GOLD OR GOLD-PLATED? BENEFIT COSTS ANALYSES OF DIFFERING METERING METHODS AND DURATIONS

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Introduction

An EPRI/BECo tailored collaborative sponsored a study of cost-effective metering strategies. The primary objectives of this study were to compare alternative measurement methods in terms of cost and accuracy, and to explore metering duration and its effect on the accuracy of savings impact measurement. The viability of various low-cost data collection protocols was compared to a higher cost metering approach. Although no monitoring approach can determine energy savings exactly, a protocol was selected that represents an established ideal or "gold-standard" for savings estimation (e.g., extended end-use metering). This protocol was used to assess the relative accuracy of less rigorous data collection protocols. Variations on metering techniques and amounts of data collection were used to develop a systematic assessment of the relative efficiency of the methods on key dimensions such as cost, precision, and bias. The balance of this paper is organized as follows:

An overview of the measurement systems (for both chillers and motors).
Methodology of computing usage and savings.
Analysis results. and,
Benefit/Cost comparison and conclusions.

Within each section there will be subsections devoted to separate issues pertaining motors and chillers.

Measurement Systems

One of the most overlooked and underestimated efforts in metering studies is the method of data retrieval, handling, and analysis. This is an issue even if the metering is performed by experienced contractors. Experienced metering professionals know that metering is no small task. Working out site-specific and logistical issues will generally increase as the level of metering increases. At what point does this provide the needed benefit?

The interval for metering, its duration and the actual period within the year, will effect the accuracy. What is the magnitude of the effect and what parameters of the estimate effect the accuracy the most?

The goal of the study is to determine relative tradeoffs between cost and accuracy of various measurement methods for chillers/motors to determine savings. The measurement methods include:

Long-term interval kW metering (plus Btu metering for chiller)
Spot measurements and runtime logging
Short-term amp logging
Site inspections and interviews
Spot measurements and interviews
Billing analysis

For example, long-term interval demand metering may provide only slightly better accuracy for a particular application compared to less expensive monitoring methods such as spot measurements and site inspections. To determine the most cost-effective data collection strategy for common technologies and applications allows for strategic decision making. In the previous example, available budget for data collection would be better spent implementing the less expensive methods and increasing the number of monitored sites.

XENERGY's approach to this study was subdivided into two components. The first component compared "measurement" methods at a site to identify a method that appears to provide the greatest cost vs. accuracy tradeoff. The second component determined the effect of sliding and re-sizing the metering intervals and evaluating the impact on savings estimates.

The goal of the first component was comparing the accuracy and cost of various "measurement" methods at the site level. In this component, the ability of each method to accurately estimate demand and energy impacts at the site was compared to a "gold-standard" method (e.g., full interval kW metering). To allow direct comparison, all methods were employed simultaneously to provide redundant impact estimates. Data collection and impact estimation costs were carefully tracked, including equipment and installation.

The second component explores the influence of other monitoring parameters on impact accuracy. The research addressed the following parameters:

Pre/post-installation monitoring vs. post-only monitoring for certain levels of metering
Short-term monitoring vs. long-term monitoring for the chiller 'gold standard' method

Measurement Levels

The measurement levels originally anticipated were modified due to equipment failures and metering problems.

In general, the monitoring techniques include the most accurate measurement technique available (the ideal, or "gold standard" approach), along with several other conventional techniques used for estimating savings of energy efficiency measures. Specifying the greatest amount of retrofit equipment available and the longest duration of both pre-installation and post-installation monitoring allows for scenarios using different levels of these data to be developed and analyzed. For example, given a full 12 months of both pre-installation and post-installation metering, estimates of the accuracy of using portions of pre and post data can be derived. Other estimates of savings using 'non-measurement' techniques can be compared to these monitored estimates.

These parameters represent ideal levels of effort, and their realization typically will depend upon the sites available for study, and the specific equipment available to monitor at the sites.

Measurement: System Design. The "gold-standard" method by which other methods are compared is interval kW measurement of all selected measures both before and after measure installation. The interval kW meters employ digital sampling techniques that account for harmonics. Distance from the metering panel, installation difficulty and labor rates all have an impact on cost. Careful site selection ensured budget compliance.

Amp loggers were installed so that data could be collected concurrently with kW interval metering. Separate amp loggers were used due to the harmonic content in signals.

