energy consumption. It can be worthwhile to determine if these distribution lines can be shut off when not needed to reduce the load on the fan and bag house.

5.3 Fan Maintenance

5.3.1 Regularly test fans

Testing fan efficiency every two to three years can help ensure that fans are performing properly and that no significant losses are occurring. This can help identify worn fan blades that may need replacement.

PUMPS
APPENDIX

1. OVERVIEW

Pumps are primarily used to transfer fluids from one location to another, pressurize vessels or to provide the motive force in hydraulic systems. Most of this appendix is dedicated to the first two as served by centrifugal pumps. Positive displacement pumps such as those commonly found in hydraulic systems have unique operating characteristics that are not well described by many of the concepts presented here. Pumps are typically powered by electric motors thus some considerations about pumps and motors may overlap.

2. GLOSSARY

To evaluate pumping systems it is important to understand key terms and concepts. The following section presents common terms you are likely to encounter regarding pumps.

A.N.S.I Standard: American National Standards Institute standards. A set of specifications (envelope dimensions, etc) for pumps manufactured in the United States.

Absolute Pressure: Atmospheric pressure added to gauge pressure.

Affinity Laws: A set of relationships that predict revised pump operation with changes in pump speed or dimensions.

Atmospheric Pressure: Pressure that results from the weight of air in the Earth's atmosphere. At sea level, atmospheric pressure is 14.7 psi.

Backpressure: Typically refers to pressure that must be overcome to induce flow such as the pressure on the discharge side of the pump.

Bernoulli's Principle: States that for an inviscid flow, as the fluid speed increases, the fluid pressure decreases.

Best Efficiency Point (BEP): The Best Efficiency Point is the operating point on a pump's performance curve that the pump operates most efficiently.

Brake Horsepower (bhp): Brake horsepower typically refers to mechanical power available in a motor's output shaft or required at the input shaft of a pump. (Note: if there is a mechanical loss between the two such as occurs in a belt drive, the motor bhp will need to be greater than the pump bhp in order to overcome this loss.)

Capacity: For pumps capacity is typically defined as fluid flow measured in volume per unit time.

Cavitation: Cavitation occurs when fluid vapor bubbles form in the fluid low-pressure area and collapse in the higher-pressure area of the pump, causing noise, damage and a loss of capacity. (Note that aeration, or entrainment of air or other gasses in a fluid flow can result in similar ill effects).

Centrifugal Pump: A type pump that uses a rotating impeller to create flow by imparting kinetic energy to a fluid.

Check Valve: A valve that allows fluid to flow to travel in a single direction, generally used to protect equipment from reverse flow.

Close Coupled: A pump impeller mounted directly on a motor shaft.

Deadhead: A condition in which a pump can discharge no fluid because the head required to induce flow is greater than the pump can develop.

Density: A measure of the mass of a unit volume of a fluid sometimes expressed in lb/in^3 or g/cm^3.

Differential Pressure: The difference between a pump's outlet pressure and inlet pressure also referred to as the Pump Total Differential Pressure.

Discharge Head: The outlet pressure developed by a pump expressed as a column height of fluid that would result in that pressure at its base.

Dynamic Head: The component of total head due to fluid motion also referred to as velocity head.

Efficiency: The power an energy conversion system such as a pump develops divided by the power it requires.

Flooded Suction: This condition occurs in a pump when the fluid source is higher than the pump and the fluid flows to the pump by gravity.

Fluid: A material that assumes the shape of its container, either liquid or gas.

Friction Head: Pressure needed to overcome resistance to flow in pipes and fittings.

Gauge Pressure: A measure of pressure using atmospheric pressure as the zero reference.

Head: Pressure expressed as the column height of fluid that would result in the specific pressure at its base.

I.D: Inside Diameter (I.D.)

I.S.O: The International Standards Organization sets pump and seals standards for the metric community.

Impeller: A component in a centrifugal pump that attaches to the end of the shaft to impart energy to fluid being pumped.

Inducer: A small axial flow vane that attaches to the impeller of a centrifugal pump to increase the N.P.S.H.A.

N.P.S.H.A: Net Positive Suction Head Available to prevent cavitation of the pump.

N.P.S.H.R: Net Positive Suction Head Required to avoid pump cavitation, as specified by the pump manufacturer performance curve. N.P.S.H.R for a pump varies with the flow developed.

O.D: Outside Diameter (O.D.)

Parallel Operation: Operation of multiple pumps that discharge to a common header.

Prime: A charge of fluid required to start the pumping action of centrifugal pumps when the fluid source is lower than the pump.

Series Operation: Operation of multiple pumps that are connected with each pump discharging to the suction of the next pump.

Shut Off Head: The maximum head a pump can deliver with a given impeller diameter, speed and horsepower driver.

Slurry: A liquid that also contains solids.

Specific Gravity: A measure of the mass of a unit volume of a fluid compared to water.

Specific Speed: A number that characterizes the shape of a pump impeller.

Static Head: Head associated with end of line pressure and the elevation change of fluid being pumped.

