BONNEVILLE POWER ADMINISTRATION

Verification by Equipment or End-Use Metering Protocol

October 2018

Verification by Equipment or End-Use Metering Protocol

Version 2.0

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Prepared for

Bonneville Power Administration

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Contract Number 00077045

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1. Introduction

1.1. Purpose

Verification by Equipment or End-Use Metering Protocol (End-Use Metering Protocol) is one of the Measurement and Verification (M&V) protocols used by the Bonneville Power Administration (BPA). It provides guidance for verifying energy savings of measures affecting building equipment or end-use systems using energy use measurements before and after the measures are installed. It assists the engineer in isolating the targeted equipment or end use and selecting the number and types of monitoring points when it would not be cost-effective to monitor all points. This guidance leads the engineer to specific M&V methods to verify the project's savings. It is intended for measures that change load or operating hours, or both load and hours. Savings can be large or small. The protocol can handle non-interactive measures and interactive measures in some circumstances.

The protocol may be implemented in adherence with *IPMVP Options A and B.*[1]

Originally developed in 2012, this *End-Use Metering Protocol* is one of ten documents produced by BPA to direct M&V activities; an overview of the ten documents is given in the *Measurement and Verification (M&V) Protocol Selection Guide and Example M&V Plan (Selection Guide).*

Chapter 8 of this protocol provides full citations (and web locations, where applicable) of documents referenced. The document *Glossary for M&V: Reference Guide* defines terms used in the collection of BPA M&V protocols and guides.

1.2. Protocols Version 2.0

BPA revised the protocols described in this guide in 2018. BPA published the original documents in 2012 as Version 1.0. The current guides are Version 2.0.

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[1] *International Performance Measurement and Verification Protocol.*

1.3. How is M&V Defined?

BPA's *Implementation Manual* (the IM) defines measurement and verification as "the process for quantifying savings delivered by an energy conservation measure (ECM) to demonstrate how much energy use was avoided. It enables the savings to be isolated and fairly evaluated."[2] The IM describes how M&V fits into the various activities it undertakes to "ensure the reliability of its energy savings achievements." The IM also states:

> *The Power Act specifically calls on BPA to pursue cost-effective energy efficiency that is "reliable and available at the time it is needed."*[3] *[…] Reliability varies by savings type: UES, custom projects and calculators.*[4,5] *Custom projects require site-specific Measurement and Verification (M&V) to support reliable estimates of savings. BPA M&V Protocols direct M&V activities and are the reference documents for reliable M&V. For UES measures and Savings Calculators, measure specification and savings estimates must be RTF approved or BPA-Qualified.*[6]

The *Selection Guide* includes a flow chart providing a decision tree for selecting the M&V protocol appropriate to a given custom project and addressing prescriptive projects using UES estimates and Savings Calculators.

M&V is site-specific and required for stand-alone custom projects. BPA's customers submit bundled custom projects (projects of similar measures conducted at multiple facilities) as either an M&V Custom Program or as an Evaluation Custom Program; the latter requires evaluation rather than the site-specific M&V that these protocols address.

1.4. Background

BPA contracted with a team led by kW Engineering, Inc. to assist the organization in revising the M&V protocols that were published in 2012 and used to assure reliable energy savings for the custom projects it accepts from its utility customers. The team conducted a detailed review and user assessment of the 2012 M&V Protocols and developed the revised version 2.0 under Contract Number 00077045.

The kW Engineering team is comprised of:

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[2] 2017-2019 Implementation Manual, BPA, October 1, 2017. *https://www.bpa.gov/EE/Policy/IManual/Documents/IM_2017_10-11-17.pdf*

[3] Power Act language summarized by BPA.

[4] UES stands for Unit Energy Savings and is discussed subsequently. In brief, it is a stipulated savings value that region's program administrators have agreed to use for measures whose savings do not vary by site (for sites within a defined population). More specifically UES are specified by either the Regional Technical Forum – RTF (referred to as "RTF approved") or unilaterally by BPA (referred to as BPA-Qualified). Similarly, Savings Calculators are RTF approved or BPA-Qualified.

[5] Calculators estimate savings that are a simple function of a single parameter, such as operating hours or run time.

[6] https://www.bpa.gov/EE/Policy/IManual/Documents/IM_2017_10-11-17.pdf, page 1.

- kW Engineering, Inc. (kW), led by David Jump, Ph.D., PE, CMVP
- Research into Action (RIA), led by Marjorie McRae, Ph.D.
- Demand Side Analytics (DSA), led by Jesse Smith

BPA's Todd Amundson, PE and CMVP, was project manager for the M&V protocol update work. The kW Engineering team compiled feedback from BPA and regional stakeholders, and the team's own review to revise and update this 2018 *End-Use Metering Protocol*.[7]

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[7] David Jump was the primary author of Version 1.0 of the End-Use Metering Protocol, under Todd Amundson's direction and supported by other members of the protocol development team.

2. Overview of Method

2.1. Description

This protocol provides guidance to verify energy savings for energy conservation measures (ECMs) performed on equipment or end uses. The methods outlined are useful when the savings for an ECM are too small to be resolved with whole-building or facility energy meters, or for stand-alone equipment as may be found in the commercial, industrial, and agricultural sectors. It may also be applied to some new construction ECMs affecting equipment or end uses, as demonstrated in the BPA *End-Use Metering Absent Baseline Measurement: An M&V Protocol Application Guide*.[8] Verifying savings from ECMs that involve multiple pieces of equipment with interactions among multiple or complex energy flow paths are not good applications for this protocol.