The kW interval meters were used to simulate run-time loggers. Run-time loggers measured operating hours and were used in conjunction with a spot measurements and site inspections to derive separate impact estimates.

In addition to the selected measurement method, "non-measurement" impact estimates were made. Data collected was that which is usually collected by an energy auditor, including inventory, equipment operating schedules, application type, nameplate efficiency ratings, horsepower, part-load %, etc. These "non-measurement" impact estimates, including BECo screening data, engineering audit and billing analysis, were compared to those derived using the selected measurement method.

Independent cost estimates were developed for all measurement methods. These cost estimates include items such as travel, site visit labor, etc. Given the goal of implementing as many techniques as possible at the site, it was essential that the costs for the various techniques be tracked in such a way that costs can be provided for each independent of one another.

In the end this study included metering and data analysis for one chiller system and seven motors at a single site. For both the chiller and motor measures distinct levels of measurement were designed, appropriate meter designs were implemented and analysis was performed to answer the above questions. The methods of measurement used is shown in Table 1.

In addition to the basic levels listed above, variations on motor levels 1 and 4 were investigated. These were labeled 1A, 1B and 4A. While no significantly improved variation on level 4 was found, level 1A used the amp logger as a runtime meter only and was an improvement on the original specification for level 1.

Table 1: Measurement Techniques

Level	Equipment/Technique Chiller	Equipment/Technique Motors
Gold / Modified Gold*	kW Interval - chiller kw and Btu, Weather	kW Interval
1	kW Interval - chiller kW	Runtime amp logger Spot kW
2	Runtime Amp Meter - chiller Spot kW	Spot Amp-Volt Runtime logger
3	Audit/Engineering Estimate (Data from Chiller Pilot Program Audit)	Spot Amp-Volt (no runtime logger)
4	Whole Premise Billing	Audit Engineering Estimate

*The limitations imposed by the failure prior to pre-period meter commissioning of one of the chillers require a modification of the gold standard definition to account for the best possible impact estimate, i.e. one that relies on post-only metering.

Methodology of Computing Usage and Savings

Chiller Methodology

For chiller systems the focus was on comparing energy use measurement techniques, not energy savings techniques, because no pre-implementation data was available as a result of the unexpected failure of the chiller in the pre-period. However, energy savings calculations were completed to evaluate metered operation of the new chiller using manufacturer's data for the old chiller as a baseline.

The following summarizes each of the five standards for the chiller. Table 2 lists each standard and the data which were used, the functional relationship which were estimated based on that data, and some additional description of variables.

Data available for the chiller gold standard included interval measurements of:

Chiller kW
CHW and CW pump kW, Cooling tower fan kW
Chiller and cooling tower supply temperature
Chiller cooling output (Btu meter)
Indoor and outdoor temperature and humidity

Energy Usage Analysis. Electric energy used by the chiller and auxiliary systems is the sum of average kW from each hour for any metered period. Chiller efficiency can be determined for any hour by dividing electric energy input by cooling energy output. Chiller system efficiency can be correlated to changes in weather and cooling load conditions using kW, Btu and temperature and humidity data.

Energy Savings Analysis. Energy savings for a given interval of time is:

$$\text{kWh Savings} = \text{Tons} * (\text{kW/ton}_{old} - \text{kW/ton}_{new})$$

The cooling load (Tons) in this equation is determined by developing an estimate for cooling load as a function of weather and efficiency (kW/ton). Total energy savings over a period of time after the energy efficient chiller is installed is the summation of the above equation over all intervals in the period. This method normalizes energy use of the old chiller to the load conditions met by the new chiller.

Chiller Issues

One major goal of the chiller analysis was to compare metering methods by differing levels of metering intensity (C-G versus C-1, C-2, C-3 and C-4) and differing durations of metering (C-G for the whole cooling season versus C-G for fortnights - two week periods). Two of the analyses performed to compare the different metering implementations (methods) were:

Compare the estimated (modeled) energy **consumption** for the differing metering implementations.
Compare the estimated (modeled) energy **savings** for the differing metering implementations.