Submersible Pump: A pump that operates only when totally submersed in the fluid being pumped. Typically powered with a waterproof motor and electrical connection.

Suction Lift: Exists when an unpressurized fluid source is below the centerline of the pump.

System Curve: A curve describing head required for any particular flow in a piping network. The curve will initiate at the static head point when there is now flow and increase in proportion to the square of the flow. The pump will operate on the intersection of the system curve and pump curve.

System Head: The head caused by friction in the piping valves and fittings.

Total Dynamic Head: Total head developed in a fluid that is pumped, defined as the sum of the Static Head and Dynamic Head. It can be found as the head at the pump's outlet minus the head at the pump's inlet.

Total Head: See Total Dynamic Head.

Vacuum: Any pressure less than atmospheric.

Vapor Pressure: The pressure at which a fluid will vaporize for a particular fluid temperature.

Vaporize: Fluid conversion from a liquid to gaseous state.

Water Hammer: Occurs in a closed piping system as a result of a rapid pressure increase. This damaging effect is usually the result of sudden starting, stopping, change of pump speed, or the opening/closing of a valve.

W.H.P: Water Horsepower typically refers to the total power delivered to a liquid by a pump as a function of flow and change in head.

3. EQUIPMENT

To evaluate pumping systems it is important to be able to identify the type of equipment in use, and understand generally how that equipment works. The following section describes common equipment encountered in pumping systems.

3.1 Pumps

Despite the wide range of types and sizes, pumps can generally be classified into two categories based on the manner in which they introduce energy to the working fluid. Although both centrifugal and positive displacement pumps can be used for a number of applications, centrifugal pumps are more common due to their simple operation, low maintenance costs, and long operating life. Centrifugal pumps also can operate over a broader range of conditions with a lower risk of damage.

3.1.1 Centrifugal Pumps

Centrifugal pumps produce a flow and head by imparting kinetic energy to a fluid. This is generally done by using a rotating impeller to increase the fluids velocity. As the fluid exits the pump it goes through a diffuser that converts kinetic energy into a pressure increase. Centrifugal pumps have a variable flow/pressure relationship which is described by a pump performance or characteristic curve. Common types of centrifugal pumps are described below.

- **End Suction Pump** – A horizontal shaft pump with an overhung impeller, flow goes in the end of the casing and out the top.

- **Vertical Turbine Pump –** A vertical shaft pump that is frequently designed to fit in a bore-hole well. The pump can have one or more impellers and diffuser bowls depending on head requirement.

- **Submersible Pump** – A submersible motor close coupled to a single stage pump that allows the entire assembly to operate fully submerged.

3.1.2 Positive Displacement Pumps

Positive displacement pumps operate by alternating between filling a cavity with fluid and displacing a given volume of fluid creating a flow and pressure. This delivers a constant volume of fluid for each cycle against varying discharge pressure. Positive displacement pumps are generally used for applications that require; low flow and high pressure, flows that must be precisely metered, and with working fluids that are highly viscous. Common types of positive displacement pumps are described below.

- **Reciprocating Pumps –** These include piston, plunger and diaphragm pumps which operate by using a alternating linear motion to displace the fluid.

- **Rotary Pumps –** These include gear, lobe, screw, and vane pumps which operate by which operate by using rotating motions to displace the fluid.

3.2 Prime Movers

Pumps are most commonly driven by AC electric motors due to their low operating cost and high reliability. In some instances, DC electric motors or combustion engines are also used. Correct selection and sizing of the prime mover can have a substantial effect on system performance and operating costs. More information regarding electric motors and control strategies can be found in the Motors Appendix.

3.3 Piping

Piping is used to transfer the working fluid from the pump to the end uses. Flow resistance and pipe diameter are inversely related such that an increase in pipe size will reduce flow resistance and pressure losses. Correctly sizing the distribution system components can greatly reduce lost energy due to these added resistances and friction losses. Larger pipes are more expensive and take up more space so there is a trade off that must be considered when sizing piping.

3.4 Valves

Valves are used to either redirect or regulate flow through the system. Flow regulating valves that either bypass or directly throttle flow are particularly inefficient and other methods of control should be considered.

4. PERFORMANCE RELATIONSHIPS

To evaluate pumping systems it is important to understand the relationships affecting system performance, efficiency and effectiveness. The following section presents common equations and relationships required to evaluate pump systems.

4.1 Head

The pressure of fluid can be thought of as being equivalent to a vertical column of the fluid which, due to its weight, exerts a force equal to the pressure in question. The height of this column is called the head and is expressed in terms of feet of fluid. The head corresponding to any specific pressure is dependent on the weight of the fluid and can be expressed as:

$$H = \frac{2.31 \times psi}{SG} \qquad \text{(Eq. 1)}$$

where

H = Head, in feet of water
psi = Pressure, in lb/in^2
SG = Specific Gravity

Static head refers to head that can be attributed to elevation back pressure due to friction base flow resistance in the piping network (friction head) and end of line pressure.