The methods in this *End-Use Metering Protocol* are based on and extend the descriptions of retrofit isolation approaches found in *ASHRAE Guideline 14-2014* and its *Annex E for Retrofit Isolation Approach Techniques*, as well as work from Texas A&M's Energy Systems Laboratory.[9] These documents focus on equipment or end uses directly affected by the ECM, such as fans, pumps, motors, lighting, chillers, and boilers typically found in facilities, whether as stand-alone equipment or as a component of a system.

In this protocol, the baseline energy use characteristics of the equipment or end use are broken down into load and hours-of-use components, and whether these components may be considered constant or variable. The impact of the ECM is used to determine the expected post-installation energy-use characteristics. When both baseline and post-installation energy-use characteristics are known, measurement and monitoring activities can be planned, implemented, and analyzed to determine savings.

Depending on available resources and M&V budget constraints, this method may be used in an *IPMVP*[10] *Option A* or an *Option B* approach. Option A is a *key parameter measurement* approach, in which only the most unknown or uncertain quantities are measured while other parameters may be reliably estimated. Under Option B, *all parameters* are measured.

To alleviate strain on budgets and resources, this protocol is flexible to allow use of readily available information, such as nameplate data, equipment specifications, and manufacturer's performance curves. This information may be validated with one-time spot measurements or more rigorously with multiple measurements over the equipment's performance range, depending on project requirements.

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[8] Hereinafter, *Absent Baseline Application Guide.*

[9] For example: *Review of Methods for Measuring and Verifying Savings from Energy Conservation Retrofits to Existing Buildings*, Haberl, J.S. and C. H. Culp, Energy Systems Laboratory, September 2003, revised April 2005.

[10] *International Performance Measurement and Verification Protocol* (IPMVP).

The Option A approach provides a means to apply this protocol to new construction ECMs. In new construction, there is no baseline equipment to measure load or hours-of-use. However, these parameters may be estimated using the manufacturer's specifications, well-founded and documented engineering assumptions, or relevant codes and standards that describe minimum performance levels for new buildings and systems. The BPA *Absent Baseline Application Guide* demonstrates the appropriate method.

Implementing this protocol requires collecting data for important parameters, such as operating hours, fuel use, energy, demand, fluid flow, or temperatures. Sometimes these data are available on a facility energy management system, but frequently stand-alone data loggers must be deployed for some period. Collection of field data is a time and cost consideration that must be addressed when implementing this protocol.

2.2. Applicability

This protocol is applicable for equipment or end uses that meet the following criteria:

- ➡ **Loads** – such as air or water flow, Btu/h, cooling tons, conveyance delivery rates, and so on – that may be isolated and measured (or estimated if using an Option A approach, see below) and their relationships to the energy use rates (i.e., kW) are known or may be developed through engineering and statistical relationships.
- ➡ **Variable equipment operating schedules** may be represented accurately by binned load frequency distributions (see below).
- ➡ **Energy flows** in and out of measurement boundaries are few and/or straightforward to account for through estimations or measurements, and there are negligible interactive effects or interactive effects are intentionally left out of the M&V scope of work.
- ➡ **End uses** that include multiple pieces of equipment but have energy characteristics similar to a single piece of equipment which is applicable under this protocol – for example, a constant volume air handling system where both supply and return fans are within the measurement boundary.

As described above, the energy-use characteristics of equipment or end uses are defined according to their load and hours-of-use components, and whether they are constant or variable. This provides the basis for which measurements and estimations may be made. This protocol is applicable to equipment or end uses that can be classified according these definitions. For brevity, the term *equipment* will be used, although the phrase *equipment and end uses* may be used interchangeably. Following are descriptions of the four load and hours-of-use categories: *constant load, timed schedule* (CLTS); *constant load, variable schedule* (CLVS); *variable load, timed schedule* (VLTS); and *variable load, variable schedule* (VLVS).[11]

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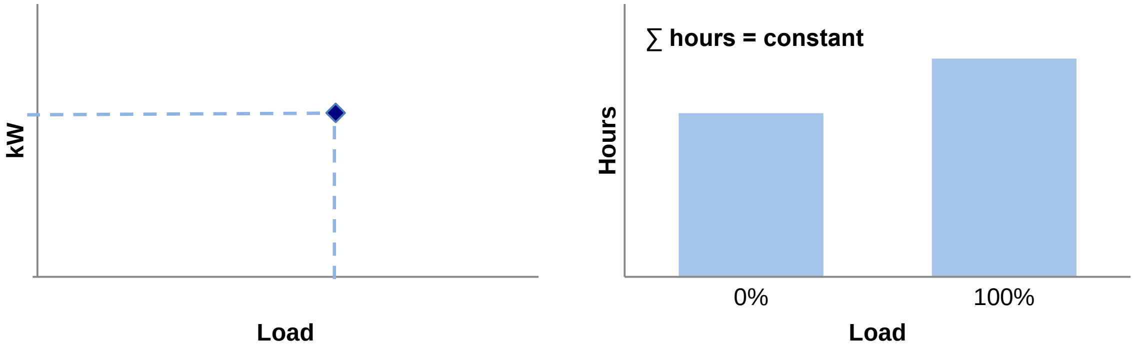
[11] We use slightly different terms than the naming convention in ASHRAE *Guideline 14-2014 Section 5.2.3.* The *Guideline's* terms for these same conditions are: *Constant Load, Constant Use*; *Constant Load, Variable Use*; *Variable Load, Constant Use*; and *Variable Load, Variable Use*.