Table 2: Chiller Standard Descriptions

Standard	Data Used	Functional Relationship	Description of Variables
CG (Gold)	Pre-period metered Btu and kW Post-period metered Btu and kW Auxiliary kW Weather	Total meter kW = f(weather variables, Btu)	Total kW is chiller kW plus kW of two cooling tower variables
C1	Pre-period Manufacturers efficiency data Post-period kW meter estimate kW	Chiller meter kW = f(weather variables) this relationship is for post-	No Btu or auxiliary kW data included
C2	Pre-period Manufacturers efficiency data Post-period amperage data to estimate kW	Estimated chiller kW = f(weather variables) this relationship is for post-	(as C1, above)
C3 (Engineering)	Full load efficiency, estimate of loads, estimate of operating conditions.	NA	NA
C4 (Billing)	Pre and post billing data Weather	kWh = f(weather)	Temperature data used to determine cooling degree days

For each metering scenario of metering **intensity**, electric consumption and savings were modeled. In one set of scenarios we compared the "Gold" standard, C-G, the most metering intense scenario where we measured kW and Tons usage for the whole cooling season, versus less metering intense scenarios (C-1, C-2, C-3 and C-4 for the whole cooling season). In C-1 we only metered kW, but did not meter Tons. In C-2 we metered amps (which were then converted to kW). Scenario C-3 was an engineering estimate of savings using no metering. Scenario C-4 used whole facility load research metering data (not just metering of the chiller) to estimate consumption and savings.

By modeling all these scenarios, we were able to quantify the tradeoffs of more intense, more costly metering versus less intense and less costly metering, scenarios C-1, C-2, C-3 and C-4.

We also compared the effect of differing metering **durations**. That is, not only can the metering intensity be modified, but the amount of time the metering equipment can be left in place can change. For this part of the analysis, we compared the C-G for whole season versus C-G for different fortnights (two-week periods) spread throughout the cooling season.

A brief overview of the model steps used for the scenarios (both by intensity and duration) are listed below:

Model cooling load in Tons as a function of weather.
Model the probability that the chiller is cooling as a function of weather, hour of the day and daytype.
Estimate the amount of time the chiller is cooling for a TMY given the first two steps.
Model kW as a function of cooling load (Tons) and weather when the chiller is cooling.
Estimate the kW usage for any given TMY hour using the above model.
Sum the kW resulting in kWh for the TMY cooling season. Adjust downward by the probability that chiller will be cooling for any given hour.
Compute Savings for kW and kWh.

In order to make valid comparisons, the analysis of the different metering implementations had to be "put on a level playing field". Table 3 sums up the unevenness of the C-G scenario compared with other scenarios.

"Leveling the playing field" is a prerequisite to valid comparison and a guiding force in the methodologies implemented. We "leveled" the playing field by comparing all the metering implementations given the weather for a Typical Meteorological Year (TMY). Using TMY data means that we are looking at chiller operation for a typical year rather than a specific year. This approach avoids bias in the savings estimates due to variations in weather.

There were other factors that shaped the chosen statistical modeling. While the relationship between kW and Tons is very strong, the relationship between weather and chiller usage is much weaker because of the following reasons):

The chiller operation is affected by operating schedule. The chiller is turned off in non-operating hours, if the predicted temperature is cool (and low humidity). Thus, given the same concurrent outside weather conditions it is impossible to know whether the chiller will be actually cooling (drawing load) at all.

Table 3
Unevenness of Different Metering Implementations

Method Compared to Whole Season C-G	**Data not included in comparison method**	**Reason "raw" comparison is not valid**
C-1 (whole season)	Tons	While both methods included metering for the whole season we used more data from the C-1 metering than C-G. In C-G we could screen out cases when kW was greater than 3kW but there were zero Tons associated with the read. For C-1 all cases with greater than 3 kW were considered valid.
C-2 (Whole Season)	Tons and kW (Use Amps and Conversion Factor to estimate kW)	Data only available for a two month period
C-G (Fortnightly - 2 week rolling periods)	The rest of the cooling season	The metering was not performed over the same periods
Pre-Period (for savings estimates)	The whole post-period.	No metering was performed for the pre-period (because of early chiller failure). Even if it had, the comparisons would have not covered the same time period.

Even given that the chiller is cooling, the cooling load that the chiller needs to meet can vary widely given the same outside temperature and humidity. Various factors that can effect the cooling load include: internal heat gains, sunlight, whether the chiller had been running in the previous hours, or left on overnight to prepare for a predicted hot day or warm night.