Velocity head is the energy of a fluid that can be attributed to its motion at some velocity. It is equivalent head in feet through which the water would have to fall to acquire the same velocity. Velocity head can be expressed using the following formula:

$$h_V = \frac{V^2}{2g} \qquad \text{(Eq. 2)}$$

where

h_V = Velocity head, in feet
V = Fluid velocity, in ft/sec
g = Acceleration of gravity (32.16 ft/sec^2)

Friction head is the head required to overcome the resistance to flow in pipes and fittings. It is dependent on the size and type of pipe, flow rate, and fluid properties and can be expressed using the following formula:

$$h_f = K \times \frac{V^2}{2g} \qquad \text{(Eq. 3)}$$

where

h_f = Friction head, in feet
K = Line loss coefficient
V = Fluid velocity, in ft/sec
g = Acceleration of gravity (32.16 ft/sec^2)

Total dynamic suction/discharge head is the static suction/discharge head plus the velocity head at the pump suction/discharge flange plus the total friction head in the suction/discharge line. It can be determined from the gauge reading at the suction/discharge flange, converted to feet of liquid plus the velocity head at the point of the gauge. When comparing the change in Total Dynamic Head (TDH) across a pump or any other system element the change in elevation between the two points of measurement must also be accounted for. It is common to define the total dynamic suction/discharge head on each side of the element of interest in relation to a common reference elevation such as the pump centerline. Total dynamic suction/discharge head it can then be expressed as:

$$h_{(d,s)} = H + h_g + h_V + h_f \qquad \text{(Eq. 4)}$$

where

- h_d = Total dynamic discharge head, in feet
- h_s = Total dynamic suction head, in feet
- H = Static head, in feet
- h_g = Gauge elevation relative to pump centerline, in feet
- h_V = Velocity head at gauge, in feet
- h_f = Friction head, in feet

Total dynamic head is the total dynamic discharge head minus the total dynamic suction head. It is the total amount of head the pump must overcome to provide a flow and can be expressed as:

$$TDH = h_d - h_s \qquad \text{(Eq. 5)}$$

where

- TDH = Total dynamic head, in feet
- h_d = Total dynamic discharge head, in feet
- h_s = Total dynamic suction head, in feet

4.2 Capacity

The capacity of a pump is usually expressed in gallons per minute (gpm). Because liquids are essentially incompressible, the relationship between capacity, pipe size and velocity are directly proportional. Capacity or flow rate can be expressed as:

$$Q = V \times \pi \times \left(\frac{ID}{2}\right)^2 \qquad \text{(Eq. 6)}$$

where

- Q = Capacity, in gpm
- V = Fluid velocity, in ft/sec
- ID = Inside diameter of pipe, in feet

4.3 Power

The work performed by a pump is referred to as the hydraulic horsepower or water horsepower and is a function of the total dynamic head and the weight of the fluid being pumped during a time period. The pump capacity and fluid specific gravity are commonly used instead of the actual fluid weight. The hydraulic horsepower can be expressed as:

$$whp = \frac{Q \times TDH \times SG}{3{,}957} \quad \text{(Eq. 7)}$$

where

whp	=	Hydraulic horsepower
Q	=	Capacity, in gallons per minute
TDH	=	Total dynamic head, in feet
SG	=	Specific Gravity

The constant 3,957 is derived by dividing the number of foot-pounds for one horsepower (33,013) by the weight of one gallon of water (8.34 pounds).

4.4 Efficiency

The brake horsepower or input power to a pump is greater than the hydraulic horsepower or output power due to mechanical and hydraulic losses that occur in the pump. Pump efficiency is the ratio of input power to output power and can be expressed as:

$$\eta_P = \frac{whp}{bhp} \times 100\% \quad \text{(Eq. 8)}$$

where

η_p	=	Pump efficiency, as a percentage
whp	=	Hydraulic horsepower developed in the fluid
bhp	=	Brake horsepower input at the pump shaft

4.5 Specific Speed

Specific speed is a non-dimensional index used to classify pump impellers. It is defined as the speed in revolutions per minute at which a geometrically similar impeller would operate if it were sized to deliver one gallon per minute against one foot head. The specific speed can be expressed as:

$$N_S = \frac{N\sqrt{Q}}{H^{3/4}} \quad \text{(Eq. 9)}$$

where

N_s	=	Specific speed, dimensionless
N	=	Pump speed, in RPM
Q	=	Capacity, in gpm at the BEP
H	=	Total head, in feet per stage at the BEP

4.6 Net Positive Suction Head

The Hydraulic Institute defines NPSH in feet absolute, determined at the suction nozzle and corrected to datum, less the vapor pressure of the fluid in feet absolute. NPSH is a measure of the amount of suction head present to prevent the fluid from vaporizing at the lowest pressure point in the pump. NPSH required is function of pump design while NPSH Available can be expressed as:

$$NPSH_A = P_B - V_P \pm Gr + h_V \quad \text{(Eq. 10)}$$

where

$NPSH_A$ = Net positive suction head available, in feet
P_B = Barometric pressure, in feet absolute
V_P = Vapor pressure of fluid at maximum pumping temperature, in feet absolute
Gr = Gauge reading at pump suction, in feet corrected to the pump centerline
h_V = Velocity head in the suction pipe at the gauge connection, in feet

If the NPSH Available is not sufficient to satisfy the NPSH required, cavitation will occur. Vapor bubbles and pockets will form on the suction side and then rapidly collapse on the impeller causing a rumbling noise and excessive wear on the impeller.

