# Comparison of Metering and Verification Methodologies of Compressed Air Systems for Utility-Based Energy-Efficiency Programs: A Case-Study

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## ABSTRACT

Measurement and verification (M&V) is an important component of energy-efficiency projects and programs because the results show if the intended savings of a project are being realized. The accuracy of these results impacts the investment strategies of energy end users and regional transmission organizations, like Pennsylvania Jersey Maryland (PJM), who can view and purchase efficiency credits as a resource. It also impacts the incentive strategies of utility efficiency programs. Often the standards for custom M&V projects place tight controls on the accuracy of the metering equipment used, but have relatively loose controls on the methodologies required to analyze the metered data. This paper provides a background on PJM's M&V standards and shows through case studies how the potential error associated with analysis approach can greatly outweigh the errors associated with selected metering equipment.

Compressed air systems are a common mechanical system chosen by industry for energy efficiency retrofits. Due to the many variables present in multiple-compressor systems, they often do not qualify for a prescriptive rebate programs. In the case studies provided, analysis is conducted for pre- and post-efficiency project scenarios with and without normalizing for air demand. In addition, the case studies demonstrate how different methodologies for normalizing can also have a large impact on the calculated energy savings.

## Introduction

Measurement and verification (M&V) is an important component of energy-efficiency projects and programs. M&V results show if the intended savings of a project are being realized. This feedback can impact investment in efficiency, such that poorly performing projects receive less investment, and well-performing projects receive more investment. For most energy efficiency projects, the majority of the financial risk is born by the end user. Thus, M&V results are potentially most important to the end-user. However, state and utility energy-efficiency programs also invest in energy-efficiency, and are often required to report their savings to meet legislative benchmarks. These programs require robust M&V evaluations to support their claimed savings. Finally, energy-efficiency is increasingly being recognized as a resource, and being procured in competitive auctions by independent system operators (ISOs) and regional transmission organization (RTOs). These auctions serve as electric resource planning markets, and thus the accuracy of the counted efficiency is important to all rate-payers.

The accuracy and certainty of energy savings are important to three distinct entities, the end-user, the energy-efficiency program administrator, and the ISO/RTO. In all these cases, a high level of accuracy is desired. This desired accuracy may come at increased costs to delivering efficiency. Next, we discuss improving accuracy through more accurate metering equipment, independent variable normalization, and/or improved sampling periods, and the requirements which drive them.

## Equipment Accuracy and Sampling period Requirements - PJM Manual 18b

In this paper, we will specifically refer to the M&V requirements of the Pennsylvania Jersey Maryland (PJM) RTO, as outlined in PJM Manual 18b. There are other RTOs and ISOs with metering requirements which we do not discuss here, but which may have similar requirements.

### Metering Equipment Accuracy Requirements

PJM requires that metering equipment meet ANSI standards, and if the electrical circuits have significant harmonics, that they meet IEEE standards. However, there are several other key requirements which drive metering equipment selection:

- Three phase equipment must have measurements on all three phases, or an equivalent method that measures demand using two phases.
- Equipment that measures demand (kW) must be true root mean square (RMS) with an accuracy of no more than +/- 2%.

There are many other requirements for the metering equipment. The requirement for true power measurements with +/- 2% accuracy, though, has significantly changed the type of metering equipment selected by practitioners. The cost of metering equipment and associated installation labor has increased as a result.

For example, prior to these metering requirements, M&V requirements were driven by the end-user, who is balancing cost of M&V with the desired accuracy. For customer-driven M&V, it would be suitable to first take spot amperage, voltage, and power readings with a hand-held power meter at various equipment loading points. These spot power readings typically show that motor phases are balanced, and that amperage measurement of a single phase can be converted to power based on conversion factors of spot power readings. A popular stereo-jack split-core transducer available through Onset has an accuracy of +/- 4.5%. It should be noted that there are many transducer manufacturers. We mention the Onset transducer as an example because we mostly use it and have observed it to be commonly used by peer companies. The corresponding data logger introduces another about +/- 2.5% of inaccuracy. Using spot-power readings to convert measurements to power may introduce more inaccuracy. This equipment does not meet PJM's accuracy requirements. Advantages, though, include low first cost, reduced installation time, safer installation, and thus reduced liability, cost, and better safety for the end user. That said, we note that in some cases a power meter can reduce overall M&V costs by reducing the analysis time required because power is measured, and does not need to be calculated.