Detailed Analysis Steps for Computing Usage and Savings by Altering Duration

While C-1 through C-4 methodologies assumed a less detailed amount of metering for the whole cooling season. The C-G **Fortnightly** analysis, assumed that the C-G metering was only present for two weeks at a time. Besides using just a subset of data, the C-G Fortnightly differed from the C-G full season in the following ways:

Since during no two week period could it be assumed that we could find the balance point, the balance point was defined by using engineering expertise. It was set at 50 degrees. Computing the probability that the chiller was ON was modeled as a function of a dummy variable of when the chiller was scheduled to be ON, the CDH and Humidity for periods when the chiller was scheduled to be ON, and the CDH and Humidity for periods when the chiller was scheduled to be OFF. A simpler model was chosen because the full model used in the C-G step resulted in models being unstable or uncomputable (because of the lack of degrees of freedom).

Motor Methodology

For high efficiency motor replacements in constant-load applications, there are at least two basic methods for estimating annual savings.

The first, most common method is to take spot measurements of motor input current or power and calculate demand savings based on motor efficiency data. Annual energy savings is then estimated using the calculated demand savings and either estimated, or measured annual hours of operation. Long-term interval demand metering afforded the opportunity to assess the accuracy of all of these assumptions.

The second method is to establish the baseline energy usage as a function of post-installation energy use. This can be achieved through the conducting the tests described in item 1 above. Measurement of post-installation energy usage can then be used to index the baseline energy use. This method is potentially the most accurate since it predicts savings based on actual, long-term post-installation usage.

There are, of course, other methods which are variations of the two described above. For example, spot measurements can be taken before and after to avoid errors in assumptions about motor efficiency. The analysis approaches established for the different levels of metered data are discussed below.

Gold Standard (M-G): kW Interval Metering and RPM Measurement

Energy Usage: Electric energy used by each motor is the sum of the average kW from each hour for all hours in any metered period.

Energy Savings: Energy savings for a single motor over a given period is equal to operating hours for the period multiplied by the reduction in average metered kW for "post" vs. "pre."

$$\text{kWh Savings}_{metered} = [(\text{Hours}_{metered,post-}) \times (\text{kW}_{max,\ pre-})] - [(\text{Hours}_{metered,post-}) \times (\text{kW}_{max,\ post-})]$$

Where "Hours" refers to operating hours determined by dividing total metered kWh by average metered kW. This method normalizes energy savings to the operating hours during the post implementation period. Furthermore, if there is a measurable difference in motor shaft speed, energy savings should also be normalized to the post implementation speed.

Comparison M-1: Instantaneous-Amp-Volt Measurement, Amp-Logger

Energy Usage: Electric energy used by each motor is the sum of the average kW from each hour for all hours in any metered period. The kW value for each hour is determined from the ratio of kW to amperage from a spot reading of these values.

Energy Savings: The approach used in M-G is used here to determine energy savings with the added inaccuracy of converting amperage data to kW while assuming that power factor remains equal to the power factor at the time of the spot kW measurement.

Comparison M-2: Instantaneous Amp-Volt Measurement, Amp Logger

Energy Usage & Energy Savings: Procedures are the same as in M-1 except that power factor is estimated in calculating the instantaneous kW value from voltage and amperage data.

Comparison M-3: Instantaneous Amp-Volt Measurement, (No Runtime Logger)

Energy Usage: Power factor is again estimated to calculate the instantaneous kW value from voltage and amperage data. Operating hours are estimated on the basis of typical operating schedules or time clock settings.

Energy Savings: Post-installation operating hours are multiplied by the reduction in connected kW due to the efficiency measure.

Comparison M-4: Energy Audit

Energy Usage & Energy Savings: Procedures are the same as in M-4 except that the kW reduction is determined based on efficiencies and horsepower corresponding to nameplate data from the standard and energy efficient motors. Power factor and motor loading are estimated based on similar applications and engineering experience.

Analysis Results

The analysis involved a comparison of the impact estimate, its variability (in terms of relative precision) and the cost, relative to the ideal (first) method listed. The comparisons of different metering and analysis levels are summarized in Table 4.