4.7 Affinity Laws

Affinity laws are relationships between several variable involved in pump performance that apply to all types of centrifugal pumps. With impeller diameter held constant they can be expressed as:

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \qquad \text{(Eq. 11)}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \qquad \text{(Eq. 12)}$$

$$\frac{whp_1}{whp_2} = \left(\frac{N_1}{N_2}\right)^3 \qquad \text{(Eq. 13)}$$

where

Q = Capacity, in gallons per minute
N = Pump speed, in RPM
H = Total head, in feet per
whp = Hydraulic horsepower

With pump speed held constant they can be expressed as:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \qquad \text{(Eq. 14)}$$

$$\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2 \qquad \text{(Eq. 15)}$$

$$\frac{whp_1}{whp_2} = \left(\frac{D_1}{D_2}\right)^3 \qquad \text{(Eq. 16)}$$

where

Q = Capacity, in gallons per minute
D = Impeller diameter, in feet
H = Total head, in feet per
whp = Hydraulic horsepower

Note that the affinity laws tend to bear out more reliably for speed changes than for dimensional changes.

4.8 Pump Performance Curves

A pump performance or characteristic curve graphically shows how total dynamic head, brake horsepower, efficiency, and net positive suction head relate over the capacity range of the pump. They can be used to estimate unknown operating parameters or to compare a pump's theoretical performance against its actual performance.

4.9 Systems Curves

A system characteristic curve shows the relationship between flow (pump capacity) and an increasing friction and total head associated with that flow in a pumpingsystem. Friction losses vary with the square of flow and the system curve forms graphically as a parabolic shape. If plotted together with the pump characteristic curve, it can be determined where the pump will operate on its curve by finding the intersection of the two curves.

5. OPPORTUNITIES

Opportunities for energy savings in pump operations are often overlooked because pumps can work at abysmal efficiencies without apparent sign of sub-optimal operation. In any pumping system, opportunities for saving energy arise from either reducing the hydraulic horsepower required or by increasing the system efficiency.

5.1 Pump and Distribution Efficiency

5.1.1 Operate pump at BEP

All centrifugal pumps are designed to operate at one Best Efficiency Point (BEP) on its capacity versus head performance curve. When system requirements move away from this point the efficiency of the pump deteriorates. If system conditions have changed since the initial pump selection, it may be operating away from the BEP, using more energy than optimally required. An oversized pump often works continuously against a throttle or damper causing even greater inefficiencies.

- **Adjust pump speed**
  Varying the pump speed will cause the pump to operate at a different point on a revised performance curve as expressed by the affinity laws. A variable speed drive (VSD) is one method to vary pump speed and is particularly useful when a wide range of capacities and head are required. If the pump is belt driven the sheaves can be modified in order to change the rpm. A motor that operates at a different rpm may also be installed..

- **Trim or replace impellers**
  A pump's operating characteristics can be adjusted by re-sizing the impeller. On a given system, it may be possible to achieve greater efficiency with a different pump impeller.

- **Replace pump**
  It may not be possible to achieve an acceptable efficiency on a system with a given pump. New equipment that is properly selected for the task may be the best option.

5.1.2 Avoid pump cavitation
Pump cavitation will reduce capacity, service life, and increase energy consumption. If a pump operates in cavitation mode its efficiency and effectiveness can be permanently impaired. Take care to operate pumps as intended, ensure that sufficient suction head is supplied, and consider replacing pumps that are operating at points significantly away from their intended design point.

5.1.3 Correctly size distribution system
Often as a facility expands and additional lines are needed, additional loads are placed on the distribution system. Pipes that are undersized for current capacity will result in increased pressure losses due to friction, using excessive energy.

5.2 Pump Controls

5.2.1 Use variable speed drive where appropriate
If loads vary significantly or another mechanical mechanism for control is currently in use, it may be cost effective to install a variable speed drive. This will allow the motor to vary speeds to match demand, reducing energy consumption. Be careful when applying VSDs to turbine pumps. Damaging vibrational harmonics may develop at certain operating frequencies. Be sure to avoid vibration frequencies in the VSD control profile. Some common instances where VSDs will typically offer return on the investment include:

- **Throttle contro**l - One of the most common and inefficient methods to control a pump is to restrict its flow. As the pressure is increased the flow is reduced. However, work required to deliver the reduced flow is greater than would otherwise be required.

- **Bypass control** - Although less common, bypass control can be an extremely inefficient method for controlling flow. In the best case, pump energy use is constant regardless of delivery to an end use. In the worst case, energy use increases with reduced delivery to the end use. As less flow is required at the end use, the excess is diverted to the bypass circuit and recirculated. The diverted fluid does not add any value to the finished product. The pump discharge remains at high capacity, as do the pumping costs during periods of low demand, which makes this control very costly.