2.2.1. Constant Load, Timed Schedule (CLTS)

CLTS includes equipment with constant load and constant hours-of-use, as depicted in Figure 2-1. The degree to which a load or hours-of-use is constant may be defined by the user; ASHRAE's *Guideline 14-2014* indicates a 5% limit in the variance[12] of load or hours-of-use to be considered constant. In this category, the measured energy use rate (kW) is often used directly in calculations, after verifying that the load is constant.

Figure 2-1: Load and Hours-of-Use Characteristics of CLTS Equipment



Examples of equipment with CLTS operating characteristics include:

1. Lighting under time-clock control
2. Constant volume air handling units under time-clock control (fan energy savings only)
3. Water treatment plant pump operation (24/7)
4. Constant-speed computer room air-handling unit fan operation (24/7)
5. Water fountain pumps

2.2.2. Constant Load, Variable Schedule (CLVS)

CLVS includes equipment with constant load and varying hours-of-use, as depicted in Figure 2-2. There are two bins in the load frequency distribution; however, the total number of hours in each bin is unknown.

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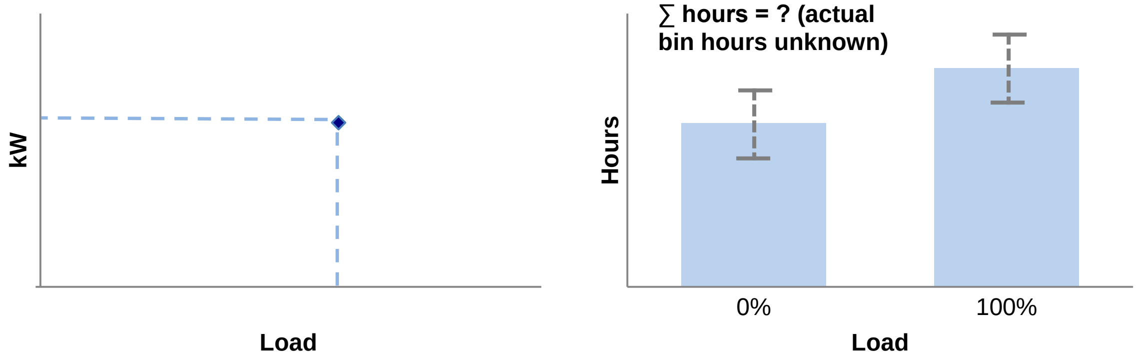
[12] For the purposes of this protocol, this variance is defined as the *coefficient of variation of the standard deviation:* CV(STD). It is calculated by CV(STD) = $\sigma/\bar{x}$, where σ = standard deviation about the mean value, and $\bar{x}$ = mean of measured values.

Figure 2-2: Load and Hours-of-Use Characteristics for CLVS Equipment



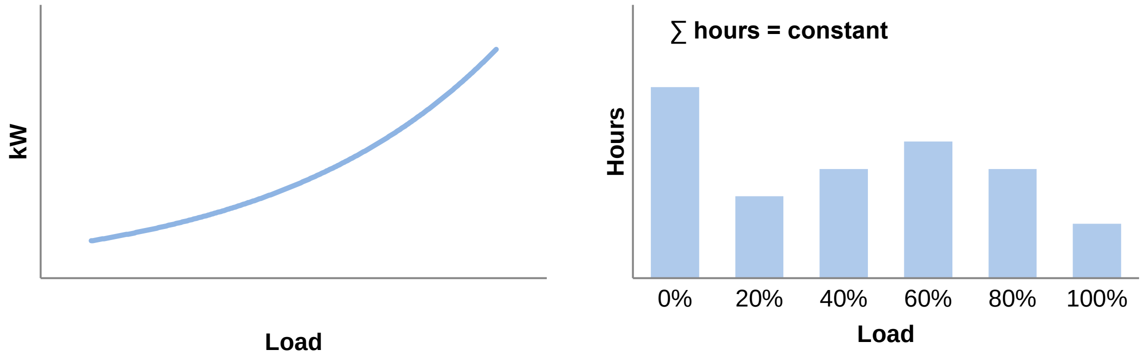
Examples of equipment with CLVS operating characteristics include:

1. Elevators
2. Lighting under occupancy-sensor control
3. Constant-speed cooling tower fan operation (schedule varies with temperature)
4. Hot water or chilled water pumping, no variable frequency drive (VFD; schedule varies with boiler/chiller operation)
5. Auto factory paint-shop exhaust fans

2.2.3. Variable Load, Timed Schedule (VLTS)

VLTS includes equipment with varying load and constant hours-of-use, as depicted in Figure 2-3. While the total number of operation hours is constant, the equipment may spend a fixed number of hours at different loads; this is the basis of the multiple percentage load bins in the load frequency distribution (chart on right-hand side). The load curve (chart on left hand side) may be obtained from engineering models, manufacturer’s performance curves or data, or empirical relationships (regressions) developed from monitored data. The energy use rate (kW) is a function of the load and the load itself may be a function of other parameters.