Table 4
Comparisons of Metering Techniques

Comparison	Variables	Parameters
Comparison 1	Pre/post measurement vs. Post only	All post period data (vs. estimated baseline where pre-installation data is available)
Comparison 2	X% Sample of post data	All data vs. 2 week samples
Comparison 3 (motors only)	X% Sample of equipment	All data vs. Increments as Appropriate, e.g.

Measurement Method/Level Comparisons

This section summarizes data comparing the savings determined using each measurement method for chillers and motors as well as the cost of each method.

Chiller Metering. Table 5 shows estimates of chiller **usage** for the different scenarios in both absolute and percentage terms in comparison to C-G.

The Table 6 shows **savings** for the different scenarios in both absolute terms as well as in comparison to level C-G.

Variations in Amount of Data (Temporal)

The C-G and C-G Fortnightly methods varied widely in their prediction of energy usage. It appears that those periods that most closely approximate the weather patterns for a whole season are better able to predict energy use.

Table 5
Chiller Energy Usage Estimate Comparison

	kWh% compared to C-G	kW % compared to C-G
C-G	n/a	n/a
C-1	113%	113%
C-2	57%	38%
C-3*	n/a	n/a
C-4**	237%	108%

*Pre and post consumption not available from Chiller Replacement Program report. **Measured on whole campus, not just chiller.

For example, fortnight "D" (June 2-June 15) tracked fortnight "Z" (April 15 to October 15) very well and it has approximately the same distribution of temperature as the cooling season as a whole. Conversely fortnight "K" consistently estimates a lower kW for the same weather conditions. Fortnight "K" was also the coolest of the fortnight periods estimated.

Chiller Metering Technique Conclusions:

> The most important implication shown in the above two tables is that while the C-1 method does a reasonably good job of estimating the overall usage compared to the C-G method (just 13% higher), it does a poor job of estimating the savings associated with the new chiller. This happens because a small percentage change in the overall usage, will lead to a much larger percentage change in the estimate of savings.
>
> If the goal is to accurately estimate savings, there seems no real substitute for the Modified C-G method.
>
> The validity of the manufacturer's efficiency curve (kW demand for a given cooling load) can only be confirmed if Btu data is metered as it was in level C-G. If the goal is to estimate usage, then the C-1 methodology could be a cost effective substitute.

Motor Metering

Results shown in Table 7 indicate that level M-1B has the most favorable weighed average percentage differences with respect to the Gold Standard. Level M-1B, however, has a much reduced cost compared to level M-G. Note that the average percentage differences include results from all seven motors and are weighted by horsepower. The overall measurements of demand and energy savings (totaling results for all motors) are within approximately 10 percent for both M-1 and M-1B. (Other variations on the basic levels included 1A and 4A, but these did not offer any improvement over the original level specification.)

Table 6
Annualized Chiller Savings Comparison to Gold Standard

Level	Annualized kWh Svgs	Annualized kW Svgs	Percentage Difference from Gold kWh Svgs	Percentage Difference from Gold kW Svgs	Measurement Cost (1 chiller)
CG	29,035	35	n/a	n/a	$54,920
C1	74,538	64	+157%	+83%	$50,970
C2	58,060	13	+100%	+37%	$10,554
C3	75,000	64	+158%	+83%	$9,760
C4	-61,989	8	-314%	-77%	$720

Table 7
Motor Savings Comparison to Gold Standard

Level	Percentage Difference from Gold* kWh Svgs	Percentage Difference from Gold* kW Svgs	Measurement (7 motors)
MG	n/a	n/a	$26,775
M-1	-51%	-50%	$6,327
M-1B	26%	25%	$6,327
M-2	328%	323%	$3,632
M-3	62%	314%	$1,369
M-4	-36%	64%	$1,050

Variations in Amount of Data (Quantity of Equipment)

Seven different motors were metered individually in this study, so it is possible to qualitatively assess the impact of varying the number of pieces of equipment metered. This comparison is only relevant for the motor analysis in this study, because there were data for multiple motors available, where as data for only one chiller was available.

Table 8 compares the *variation* in savings estimate accuracy relative to the gold standard for each of the seven motors analyzed.