5.2.2 Use on-off control where appropriate
On-off control works when a pump is maintaining a reservoir level instead of a constant flow. The pump can be set to operate only at optimum efficiency, fill the reservoir, and then shut off. This could however create excessive cycling if the pump operates close to

full capacity. It can also result in a much greater fluid velocity and associated friction loss when the pump operates if the pump is off for a significant portion of the time.

5.3 Pump Maintenance

5.3.1 Regularly test pumps

Testing pump efficiency every two to three years can help ensure pumps are performing properly and that no significant losses are occurring. Depending on the required head and flow, pumps can feasibly reach efficiencies as high as 80%. Unfortunately they are able to get the job done at abysmal efficiencies (as low as 20% efficiency) with little outward sign of inefficient operation. Guidelines for given efficiencies follow. (Note that in some combinations of flow and head, maximum possible efficiency can be below these typical values.)

- *Efficiencies Above 60%* - No action is necessary, although efficiency may be improved by adjusting impeller clearances.

- *Efficiencies Between 50% and 60%* - Adjusting the impeller to housing clearance is recommend as efficiency may increase by up to 10-15%.

- *Efficiencies Between 50% and 55%* - Damage to the impeller is likely and repair is recommended as efficiency may increase by up to 20%.

- *Efficiencies Below 50%* - Replacement is recommended in most cases, it may be caused by an improperly sized motor for the application. Consider resizing components for optimum efficiency.

SOLAR
APPENDIX

1. OVERVIEW

Solar systems are used heating or generate electricity. This is done by two main methods, either solar thermal technology or photovoltaic panels. These two different technologies will be covered in depth in this appendix. The opportunities that exist for solar thermal applications can be unique; whereas those involved in photovoltaics are the same, simple electricity generation.

2. GLOSSARY

To evaluate solar systems it is important to understand key terms and concepts. The following section presents common terms you are likely to encounter regarding a solar system.

Absorber: A material that absorbs radiation or causes it to lose energy.

Alternating Current: An electric current that reverses direction at regular intervals, having a magnitude that varies continuously in sinusoidal manner.

Amorphous Silicon: A thin-film, silicon photovoltaic cell having no crystalline structure.

Angle of Incidence: The angle that a straight line, ray of light, meeting a surface, makes with a normal to the surface at the point of meeting.

Anti-reflection Coating: A thin coating of material applied to a solar cell to reduce light reflection, thus increasing light transmission.

Azimuth: The angle of horizontal deviation, measured clockwise, of a bearing from a standard direction, as from north or south.

Blocking Diode: A semiconductor connected in series with a solar cell and a battery to prevent the battery from discharging through the cell when there is no output.

Bypass Diode: A semiconductor connected across multiple solar cells that will conduct if the cells become reverse biased. This protects solar cells from thermal destruction in case of total or partial shading of individual cells.

Concentrator: Optical components such as lenses that direct and concentrate sunlight onto a solar cell of smaller area.

Crystalline Silicon: A type of photovoltaic cell made from a slice of single-crystal silicon or polycrystalline silicon.

Direct Current: An electric current of constant direction, having a magnitude that does not vary or varies only slightly.

Direct Isolation: Sunlight directly striking a solar collector.

Incident Light: Light that shines onto the surface of as solar collector.

Insolation: The solar power density incident on a surface of fixed area and orientation, expressed in either Watts per square meter or Btu per square foot per hour.

Inverter: A device that converts Direct Current (DC) into Alternating Current (AC).

Irradiance: The direct, diffuse and reflected solar radiation that strikes a surface.

Orientation: Placement with respect to the cardinal directions, North, South, East, West.

Peak Sun Hours: The equivalent number of hours per day when solar irradiance averages 1,000 watts per square meter.

Photovoltaic: The direct conversion of light into electricity.

Rectifier: A device that converts Alternating Current (AC) into Direct Current (DC).

Solar Constant: The average amount of solar radiation that reaches the earth's upper atmosphere on a surface perpendicular to the sun's rays. This is equal to 1,353 Watts per square meter or 492 Btu per square foot.

Solar Resource: The amount of solar insolation a particular location receives, expressed in Kilowatt-hours per square meter per day.

Solar Spectrum: The total distribution of electromagnetic radiation emitted from the sun.

Tilt Angle: The angle at which a solar array is set to face the sun relative to a horizontal position.

Zenith Angle: The angle between the direction of interest (the sun) and the zenith (directly overhead).

3. EQUIPMENT AND PHYSICS

To evaluate solar systems it is important to be able to identify the type of equipment in use, and understand generally how that equipment works. The following section presents common equipment you are likely to encounter in a solar system along with important details. It is also important to know how the basic physics behind solar technology works, this is outlined below.

3.1 Photovoltaic

Photovoltaic (PV) cells utilize a special semi conductor material that silently and directly converts solar energy into electricity at the atomic level without using complex machinery usually associated with electrical generation. This is possible because of a material property known as the photoelectric effect, which allows the material to absorb photons of light and release electrons. These free electrons can then be captured resulting in a electrical current that can be used as electricity. Because the resulting electrical current is Direct Current (DC), an inverter must be used to convert it into Alternating Current (AC) before it can be used. Currently, most photovoltaic cells are manufactured from silicon although other exotic materials such as gallium arsenide are becoming more and more common. Following are the three most common types of photovoltaic systems.