By comparison, real power can be measured by a power meter, such as an Onset Veris power meter, which measures current and voltage within +/- 0.4%. The corresponding transducers are also more accurate at +/- 1%. The downside is additional first cost, additional labor cost to install, and additional liability from the increased time and skill required to install the power meter only records a reading every minute. This loss of resolution can significantly impede the M&V team from identifying important operational characteristics of equipment, such as capacity control parameters on a compressor. As previously mentioned, there can be a positive benefit from power metering if the analysis time is reduced. It should also be noted that this paper uses the Onset Veris power meter as an example of representative power meter because it is one we are most familiar with. However, many other power meters brands exist and we also use some of them. In general, similar to the Onset Veris, all power meter options require additional first costs, labor costs, liability and skill to install.

On a recent project we logged the energy consumption of a new VFD compressor using both new Onset Veris true power metering equipment as well as with a standard split-core transducer (accuracy of +/-4.5%) and Onset Hobo data logger. Energy was then calculated for the logged amperage data of the Onset Hobo data logger based on voltages and power factors measured as a spot reading with a multimeter. The difference in projected annual energy consumption came out to 3%. This is within the accuracy bounds in the product literature. The results are summarized in Table 1.

**Table 1. Comparison of Energy Metering Equipment Results**

| | Energy (kWh/year) |
|---|---|
| Calculated w/ Spot Readings & Amperage Logger on 1 leg | 2,227,743 |
| Measured w/ Onset Varis True Power Meter | 2,151,792 |
| % Difference | 3% |

Table 2 presents the difference in first costs, and estimated installation time per metered project. While a power meter can yield more accurate energy measurements, there is an additional equipment cost and installation time.

**Table 2. Comparison of Energy Metering Equipment Costs and Installation Time**

| Equipment to Meter a Typical 3-Phase Motor | Equipment Cost ($) | Install Time (hours) |
|---|---|---|
| 500-Amp Current Transducer, Onset Hobo Logger, Multimeter | $710 | 0.25 |
| Onset Varis Power Meter with Wires, Clamps, CTs | $1,361 | 1.0 |
| % Difference | -92% | -300% |

## Metering Methodology Accuracy Requirements

Metering equipment accuracy is only one component of the overall accuracy of a savings measurement. PJM recognizes this at multiple places throughout Manual 18b. For example, in Section 9.1.1, PJM lists several sources of bias that could be present in measured savings. Project savings can be calculated by one of four methods, Options A through D, all of which are derived from the International Performance Measurement & Verification Protocol (IPMVP) Volume 1. For metered projects, Options C & D would not apply. This limits guidelines to either Option A: Partially Measured Retrofit Isolation/Stipulated Measurement, or Option B: Retrofit Isolation/Metered Equipment. Option A is intended for projects where performance factors or operational factors

> "can be measured on a spot or short-term basis during baseline establishment and post-installation periods, or for measures for which a measured proxy variable can, in combination with well-established algorithms and/or stipulated factors, can provide an accurate estimate of the Nominated EE Value."

By comparison, Option B is

> "Intended for retrofits with performance factors and operational factors that can be measured at the component or system level using interval electrical demand meters…"

Option B goes on to define that spot or short-term electrical demand measurements should only be used if the sampling period is representative of the variations in performance and operations across the commitment years. A given project may have a measure life of 10 years or more. Thus, there are likely many projects that, especially for manufacturing facilities, where short-term measurements will likely never capture the full variety of performance and operations across the commitment years.

Our interpretation is that Option B should be used in one of two cases. First, Option B should be used if amperage cannot be measured as a proxy variable and reliably converted to power. We do not think there are many cases where this would apply. Second, Option B should be used if the equipment loading cannot be captured by short-term sampling. This likely does occur frequently, especially with manufacturing projects.