Table 8
Range of kWh Savings Variation Among Motors

Level	Variation From Level MG Highest Svgs	Variation From Level MG Lowest Svgs	Average Variation
MG	n/a	n/a	n/a
M-1	75%	-344%	-51%
M-1B	101%	-24%	26%
M-2	975%	-16%	328%
M-3	170%	-12%	63%
M-4	15.7%	-62.1%	-36%

These data indicate that the average savings accuracy for a given metering level is not the only indicator of the validity of that metering level. Levels with the highest variation in accuracy among the motors in the sample do not provide reliable estimates of savings. This provides additional support for using the M-1B approach.

Motor Metering Technique Conclusions:

Amp loggers provide a very inaccurate means of measuring kW over time, but are good for accurately measuring total operating hours and operating time periods. However, simple runtime loggers are a less expensive means of measuring operating hours.

Spot measurement of amperage and voltage does not necessarily provide more accurate savings measurements than engineering estimates based on nameplate data.

Metered operating hours can be significantly different from facility staff estimates.

Cost/Benefit Comparison and Conclusions

Cost/Benefit Comparison

Establishing a quantitative cost/benefit ratio for each metering level was not possible given the small number of chillers and motors metered in this study. Metering costs, however, can be compared to the value of the amount of energy savings error for each level. The annual energy savings error was valued at $0.10 per kWh. Thus the most cost effective metering should have the lowest total cost for metering and error cost combined. Two time frames have been included in the tables for a qualitative indication of the increasing value of accurate metering as the measure life increases. (This does not imply that the metering should be left in place for ten years, rather that the measure will be in place for a long time period and savings will be expected throughout this period.) Since this is a qualitative comparison, we assume that there is no error cost associated with the gold standard.

Looking at the error cost over the short term, the whole premise billing estimate is so simple and inexpensive that the total combined estimate and error cost is smallest for this level. This is not necessarily relevant, however, because the whole premise estimate can be far from the actual savings. It is very valuable to have Btu metering data. Table 9 shows that this addition to level C1 is worthwhile even for the short term.

Looking at error costs over a longer term period of energy efficiency measure operation, levels CG, C2 and C3 are all comparable in total cost (especially with respect to this small sample). Considering that the full CG level offers a much more accurate savings estimate due to the use of Btu metering this method should be considered in preference to the others. Also, note that the relationship between amperage measurement and kW used in level C-2 is highly variable with load such that results of this method depend on when the kW reading is made.

When looking at a short time period, the cost of the energy savings error is not significant enough to show the value of the more expensive metering options. Looking at the long term, however, Level M-1B has the minimum combined metering and error cost, as show in Table 10.

Furthermore:

For minimal incremental cost, it is much more worthwhile to make spot measurements with a kW meter as compared to voltage and current measurement with estimated power factor.

Overall, the best compromise between cost and accuracy for evaluating savings for motors with constant (or nearly constant) loading is to make spot kW measurements and use simple run-time metering to accurately measure operating hours. The run-time or amperage logging should occur for as long a duration as possible to accurately reflect operating practices. In addition, the kW measurements to the original motor and the new motor should be made during operating conditions that are as similar as possible with respect to motor loading.

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Table 9
Chiller Metering Cost vs. Error Cost Comparison

	Metering	**One Year**		**Ten Years**	
Level	**Cost**	**Error Cost***	**Cost Total**	**Error Cost***	**Cost Total**
CG	$54,920	0	$54,920	0	$54,920
C1	$50,970	$4,550	$55,520	$45,500	$96,470
C2	$7,014	$2,903	$9,917	$29,000	**$36,014**
C3	$6,822	$4,597	$11,419	$45,970	$52,790
C4	$720	$9,100	**$9,820**	$91,000	$91,720

*Assumes $0.10 per kWh average electric rate.

Table 10
Motor Metering Cost vs. Error Cost Comparison

	Metering	**One Year**		**Ten Years**	
Level	**Cost**	**Error Cost***	**Cost Total**	**Error Cost***	**Cost Total**
MG	$26,775	$0	$26,775	0	$26,775
M-1	$6,327	$1,429	$7,756	$14,294	$20,621
M-1B	$6,327	$790	$7,117	$7,899	**$14,226**
M-2	$3,632	$10,205	$13,837	$102,049	$105,681
M-3	$1,369	$24,066	$25,435	$240,656	$242,025
M-4	$1,050	$2,624	**$3,674**	$26,237	$27,287

*Assumes $0.10 per kWh average electric rate.