Figure 2-3: Load and Hours-of-Use Characteristics for VLTS Equipment



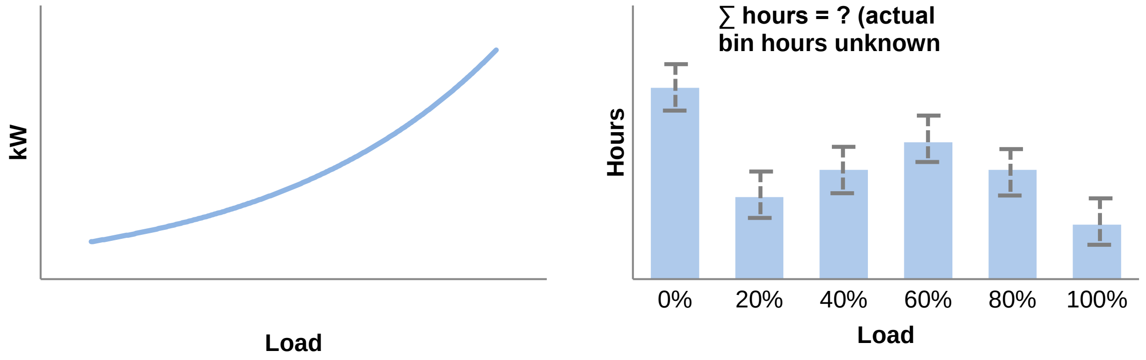
Examples of equipment with VLTS operating characteristics include:

1. Bi-level lighting under time-clock control at each level
2. Variable volume air-handling unit fans under time-clock control for specific flow levels
3. Wastewater treatment plant air blowers maintaining constant dissolved oxygen level (24/7)
4. Industrial 2-speed cooling tower fan operation (speeds controlled by process)
5. Computer room air-conditioning unit operation (condenser unit on roof)

2.2.4. Variable Load, Variable Schedule (VLVS)

VLVS includes equipment with varying load and varying hours-of-use, as depicted in Figure 2-4. In this case, the total number of hours of operation and the number in each percentage load bin are unknown. Load curves may be developed as described above for VLTS.

Figure 2-4: Load and Hours-of-Use Characteristics for VLVS Equipment



Examples of equipment with VLVS operating characteristics include:

1. Variable air volume air handling unit (AHU) under thermostat control
2. Hot-water boiler serving reheat coils in zones
3. Chilled water system maintaining a chilled water supply set point reset schedule
4. Industrial compressed-air system VFD compressor
5. VFD controls on an irrigation pump

2.3. Additional Considerations

Safety

Application of the End-Use Metering Protocol requires that energy use data are collected before and after installation of the energy efficiency project. While most efficiency projects are on systems and equipment that operate in the low voltage range,[13] the voltage levels are high enough to cause severe injury or worse if proper safety precautions are not taken before making electric power measurements. It is of primary importance that personnel follow their organization's safety procedures and equipment whenever the situation warrants it. Implementers of this protocol will need to make decisions about collecting the necessary data based on several factors including: the type and location of measurements, the ability to safely make measurements, and the resources available to make safe measurements. These factors can ultimately determine whether the End-Use Metering Protocol may be applied on the project.

Data Collection Techniques and Devices

This protocol characterizes equipment operation into constant and variable loads and schedules, from which data collection plans will be developed. The plans will describe the data collection techniques to be used, and these techniques will include specification of data collection devices. Generally, data collection devices are either hand-held instruments or data loggers that are left in place to store collected data. BPA and its efficiency program partners maintain inventories of data collection instruments and devices. Please consult your organization's resources for data collection tools. The techniques used to collect data fall into these categories:

1. **Constant loads**. When loads are constant, a single measurement (often referred to as a 'spot' measurement) may suffice to determine the load value. In this case a hand-held power meter measuring volts and amps may be used. A device that measures amperage alone may also be used, and power estimated using the amperage measurement and equipment voltage ratings. More accurate estimates of the load are made from averages of multiple readings taken on the equipment.
    a. Alternatively, it may be necessary to confirm the load is constant by making multiple measurements over time and analyzing the data to assure its variation is low. This is discussed later in this protocol.
2. **Variable loads.** Variable loads require that data be collected over the time period of the load variation cycle, and often over multiple cycles and operating conditions to assure enough data is collected to properly characterize equipment operation in analysis. The duration of the cycle and operating conditions are factors in deciding the duration of the monitoring period as well as the data collection interval, which is how often measurements are made. When using commercially available monitoring devices, a limiting factor is the data storage capacity of the device. Often, an automated control system with trending capability is present and has relevant points on the project

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[13] There are multiple classifications of voltage levels. The low voltage range is 0 to 600V for three-phase power distribution circuits according to ANSI C84.1-1989.

equipment. Trends may be set up to collect data over time. Use of data from the facility's own control system is often preferable, as it is safer, and avoids costly trips back and forth to project sites.