3.1.1 Mono-crystalline

The majority of photovoltaic systems available on the market today are single-crystal silicon based. These are usually a uniform blue or black and are manufactured by melting highly purified silicon and crystallizing it into ingots which are sliced into thin wafers to make individual cells. These cells are backed with a metal back-plane to provide support and a electrical contact on the bottom of the cell. The top of the cell is covered with a thin metallic mesh to allow sunlight through while also providing another electrical contact. Solar radiation from the sun contains small particles referred to as photons. As these photons move into a cell and strike electrons, they dislodge the electrons and create empty spaces. The dislodged electrons move toward the top layer of the cell and into the metallic mesh as the photons continue to dislodge more electrons. If an electrical circuit is completed from the top mesh and the back-plane, the electrons will flow through the circuit creating a current. As more cells are connected to the array the current will continue to increase while the voltage remains relatively constant.

3.1.2 Polycrystalline

Polycrystalline photovoltaic cells are very similar to mono-crystalline cells in the way they are manufactured and function. The main difference is that polycrystalline cells are made from lower quality silicon resulting in reduced efficiency. This also reduces the manufacturing cost which is the main benefit over mono-crystalline cells.

3.1.3 Amorphous Silicon

Amorphous silicon photovoltaic cells, unlike mono and poly crystalline cells, have no distinct crystal structure. Instead amorphous silicon cells (thin film silicon) are made from depositing thin layers of vaporized silicon in a vacuum onto a support structure (glass, metal or plastic). Because some light passes through the top layers of the cell, multiple layers are deposited increasing the total power of the cell. Despite this, the efficiency of thin film silicon cells is around half that of its mono and polycrystalline counterpart.

3.2 Solar Thermal

Solar thermal technologies use solar radiation to provide heat for a wide range of applications including space heating, pool heating, domestic water heating, and even power generation. Solar thermal systems are generally more economically feasible then photovoltaic systems despite recent advances in PV technology. Solar thermal collectors are about five times as efficient as currently available photovoltaic panels, yet they cost about one-tenth as much. Solar collectors generally fall into one of two categories; concentrating or non-concentrating. In the non-concentrating type, the collector area is the same as the absorber area while in a concentrating type the collector area is separate from the smaller absorber area.

3.2.1.1 Non-concentrating Collectors

Non-Concentrating collectors are often used in smaller-scale production situations due to their lower cost and ease of maintenance. These systems ~~intergrate~~integrate both the collector and the absorber into the same component. This eliminates the need for solare tracking systems although they may still be used to increase the efficiency.

3.2.1.2 Flat-Plate

Flat-plate collectors are the most common type of non-concentrating collector. Flay-plate collectors consist of a absorber plate made from a thin sheet of thermally stable polymers, copper, aluminum or steel coated with a matte black finish. The matte black is used to increase the absorbance of solar radiation. The absorber sheet is commonly backed with a grid or coil of tubing that the heat transfer fluid passes through. The bottom of the panel is plated with a insulating material while the tope is covered with a translucent material to reduce heat losses. As solar radiation passes through the translucent material and strikes the absorber, it heats up. This heat is conducted into the tubing and the heat transfer fluid then transfers the heat from the absorber to a storage tank.

3.2.1.3 Evacuated Tube

Evacuated tube collectors are the most efficient type of non-concentrating collectors on the market. They are made using concentric strengthened ~~borosilicated~~borosilicate glass tubes. The outer tube is translucent, allowing solar radiation to pass through unrestricted while the inner tube is treated with a special optical coating resulting in energy absorption without reflection. The gap between the inner and outer tube is evacuated creating a vacuum, which significantly reduces heat loss due to convention and conducting, thus increasing efficiency. A heat pipe consisting of a copper tube is filled with a proprietary liquid that boils under very lower pressure and temperature situations is inserted inside the inner glass tube. As the liquid absorbs heat it vaporizes and rises to the top of the heat pipe. The heat is transferred to a common manifold through which a heat transfer fluid flower removing the heat to be used or stored. Once the heat has been transferred the liquid condenses and gravity returns it to the base of the heat pipe where the process continually repeats.

3.2.2.1 Concentrating Collectors

Concentrating collectors use optical components to reflect light collected over a large area onto the smaller absorber area. This allows for much higher operating temperatures than non-concentrating collectors increasing efficiency and cost-effectiveness. However, because light is reflected onto a focal line or point either 1-axis or 2-axis solar tracking must be used to ensure proper alignment and operation. These types of systems are often used for large hot water needs or to generate electricity.

3.3 Photon Flux

This is how many photons actually strike the solar panel; it is most commonly affected by the size and orientation of the panels.