The definitions of Option A and B imply an association between proxy and short-term measurements, and metering equipment accuracy. This is the root of a spreading industry-wide problem which this paper attempts to address. We posit that the accuracy associated with the sampling period should be considered independently of the accuracy associated with the metering equipment. We will go on to show that normalization of the data for flow, production, etc., and thus the sampling period is more important to savings accuracy than the equipment accuracy.

**M&V in Practice**

In practice, Option A is used almost exclusively when the M&V is client-driven. However, for utility or state programs, especially those bidding efficiency resources into an RTO or ISO auction, increasingly Option B is used, or at least the metering equipment required by Option B. This is especially true of manufacturing projects. One reason why this may be is that manufacturing equipment loading varies significantly over time. However, in our experience, program evaluators do not always consider the loading. Measured savings may instead be a pure pre-metered versus post-metered data comparison, with no normalization for production, flow, etc. Moreover, even if energy savings were normalized, the metering sampling period does not necessarily reflect the loading that could be expected over the commitment years. Very little is known about how long of a sampling period is needed to have some confidence that loading will reflect future commitment years. In fact, the extra cost of the metering equipment can lead to reduced sampling periods, inadvertently reducing overall accuracy.

Two examples of general guides for metering period length versus metering interval recording can be found in the State of Ohio Technical Reference Manual (TRM) or the recently published The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures from the U.S. DOE. It should be noted that the Ohio TRM is available to the public, but still under review at the PUCO. With regards to appropriate metering periods, the Ohio TRM states:

> "Metering periods shall be a minimum of one week, including a weekend, for constant load equipment and at least two weeks, including weekends, for variable load equipment, but as noted above, must be long enough to capture representative variations in load expected over the entire analysis period."
>
> Ohio TRM states for appropriate interval periods:
>
> "For short-cycling or modulating systems, 30-second or 1-minute data intervals are preferred, with a maximum recommended interval of 5 minutes. For constant load systems, the metering interval can be longer. No metering interval should exceed 15 minutes."

The Uniform Methods Project guide provides a specific guideline for compressors, as requiring a metering period of four weeks with a power meter at 15 minute intervals. It also provides an alternate suggested option of a metering period of four weeks, with spot readings and Amp metering at two minute intervals.

Additionally, we have found that a significant number of energy-efficiency projects requiring metering involve variable-frequency drives (VFDs) driving the equipment motor. Most of the VFD-driven equipment we measure introduces harmonics into the lines, which can distort even true power measurements. As a result, we often have to rely on specific equipment that can measure power at frequencies other than 60 Hz, an expensive solution with an elaborate temporary installation set-up. Other national-level efficiency evaluation firms resort to taking only spot power measurements to quantify savings in these situations. This highlights that while in some cases considerable extra cost is incurred to gain accuracy in metering equipment, in other common cases where this equipment cannot be used, the focus on equipment accuracy and sampling period is neglected. In other words, there is not consistent application of Option A and Option B.

Manufacturing loads vary so significantly, and are so unpredictable, that the only way to absolutely capture a representative sample of metered data is to have continuous metering. Given that the cost of continuous metering is prohibitive, instead appropriate focus should be given to capturing as much of the loading profile on industrial equipment as is economical. Additionally, the influence of the loading is significant, as we will show in the following case studies.

## Case Study 1

These case studies present scenarios where energy savings are calculated based on both a non-normalized pre and post-installation M&V analysis and a compressed air demand-normalized analysis. The objective of these studies is to demonstrate the error that can be introduced by not conducting an appropriate analysis of pre and post-installation data and the significant role the selected logged sampling duration plays in overall accuracy.

### Baseline System and Data Collection

The baseline system consists of two 100-hp rotary screw compressors. Spot electrical current, voltage, power draw, and power factor readings of the equipment were taken. The measured equipment spot electrical readings averaged over all three electrical legs are shown in Table 3.