3. **Schedules**. When schedule data is unknown, it may be obtained through the use of data loggers or collection of control system trend data. If data loggers are needed for measuring loads on variable equipment, this data may also be used to determine schedule information. If data loggers are only required to measure equipment schedules, often only equipment status sensors are needed, not power or current measurements that require safety equipment be used. Control system trends are also good sources of data that may be used to define schedules.

Code and Standard Baselines

As described in the Selection Guide, the choice of baseline for any project depends on whether the equipment purchase is optional and based on whether the existing equipment is near the end of its useful life or not. If it is not near the end of its useful life, an existing conditions baseline is used. If it is within a year of the end of its useful life, a current practice baseline is used. Both situations are addressed in this protocol, as well as in the End-Use Metering Absent Baseline protocol. When existing conditions are used, measurements are made on the baseline equipment load and schedule parameters. When current practice baselines are used, baseline measurements may only be made to quantify the schedule parameters, with the load parameter defined by the governing efficiency code requirement.

2.4. Advantages of this Protocol

Use of this *End-Use Metering Protocol* has several advantages:

➡ The protocol enables verification of ECMs on specific equipment through the use of data and information that was used to develop the savings estimates.

➡ This protocol quantifies savings that would otherwise be too small to detect at the whole building level.

➡ Under Option A, this protocol allows use of the abundant technical information from manufacturers, such as equipment performance curves, design and nameplate information, and so on.

➡ With judicious application of data collection devices, many of the measurements required by this protocol can be achieved in a relatively short time period.

➡ The methods described here may be applied to more complicated systems, as long as their operational characteristics fall into the categories identified above.

➡ The methods allow uncertainty in the savings estimates to be quantified, should that be a project requirement.

2.5. Disadvantages of this Protocol

This protocol is not appropriate for multiple ECMs installed throughout a building, where a whole-building approach is more appropriate. The methods described here do not account for energy interactions, such as heating savings from a lighting retrofit project. Projects with highly randomized load and schedule characteristics may not be appropriate for this methodology. Collection of data over the operating range of the equipment may be inadequate if metering periods are too short.

3. Algorithms

3.1. Basic Procedure

Characterizing the equipment's energy-use properties into constant or variable load and hours-of-use facilitates development of the M&V Plan for each project. The fundamental procedure is:

1. Identify which of the four categories – CLTS, VLTS, CLVS, or VLVS – best represents the baseline equipment's load and hours-of-use characteristics.
2. Determine the impact the ECM will have on the equipment's load or hours-of-use. Determine if it will change the load or hours-of use, or change them from constant to variable.
3. Identify which of the four categories best represents the anticipated post-installation equipment's load and hours-of-use characteristics.
4. Identify the most appropriate equations to be used to determine energy savings
5. Determine the relationships between load and hours-of-use terms in the energy savings equation and other parameters, such as temperature, air or water flow, pressure, and so on.
6. Identify and collect the required data in the respective baseline and post-implementation periods.
7. Calculate energy savings using equations and tips as provided below.

Depending on various factors, such as available monitoring resources, savings magnitude, required accuracy, and so on, an *IPMVP Option A Retrofit Isolation: Key Parameter Measurement* or *Option B Retrofit Isolation: All Parameter Measurement* methodology may be used.

Under Option A, key parameters for measurement are identified and the other parameters to the savings calculation may be estimated based on reliable sources. The key parameters to be measured are normally the most uncertain or unknown parameters. Reliable sources include past measurements, manufacturer specifications and performance curves, lighting wattage tables, and so on. Note that in the categories defined above, load and hours-of-use may depend on many other parameters, both constant and time-varying, and Option A allows judicious selection among these parameters for measurement. Note that when a current practice baseline is used, the efficiency requirements specified by the governing jurisdiction's code are used. Because these parameters are not measured, it is considered an application under Option A.

As a simple example, an ECM consists of a lighting occupancy sensor controlling lighting in a general office area. The fixture wattage (load) may be estimated based on a lighting wattage table, but the actual hours of operation of the fixture are measured with lighting status loggers.

Note that Option A does *not* allow both load and hours-of-use parameters (including all their sub-parameters) to be estimated; key parameters must be identified and *measured*. (See below for recommended measurement strategies.)

Under Option B, *both* load and hours-of-use parameters must be measured. The amount and duration of metering depends on the equipment's load and hours-of-use characteristics. For variable load or hours-of-use systems, it is important to capture data over as much of the operation range as possible. Energy consumption is usually expressed on an annual basis. However, variable load or variable hours-of-use equipment often range through their normal operating cycles over much shorter time periods. Unless the required data is collected for other reasons, it is costly and impractical to monitor data for a full year. Results from shorter monitoring periods must be extrapolated to determine annual use. This introduces uncertainty into the calculations, especially if there are seasonal effects on energy use. A general rule to minimize uncertainty is to collect as much data as possible to lessen the amount of extrapolation required.

Table 3-1 lists the suggested sources of data for each of the four categories, showing how some parameters may be estimated under Option A and measured under Option B. As stated above, only one parameter may be estimated under Option A; the other parameter must be measured. The measurement strategies under Option B in the table may be used for these purposes.