3.3.1 Array Orientation

The power output of solar panels is greatly affected by their orientation and tilt angle to the sun. Because the suns position and angle changes in the sky depending on the time of year, solar systems are most efficient if used with a solar tracking mechanism. Static mounted systems can still provide adequate performance if optimized using sun charts to determine the best position and angle.

3.3.2 Array size

Solar panels (photovoltaics) are broken into cells which are then connected in parallel. This allows the provided voltage/flow to remain constant no matter the number of cells, this means the power output of a solar system is directly proportional to its area.

3.4 Photon Intensity

This is the amount of energy each photon contains; it is most commonly affected by the local climate and the latitudinal position of the panels.

3.4.1 Latitudinal position

Geographic locations further from the equator experience a seasonal reduction in solar radiation availability. For best performance in these locations in the panel angle is often set to the angle of the latitude, however, performance can be improved by adjusting the panel angle on a per season basis or by using a solar tracking system to continuously adjust the panels to the optimum angle

3.4.2 Climate

Local climate can significantly affect the power output of solar arrays. During the winter the sun sits lower in the sky decreasing the light intensity and length. Additionally, locations with cloudy, rainy, or snowy conditions for large portions of the year may encounter significant power decreases.

4. PERFORMANCE RELATIONSHIPS

To evaluate pumping systems it is important to understand the relationships affecting system performance, efficiency and effectiveness. The following section presents common equations and relationships required to evaluate solar systems.

4.1 Solar Position

The angle between the earth-sun line and the earth's equatorial plane is called Solar Declination angle. This angle varies with date and can be approximated using the following equations. The change in solar declination is the primary reason for our changing seasons.

$$\delta = 23.45 \sin\left[2\pi\left(284 + N\right)/365\right] \quad \text{(Eq. 1)}$$

where

N = the number of the day on the calendar year, days

The difference between apparent solar time (AST) and mean solar time (MST) for a given location due to obliquity of the ecliptic and eccentricity of earth orbit around the sun can be determined by the equation of time. The values for the equation of time are generally considered to be look up values but can be approximated by:

$$\frac{\Delta t}{\min} = 229.18\left[-0.0334 \sin\left(\frac{2\pi}{365.24}\frac{t-t_{\_}}{day}\right) + 0.04184 \sin\left(\frac{4\pi}{365.24}\frac{t-t_{\_}}{day} + 3.5884\right)\right] \quad \text{(Eq. 2)}$$

where

$t-t_{\_}$ = the relative day of the year it is

The angle of incident is the angle between the line normal to the irradiated surface and the earth-sun line. It affects the direct component of the solar radiation striking the surface and the ability of the surface to absorb, transmit or reflect solar irradiation.

$$\sin\beta = \cos\left(LAT\right)\cos\delta\cos H + \sin\left(LAT\right)\sin\delta \quad \text{(Eq. 3)}$$

$$\sin\phi = \cos\delta\sin H / \cos\beta \quad \text{(Eq. 4)}$$

$$\cos\theta = \cos\beta\cos\gamma\sin\Sigma + \sin\beta\cos\Sigma \quad \text{(Eq. 5)}$$

where

- θ = angle of incidence
- β = solar altitude
- δ = solar declination
- Σ = the angle of the absorbing surface with respect to the horizontal
- γ = surface azimuth angle
- H = number of hours from solar noon
- ϕ = solar azimuth

Apparent solar time (AST), or simply solar time, generally differs from local standard time (LST) or daylight savings time (DST).

$$AST = LST + Equation\ of\ Time + (4\min)(LST\ Merdian - Local\ Longitude) \quad \text{(Eq. 6)}$$

where

LST	=	Local Standard Time, 24 hr based. If using DST subtract one hour.
Equation of Time	=	Δt/min
LST Meridian	=	longitude of the time zone that you are in, ° based
Local Longitude	=	the longitude in degrees at your current location, ° based

4.2 Solar Irradiation Intensity

There are various components that are used to calculate solar irradiation intensity. They are all measured in W/m^2. The intensity is primarily dependent on location then on solar positioning.

This is the total irradiation on a surface that can be utilized. It is the sum of the direct, diffuse and the reflective radiation.

$$I_{t\theta} = I_{DN}\cos\theta + I_{d\theta} + I_r \quad \text{(Eq. 7)}$$

where

$I_{d\theta}$	=	the diffuse component
I_r	=	the reflective component
I_{DN}	=	the direct component, a tabulated value

Diffuse radiation is radiation that has been scattered by the atmosphere but can still be absorbed by the absorber. This is primary dependent on location

$$I_{d\theta} = I_{dH}(1+\cos\Sigma)/2 \quad \text{(Eq. 8)}$$

where

ϕ	=	solar azimuth
Σ	=	is the angle of the absorber with respect to earths horizontal plane
I_{dH}	=	diffuse radiation incident on a surface with no cloud cover

Reflective radiation is radiation that has been reflected off the ground. This is dependent on the reflectance of the ground, which is a value that ranges from 0 to 1. An example of this is snow vs. pavement, fresh snow has a reflectance factor of 0.87 and pavement is typically less than 0.10.

$$I_r = I_{tH}\rho_g(1-\cos\Sigma)/2 \quad \text{(Eq. 9)}$$

where

I_{tH}	=	total horizontal irradiation
ρ_g	=	the reflectance factor, a look up value for surrounding surfaces

4.2 System Power Output

Of the two types of solar systems discussed, solar thermal systems will have a varied efficiency dependent on local conditions such as ambient air temperature, whereas photovoltaic systems will have a given efficiency when purchased from the retailer.