**Table 3. Pre-Installation Equipment Summary and Average Spot Electrical Readings**

| | | | | | Spot Reading Average of 3 Phases | | | |
|---|---|---|---|---|---|---|---|---|
| ID | Equipment Type | Make | Model | Motor Rating (hp) | Loaded Amperage (A) | Voltage (V) | Loaded Power Draw (kW) | Loaded Power Factor (kW/kVA) |
| A1 | Air Compressor | Ingersoll Rand | SSR-EP100 | 100 | 130.3 | 451 | 84.3 | 0.84 |
| A2 | Air Compressor | Ingersoll Rand | SSR-EP100 | 100 | 128.3 | 458 | 91.7 | 0.89 |

Electrical current on each phase of both air compressors was logged for a period of ten days, at 20-second intervals. In addition, one phase of each compressor was logged for 24-hours, at 2-second intervals. This 2-second interval data allows for a stronger understanding of how the compressors are sequenced and operate. The logged data indicates that compressor A1 operates in modulation capacity control mode and compressor A2 operates in load/unload mode. The plant's compressed air system pressure was also logged during this same time period. An example of the logged amperage data at 2-second intervals can be seen in Figure 1.

When analyzing the power consumption of a load/no-load controlled compressor, it is necessary to consider the change in power factor when loaded versus unloaded. With a spot power measurement, we measured the loaded power factor to be about 0.89 kW per kVA and the unloaded power factor to be about 0.70 kW per kVA. With a linear correlation between 0.89 kW per kVA at 128.3 amps and 0.70 kW per kVA at 63.7 amps, we extrapolate an estimated power factor for all logged amperages of compressor A2.

## Proposed System and Data Collection

In the post-installation scenario, a new 150-hp variable speed drive (VFD) compressor operates as lead and typically carries 100% of the plant's compressed air needs. One of the pre-existing 100-hp compressors operates as a back-up and is occasionally needed to meet peak air demands. Though we did not observe the back-up compressor cycle on during our post-installation logging period, we know it operates as standby in load/no-load capacity control mode with automatic shut off. The measured equipment spot electrical readings, averaged over all three electrical legs, are shown in Table 4.

**Table 4. Post-Installation Equipment Summary and Average Spot Electrical Readings**

| | | | | | Spot Reading Average of 3 Phases | | | |
|---|---|---|---|---|---|---|---|---|
| ID | Equipment Type | Make | Model | Motor Rating (hp) | Loaded Amperage (A) | Voltage (V) | Loaded Power Draw (kW) | Loaded Power Factor (kW/kVA) |
| VFD | Air Compressor | Ingersoll Rand | R110N-A145 | 150 | 191.0 | 465 | 149.7 | 0.97 |
| A1 | Air Compressor | Ingersoll Rand | SSR-EP100 | 100 | 128.3 | 458 | 91.7 | 0.89 |

Electrical current was logged on one phase of each compressor for a period of ten days, at 20-second intervals. The logged data indicates that VFD compressor always operated in a VFD capacity control mode and compressor A1 never cycled on.

## Non-normalized Energy Savings Analysis

This section explains the energy savings analysis conducted purely based on pre and post-installation metered energy consumptions. This analysis approach has so far been acceptable in our experiences with utility efficiency rebate programs within Ohio.

Only seven of the ten days of logged amperage data is used for the analysis of both the pre and post-installation scenarios. This allows for each metering period to represent one typical production week of five weekdays and two weekends. The logged amperage data and the average voltage and power factor measurements were used to calculate the power draw of each piece of equipment using the following equation:

$$\text{Power draw (kW)} = \text{Amperage (A)} \times \text{Voltage (V)} \times \text{Power factor (kW/kVA)} \times 1\ \text{kVA}/1000\ \text{VA} \times \sqrt{\#\ \text{phases}}$$

This calculation was repeated for every 20-second interval of the logged current draw for each piece of equipment. Based on these calculations, the annual energy use and savings for each piece of equipment is summarized in Table 5.