Table 3-1: Option A and Option B Data Sources and Measurement Strategies by Category

Option	Parameter	Data Source / Measurement Strategy
		Constant Load, Timed Schedule (CLTS)
Option A	Load	Nameplate information Equipment specifications
	Hours-of-Use	Facility/equipment operation logs Interviews with facility operators
Option B	Load	Spot measurement Average of multiple measurements
	Hours-of-Use	Data logger to record equipment operation status EMS trend on equipment status
		Variable Load, Timed Schedule (VLTS)
Option A	Load	Manufacturer's equipment performance curve Validation of manufacturer's curve with spot measurement of one point to validate curve Use of ambient temperatures as a substitute for load
	Hours-of-Use	Facility/equipment operation logs Interviews with facility operators Hours in ambient temperature bins
Option B	Load	Measurements of load and energy variables over the entire range of operation, development of in-situ performance curve
	Hours-of-Use	Use of logged or trended load data to populate bins in the load frequency distribution

Continued

Option	Parameter	Data Source / Measurement Strategy
		Constant Load, Variable Schedule (CLVS)
Option A	Load	Nameplate information Equipment specifications
	Hours-of-Use	Facility/equipment operation logs Interviews with facility operators
Option B	Load	Spot measurement Average of multiple measurements
	Hours-of-Use	Use of loggers or EMS trends to monitor hours-of-operation over representative periods
		Variable Load, Variable Schedule (VLVS)
Option A	Load	Manufacturer's equipment performance curve Validation of manufacturer's curve with spot measurement of one point to validate curve Use of ambient temperatures as proxy for load
	Hours-of-Use	Facility/equipment operation logs Interviews with facility operators If load driven by ambient temperature, use binned weather data
Option B	Load	Measurements of load and energy variables over the entire range of operation, development of in-situ performance curve
	Hours-of-Use	Use of logged or trended load data to populate bins in the load frequency distribution

3.2. Equations

It is often not necessary to repeat baseline data collection activities in the post-implementation period. In many circumstances, only one parameter must be measured in the baseline period. For example, in a CLTS system where the equipment's power will be reduced, such as in a lighting fixture replacement, it is only necessary to measure the equipment's power in the baseline period and the (reduced) power and hours of operation in the post-installation period, since the hours of operation do not change. Conversely, the hours of operation may be measured in the baseline period. Savings are calculated based on:

- **Equation 1:** $$kWh_{saved} = \left(kW_{base} - kW_{post}\right)HRS_{post}$$

where: kW = electric power demand
kWh = electric energy use
HRS = hours of operation
$base$ = indicates parameter measured (or estimated) in baseline period
$post$ = indicates parameter measured (or estimated) in post-installation
$saved$ = indicates quantity saved

The impact of the ECM on the characteristics of the equipment's load or hours-of-use must be understood prior to planning the data collection and analysis activities of the M&V plan. This can save time and reduce requirements for data collection devices in either the baseline or the post-installation periods.

Table 3-2 through Table 3-5 contain energy savings equations that may be used for each combination of load and schedule category. Within each table, the impact of the ECM on the load, hours-of-use, or both, determines the potential energy savings equations that may be used. These equations show important parameters to measure in the respective baseline and post-installation periods. Please note that these are not an exhaustive set of equations; depending on the equipment and its energy-use characteristics, the equations may take on other forms than those listed. Additional parameters shown in Table 3-2 through Table 3-5 include:

- Q = equipment load such as air or water flow, cooling tons, conveyance delivery rate, and so on
  - Eff = equipment normalized power, expressed as kW/ton, kW/cfm, and so on

Note that the energy rate kW, load Q, and efficiency Eff are often functions of other parameters. For example, cooling tons are a function of the supply and return water temperatures, and flow rates, each of which may be measured. These relationships may be obtained from engineering definitions and principles, or may be obtained from empirical relationships, such as from statistical regression techniques. (See the companion BPA *Regression for M&V: Reference Guide*[14] for more information.)

IPMVP-adherent M&V requires that baseline and post-installation energy use be brought to the same set of conditions, in order to make a fair determination of savings. When the energy rate, load, and efficiency are expressed in terms of measurable independent parameters, the functional forms of the relationships allow savings to be calculated from the same set of conditions (Table 3-2).

Table 3-2: Constant Load, Timed Schedule (CLTS) Equations

ECM Impact	Basic Savings Equation
Changes Load	$kWh_{saved} = (kW_{base} - kW_{post}) \cdot HRS_{post}$ $kWh_{saved} = (Eff_{base} - Eff_{post}) \cdot Q_{base} \cdot HRS_{base}$ $kWh_{saved} = (1 - Eff_{post}/Eff_{base}) \cdot kW_{base} \cdot HRS_{base}$ $kWh_{saved} = (Eff_{base} - Eff_{post}) \cdot Q_{post} \cdot HRS_{post}$ $kWh_{saved} = (Eff_{base}/Eff_{post} - 1) \cdot kW_{post} \cdot HRS_{post}$

Continued

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[14] Hereinafter, *Regression Reference Guide.*