The thermal output of a solar thermal system is dependent on the area and the temperature of the ambient air and the fluid within the collector. The inefficiencies that exist are due to radiative and convective heat losses. Radiative losses exist when there is an large temperature difference between the fluid and the ambient air temperature, the relationship is exponential; the larger the difference the more losses that will exist. Convective heat losses exist any time when there is a temperature gradient, if the fluid is not fully insulated.

$$P_{real} = A_{GA} \times \left(\eta_o \times I_{t\theta} - a_1 \times (T_m - T_a) - a_2 \times (T_m - T_a)^2\right) \qquad \text{(Eq. 10)}$$

where

ϕ	=	solar azimuth
A_{GA}	=	Gross area
η_o	=	Zero-Loss Efficiency
$I_{t\theta}$	=	Total solar irradiation, W/m^2
a_1	=	first order heat loss coefficient, $W/m^2/K$
T_m	=	Temperature media
T_a	=	Temperature atmosphere
a_2	=	second order heat loss coefficient, $W/m^2/K^2$
P_{real}	=	power available from the solar thermal system

The total system efficiency is determined by the real power and both the piping and thermal storage efficiency. The thermal storage is depended on what fluid you are using and the insulation value of the storage unit.

$$P_{system} = P_{real} \times \eta_P \times \eta_T \qquad \text{(Eq. 11)}$$

where

P_{system}	=	total power output of the entire system, W
η_P	=	piping efficiency
η_r	=	thermal storage efficiency

The electrical output of a photovoltaic system is greatly dependent on the quality of the panel, and thereby the efficiency. An efficiency of 15% is a good general estimate for commercial panels.

$$T_{cell} = T_{air} + I_{t\theta}\left(\frac{T_{NOCT} - 20}{800}\right) \qquad \text{(Eq. 11)}$$

where

T_{cell}	=	Temperature of the cell
T_{air}	=	Temperature of the air
T_{NOCT}	=	Nominal operating cell temperature

The real power that is produced per module prior to converting to AC. This is dependent on the amount of radiation that is imparted on the panel and specifics about the panel type; mono-crystalline, poly-crystalline, amorphous silicon.

$$P_{real} = P_{MP} \times \frac{I_{t\theta}}{1{,}000W/m^2} \times \left[1 - \lambda_P \left(T_{cell} - 25\right)\right] \qquad \text{(Eq. 12)}$$

where

λ_p = power temperature coefficient
P_{MP} = Standard test conditions power rating
P_{real} = Real power generated from the solar panel
P_{system} = The total power output of the photovoltaic array

Total system power is dependent on the power output of each module and the efficiency of the inverter being used.

$$P_{system} = P_{module} \times N_M \times \eta_I \qquad \text{(Eq. 13)}$$

where

N_M = Number of modules
η_I = Efficiency of the inverter

5. OPPORTUNITIES

Following is a list of common opportunities found in solar systems detailing general information about each opportunity, as well as an analysis based on an annotated reference spreadsheet.

5.1 Photovoltaic Array

5.1.1 Location

Generally the most important factor when considering using a photovoltaic array is location. This is because photovoltaic arrays have a fixed efficiency and generate electricity proportional to the amount of sunlight available. Thus, the more sunlight available the quicker the payback period will be.

- **Highly rural area**
  Areas where you are required to generate electricity by your own means, such as a diesel generator. Photovoltaic arrays can provide a supplemental source of energy to decrease the dependence on diesel.

5.2 Solar Thermal

5.2.1 Location

As also mentioned in the photovoltaic opportunities, location is very important for any solar endeavors. However, because the conversion efficiency is higher in the solar thermal conversion process it is not necessarily as important to have the most ideal location; other less fitting locations will suffice.

5.2.2 Need for heated process water (or fluid)

By simply heating a fluid one can save energy by using the sun, and there by a solar thermal energy source. This is not only renewable but it will also save money that would arise from purchasing electricity or natural gas to heat the liquid. Below is a list of opportunities when solar thermal process heat can be even more effective.

- **Direct Conversion**
  There is a very high efficiency when converting directly to a liquid, part of this is because there are no transition steps; in essentially all medium transitions energy is lost. When one has the opportunity to directly heat water, preheat cleaning water, warm sea water, heat a fluid used to heat a building, it should be taken

- **Low Temperature uses**
  Low temperature applications of solar heating are excellent opportunities for energy savings. At low temperatures one does not have to worry about radiative heat loss from the collector, whereas at higher temperature applications a significant amount of heat loss can arise from radiative losses, this occurs in an exponential fashion. When needing to warm or preheat a fluid, solar thermal heating offers a great way to use a renewable energy while saving money.