**Table 5. Pre- and Post-Installation Power Draw and Energy Use**

| | Compressors | | |
|---|---|---|---|
| **Pre-Installation Analysis** | | | |
| | **A1** | **A2** | **Total** |
| **Ave Power (kW)** | 83.5 | 57.8 | |
| **Energy (kWh/year)** | 731,202 | 506,332 | **1,237,534** |
| **Peak Demand (kW)** | | | **157.4** |
| **Post-Installation Analysis** | | | |
| | **VFD Comp** | **A1** | **Total** |
| **Ave Power (kW)** | 105.0 | 0.0 | |
| **Energy (kWh/year)** | 920,208 | 0 | **920,208** |
| **Peak Demand (kW)** | | | **119.0** |
| **Savings** | | | |
| | | | **Total** |
| **Energy (kWh/year)** | | | **317,325** |
| **Demand (kW)** | | | **38.4** |

Billed demand is based on the greatest on-peak electricity consumption over any 30-minute period. To determine the peak demand, we calculated an average rolling 30-minute power draw for the compressors. The pre- and post-installation scenario peak demands are shown in Table 5, along with the savings.

## Normalized Analysis of Collected Data

To perform an analysis that normalizes for compressed air demand we must calculate the theoretical compressed air output flow from each compressor based on the measured power draw and each compressor's typical fraction capacity (FC) versus fraction power (FP) curves. Each compressor's FC versus FP curve parameters are determined based on information gathered from Compressed Air and Gas Institute (CAGI) performance data sheets, fully loaded and unloaded spot power measurements and system pressure readings. For this analysis, the applied curves for the 100-hp Ingersoll Rand compressors and the 150-hp VFD compressor are:

*Modulation Mode: FP = 0.30 x FC + 0.70*
*Load/Unload Mode: FP = 0.69 x FC + 0.39*
*VFD Mode: FP = 0.85 x FC + 0.15*

Based on the CAGI data sheets, the maximum flow and power draw for each compressor at the plant operating pressure is shown in Table 6 below.

**Table 6. Summary Maximum Air Flow and Power Draw**

| Make | Model | Motor Rating (hp) | Maximum Flow (acfm) | Maximum Power (kW) |
|---|---|---|---|---|
| Ingersoll Rand | R110N-A145 | 150 | 482 | 89.0 |
| Ingersoll Rand | SSR-EP100 | 100 | 701.0 | 136.0 |

The flow output from each compressor can be calculated based on the equations describing the FC versus FP curves, the maximum flow values and maximum power draw. The compressor output flow is calculated for each 20-second logged data point in both the pre and post-installation scenarios.

It can be seen in the pre- and post-installation flow profiles that the plant's air demand is significantly lower in the post-installation scenario. The average air flow in the pre-installation scenario is 587-cfm; it is 515-cfm in the post-installation scenario. This is a 14% difference. This type of demand change is common in industry, as production output can vary week to week due to events such as equipment downtimes or product sales. To normalize for change in compressed air demand, both the pre and post-installation compressor set-ups need to be subjected to the same flow profile. One way to do this would be to subject both scenarios to the pre-installation flow profile. The projected energy consumption of the post-installation system can then be calculated by using the FC versus FP curve equations. The advantage to using the pre-installation flow profile is that no further analysis needs to be done to the baseline analysis. Only the post-installation scenario needs further analysis. It should be noted that this section only provides analysis for using one week's worth of flow data to normalize, which may be an insufficient metering period. The next section normalizes the data across two weeks of flow data, doubling the flow metering period, to allow for comparison of results.

The simulated energy consumption and savings from subjecting the post-installation system to the pre-installation flow profile is shown in Table 7.

**Table 7. Normalized Pre- and Post-Installation Power Draw and Energy Use Based on Pre-Installation Flow Profile**

| | Compressors | | |
|---|---|---|---|
| **Pre-Installation Analysis** | | | |
| | **A1** | **A2** | **Total** |
| **Ave Power (kW)** | 83.5 | 57.8 | |
| **Energy (kWh/year)** | 731,202 | 506,332 | **1,237,534** |
| **Peak Demand (kW)** | | | **157.4** |
| **Post-Installation Analysis** | | | |
| | **VFD Comp** | **A1** | **Total** |
| **Ave Power (kW)** | 115.6 | 0.3 | |
| **Energy (kWh/year)** | 1,012,996 | 2,749 | **1,015,745** |
| **Peak Demand (kW)** | | | **173.9** |
| **Savings** | | | |
| | | | **Total** |
| **Energy (kWh/year)** | | | **221,789** |
| **Demand (kW)** | | | **-16.5** |

## Normalized Analysis of Collected Data with 14 Day Flow Profile

Alternately, the flow profile duration used for normalization could be doubled if all fourteen days of the totaled pre and post-scenario profiles were used. This would require calculating the theoretical energy consumption of both pre- and post-scenarios based on the known sequencing and FC versus FP curves. This analysis was also performed for comparison and the results are shown in Table 8.