ECM Impact	Basic Savings Equation
Changes Hours-of-Use	$kWh_{saved} = kW_{base} \cdot \left(HRS_{base} - HRS_{post}\right)$ $kWh_{saved} = Eff_{base} \cdot Q_{base} \cdot \left(HRS_{base} - HRS_{post}\right)$ $kWh_{saved} = Eff_{post} \cdot Q_{post} \cdot \left(HRS_{base} - HRS_{post}\right)$
Changes Load and Hours-of-Use	$kWh_{saved} = kW_{base} \cdot HRS_{base} - kW_{post} \cdot HRS_{post}$ $kWh_{saved} = \left(Eff_{base} \cdot HRS_{base} - Eff_{post} \cdot HRS_{post}\right) \cdot Q_{post}$
Changes Load from Constant to Variable $HRS = \sum_i HRS_i$	$kWh_{saved} = kW_{base} \cdot HRS - \sum_i \left[kW_{post,i} \cdot HRS_i\right]$ $kWh_{saved} = Eff_{base} \cdot Q_{base} \cdot HRS - \sum_i \left[Eff_{post,i} \cdot Q_{post,i} \cdot HRS_{post,i}\right]$
Changes Hours-of-Use from Constant to Variable $HRS_{base} \neq HRS_{post}$ $HRS_{post} = \sum_i HRS_{post,i}$	$kWh_{saved} = kW_{base} \cdot HRS_{base} - kW_{base} \sum_i HRS_{post,i}$ $kWh_{saved} = Eff_{base} Q_{post} HRS_{base} - Eff_{base} Q_{post} \sum_i HRS_{post,i}$
Changes both Load and Hours-of-Use from Constant to Variable	$kWh_{saved} = kW_{base} HRS_{base} - \sum_i \left[kW_{post,i} \cdot HRS_{post,i}\right]$ $kWh_{saved} = Eff_{base} \cdot Q_{base} \cdot HRS_{base} - \sum \left[Eff_{post,i} \cdot Q_{post,i} \cdot HRS_{post,i}\right]$

Table 3-3: Variable Load, Timed Schedule (VLTS) Equations

ECM Impact	Basic Savings Equation
Changes Load $\sum_i HRS_{base,i} = \sum_i HRS_{post,i}$	$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot HRS_{base,i} - kW_{post,i} \cdot HRS_{post,i}\right]$ $kWh_{saved} = \sum_i \left[\left(Eff_{base,i} \cdot HRS_{post,i} - Eff_{post,i} \cdot HRS_{post,i}\right) \cdot Q_{post,i}\right]$
Changes Hours-of-Use	$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot \left(HRS_{base,i} - HRS_{post,i}\right)\right]$ $kWh_{saved} = \sum_i \left[Eff_{base,i} \cdot Q_{base,i} \cdot \left(HRS_{base,i} - HRS_{post,i}\right)\right]$
Changes Load and Hours-of-Use	$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot HRS_{base,i} - kW_{post,i} \cdot HRS_{post,i}\right]$ $kWh_{saved} = \sum_i \left[\left(Eff_{base,i} \cdot HRS_{base,i} - Eff_{post,i} \cdot HRS_{post,i}\right) \cdot Q_{post,i}\right]$

Continued

ECM Impact	**Basic Savings Equation**
Changes Hours-of-Use from Constant to Variable	$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot \left(HRS_{base,i} - HRS_{post,i}\right)\right]$ $kWh_{saved} = \sum_i \left[Eff_{base,i} \cdot Q_{base,i} \cdot \left(HRS_{base,i} - HRS_{post,i}\right)\right]$

Table 3-4: Constant Load, Variable Schedule (CLVS) Equations

ECM Impact	**Basic Savings Equation**
Changes Load	$kWh_{saved} = \left(kW_{base} - kW_{post}\right) \cdot HRS_{base}$ $kWh_{saved} = \left(Eff_{base} - Eff_{post}\right) \cdot Q_{base} \cdot HRS_{base}$ $kWh_{saved} = \left(1 - Eff_{post} / Eff_{base}\right) \cdot kW_{base} \cdot HRS_{base}$ $kWh_{saved} = \left(Eff_{base} - Eff_{post}\right) \cdot Q_{post} \cdot HRS_{post}$ $kWh_{saved} = \left(Eff_{base} / Eff_{post} - 1\right) \cdot kW_{post} \cdot HRS_{post}$
Changes Hours-of-Use	$kWh_{saved} = kW_{base} \cdot \left(HRS_{base} - HRS_{post}\right)$ $kWh_{saved} = Eff_{base} \cdot Q_{base} \cdot \left(HRS_{base} - HRS_{post}\right)$ $kWh_{saved} = Eff_{post} \cdot Q_{post} \cdot \left(HRS_{base} - HRS_{post}\right)$
Changes Load and Hours-of-Use	$kWh_{saved} = kW_{base} \cdot HRS_{base} - kW_{post} \cdot HRS_{post}$ $kWh_{saved} = \left(Eff_{base} \cdot HRS_{base} - Eff_{post} \cdot HRS_{post}\right) \cdot Q_{post}$
Changes Load to from Constant to Variable $HRS_{base} = \sum_i HRS_{post,i}$	$kWh_{saved} = kW_{base} \cdot HRS_{base} - \sum_i \left[kW_{post,i} \cdot HRS_{post,i}\right]$ $kWh_{saved} = Eff_{base} \cdot Q_{post} \cdot HRS_{base} - \sum_i \left[Eff_{post,i} \cdot Q_{post,i} \cdot HRS_{post,i}\right]$