**Table 8. Normalized Pre- and Post-Installation Power Draw and Energy Use Based on Pre and Post-Installation Flow Profile**

| | Compressors | | |
|---|---|---|---|
| **Pre-Installation Analysis** | | | |
| | **A1** | **A2** | **Total** |
| **Ave Power (kW)** | 88.9 | 39.7 | |
| **Energy (kWh/year)** | 778,718 | 347,597 | **1,126,315** |
| **Peak Demand (kW)** | | | **151.9** |
| **Post-Installation Analysis** | | | |
| | **VFD Comp** | **A1** | **Total** |
| **Ave Power (kW)** | 109.4 | 0.2 | |
| **Energy (kWh/year)** | 958,103 | 1,374 | **959,478** |
| **Peak Demand (kW)** | | | **173.9** |
| **Savings** | | | |
| | | | **Total** |
| **Energy (kWh/year)** | | | **166,837** |
| **Demand (kW)** | | | **-22.0** |

## Discussion and Comparison of the Results

Conducting an analysis that normalizes for compressed air flow reduces the calculated energy savings in the case study analysis provided. A comparison of the energy and demand savings between the two analyses is shown in Table 9. Energy savings were reduced by 30% and demand savings decreased by 143%, making them negative. We believe these negative demand savings to be accurate. Even though the facility properly installed a new VFD compressor to efficiently meet almost all compressed air demands, the overall compressed air system motor capacity was increased from 200-hp to 250-hp. Thus, during the few hours of each month when air demand exceeds the capacity of the VFD compressor, the lag load/unload controlled compressor will operate with a relatively poor part load efficiency. This discovery could only be made by conducting a savings analysis that examined and normalized for air demand. It is important to note that this specific case study shows reduced energy savings after normalizing for air demand. However, savings should just as often be increased from normalizing for air demand, as shown in the following case study.

**Table 9. Summary of Flow-Normalized versus Non-Normalized Annual Energy Savings and Peak Demand Reduction**

| | Energy (kWh/year) | Demand (kW) |
|---|---|---|
| Non-Normalized Savings | 317,325 | 38.4 |
| Flow-Normalized Savings | 221,789 | -16.5 |
| % Difference | **30%** | **143%** |

## Case Study 2

The same analysis methodology explained in Case Study 1 was applied to another compressed air system to compare normalized and non-normalized energy savings. This system consisted of three screw compressors, where one was upgraded to a VFD compressor. The results shown in Table 10 show the non-normalized savings versus the normalized savings, based on a 14 day flow profile. It can be seen that the electric consumption savings are cut by 41% after normalization and the demand savings slightly increase by 6%.

**Table 10. Summary of Flow-Normalized versus Non-Normalized Annual Energy Savings and Peak Demand Reduction**

| | Energy (kWh/year) | Demand (kW) |
|---|---|---|
| Non-Normalized Savings | 806,925 | 15.8 |
| Flow-Normalized Savings | 473,345 | 16.8 |
| % Difference | **41%** | **-6%** |

## Case Study 3

This case study presents a scenario where actual flow data from the compressors was available through installed flow meters. The normalization methodology performed is different from the methodology of Case Study 1. The objective of this case study is to further demonstrate the error that can be introduced by not conducting an appropriate analysis of pre and post-installation data and to explain a second methodology for conducting an air compressor efficiency project M&V analysis.

The baseline scenario consists of five 150-hp rotary screw compressors that operated in load/no-load and modulation mode. In the new scenario, two 200-hp compressors were, one with a VFD control to operate as the trim compressor.

Similarly to Case Study 1, amperage loggers were used to log amperages of each compressor over one week of pre- and post- scenarios. Through spot measured power factor and voltage measurements, these logged amperages were converted into calculated power draws. The metered pre and post-scenario energy consumption and savings are shown in Table 11.

**Table 11. Pre- and Post-Installation Power Draw and Energy Use**

| | |
|---|---|
| **Pre-Installation Analysis** | |
| | **Total** |
| **Ave Power (kW)** | |
| **Energy (kWh/year)** | 3,513,675 |
| **Peak Demand (kW)** | 602.9 |
| **Post-Installation Analysis** | |
| | **Total** |
| **Ave Power (kW)** | |
| **Energy (kWh/year)** | 2,942,877 |
| **Peak Demand (kW)** | 602.5 |
| **Savings** | |
| | **Total** |
| **Energy (kWh/year)** | 570,798 |
| **Demand (kW)** | 0.4 |

It can be seen that there are 570,798 kWh per year in energy savings in almost zero demand savings. However, normalizing for air demand reveals significantly different savings. The methodology used to normalize in this analysis was to take the average power draw in the pre- and post-metering scenarios and divide by the average measured air flow across the same time periods. The average flow in the pre-scenario was 1,640 cfm and in the post-scenario was 2,063 cfm. Thus, the average energy intensity of producing compressed air was 0.24 kW/cfm in the pre-scenario and 0.16 kW/cfm in the post-scenario. This is a reduction of 33% in energy intensity. To determine the normalized energy savings, these energy intensities are then multiplied by the average of the pre- and post-scenario flow averages, which is 1,852 cfm. Multiplying this result over the span of an entire year produces annual energy savings. The peak demand savings were then calculated by multiplying the energy intensities by the peak half hour of recorded air flow, which was 2,953 cfm.

The normalized pre- and post-scenario energy consumption and savings are shown in Table 12.

**Table 12. Normalized Pre- and Post-Installation Power Draw and Energy Use Based on Pre-Installation Flow Profile**

| | |
|---|---|
| Pre-Installation Analysis | |
| | Total |
| Ave Power (kW) | |
| Energy (kWh/year) | 3,966,607 |
| Peak Demand (kW) | 736.9 |
| Post-Installation Analysis | |
| | Total |
| Ave Power (kW) | |
| Energy (kWh/year) | 2,641,280 |
| Peak Demand (kW) | 602.5 |
| Savings | |
| | Total |
| Energy (kWh/year) | 1,325,327 |
| Demand (kW) | 134.4 |

### Discussion and Comparison of the Results

Conducting this analysis shows that actual normalizing for air demand significantly increased calculated energy savings. A comparison of the energy and demand savings between the two analyses is shown in Table 13.

**Table 13. Summary of Flow-Normalized versus Non-Normalized Annual Energy Savings and Peak Demand Reduction**

| | Energy (kWh/year) | Demand (kW) |
|---|---|---|
| Non-Normalized Savings | 570,798 | 0.4 |
| Flow-Normalized Savings | 1,325,327 | 134.4 |
| % Difference | -132% | -33500% |

## Conclusions

Though M&V standards and manuals tend to place clear and strict requirements on the accuracy of metering equipment used, the requirements on the analysis techniques of the logged data are soft and vague. This is to be expected since it is much easier for programs to control metering equipment accuracy than it is to control the quality of M&V analysis. In some cases it is even necessary to have flexible requirements since most custom projects are unique and unique analysis approaches are most appropriate.

The presented case studies demonstrate that quality of the analysis approach can far outweigh the accuracy of the logging equipment. It was shown earlier in the paper that we have found about a 3% difference between higher accuracy true power metering equipment and our calculated energy consumption through a single current transducer and spot readings. However, each case study shows much higher percent differences between using normalized analysis approaches versus a non-normalized approach. Furthermore, there are many methods for normalizing and these methods alone can significantly impact deemed savings. For example, the two different normalized flow profiles, shown in Case Study 1, result in a difference in energy savings of 25%.

Thus, this paper demonstrates the importance of technically strong M&V teams that understand the equipment and how energy savings occur from different improvements to understand how to properly meter the equipment and then conduct an appropriate analysis of the data. It also demonstrates the further studies and guidance that should be provided to M&V programs regarding appropriate metering periods, interval periods and variable considerations.

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