Table 3-5: Variable Load, Variable Schedule (VLVS) Equations

ECM Impact	**Basic Savings Equation**
Changes Load	$kWh_{saved} = \sum_i \left[\left(kW_{base,i} - kW_{post,i}\right) \cdot HRS_{post,i}\right]$ $kWh_{saved} = \sum_i \left[\left(Eff_{base,i} - Eff_{post,i}\right) \cdot Q_{post,i} \cdot HRS_{post,i}\right]$

Continued

ECM Impact	Basic Savings Equation
Changes Hours-of-Use	$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot (HRS_{base,i} - HRS_{post,i}) \right]$ $kWh_{saved} = \sum_i \left[Eff_{base,i} \cdot Q_{post,i} \cdot (HRS_{base,i} - HRS_{post,i}) \right]$
Changes Load and Hours-of-Use	$kWh_{saved} = \sum_i \left[kW_{base,i} \cdot HRS_{base,i} \right] - \sum_i \left[kW_{post,i} \cdot HRS_{post,i} \right]$ $kWh_{saved} = \sum_i \left[Eff_{base,i} \cdot Q_{post,i} \cdot HRS_{base,i} \right] - \sum_i \left[Eff_{post,i} \cdot Q_{post,i} \cdot HRS_{post,i} \right]$

4. Measurement and Monitoring

Application of these methods, either under an Option A or Option B approach, requires some measurements or monitoring of load or schedule characteristics. This chapter provides background information to help users develop measurement strategies for their projects.

By convention, savings are reported on an annual basis. Adherence with IPMVP requires that savings be reported only for periods in which measurements are made. It is rarely cost-effective to measure load and hours-of-use parameters for an entire year. Instead, results from shorter time periods are extrapolated. As described previously, the more data that is collected over longer time periods, the less extrapolation that is required. However, any savings result based on such extrapolations is not IPMVP-adherent.

As the energy savings equations show, separating out the load and schedule parameters allows them to be separately determined. Once it is determined that an Option A or an Option B method will be used, the parameters to be monitored are identified.

- ➡ Generally, measurements that characterize the loads do not need to be measured or monitored over an entire year; however, they do need to be measured over a majority of their range of operations.
- ➡ Hours-of-use should be measured over the entire year to be adherent with IPMVP requirements for buildings; however, developing the bin-hours of the load frequency distribution over a representative period and extrapolating to annual totals is a generally accepted practice.

The following sections provide examples of how constant and variable loads may be developed, and how hourly bins may be populated in the load frequency distributions.

4.1. Constant Loads

As described above, the energy-use rate (kW) for constant-loaded systems may be directly measured with spot measurements or quantified by an average of multiple measurements over a short time period. If the variation in the data is less than 5%, then the average value can be considered the constant rate of energy use. Examples of constant-loaded systems, where the rate of energy use is directly measured, include lighting fixture or circuit wattages, and constant-loaded pumps and fans.

4.2. Variable Loads

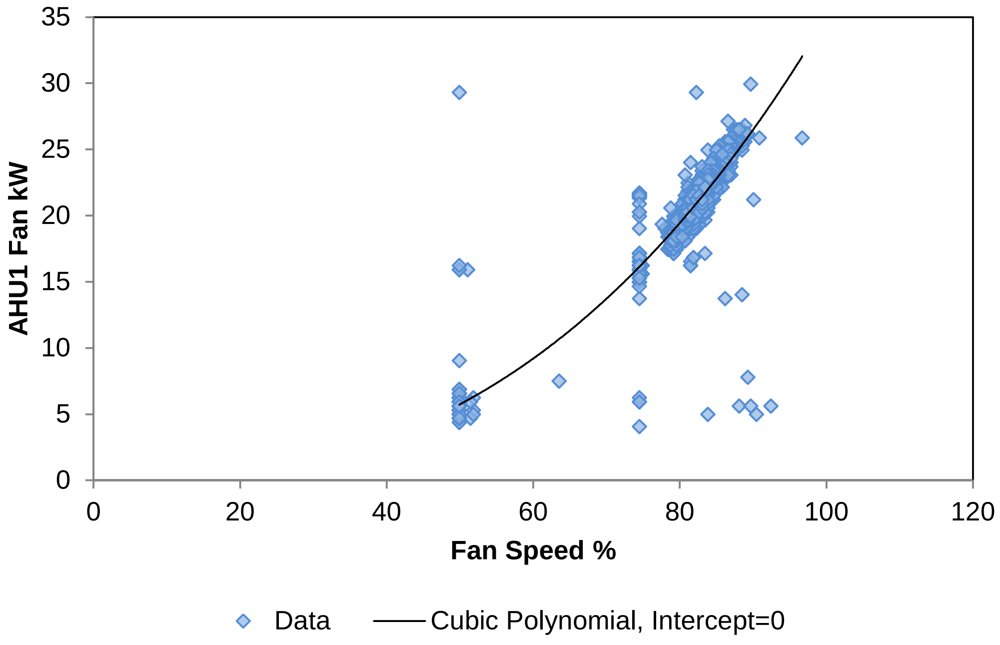
Several terms in the equations above require relationships between energy-use rate and load, and between load and other parameters. There are several techniques that may be used to develop these relationships:

- ➡ Obtain the manufacturer's curve for equipment and use measurements to validate multiple points on the curve.
- ➡ Install monitoring devices to measure power and load and monitor each as equipment is forced though its range of loads by adjusting control settings.
- ➡ Install monitoring devices to measure power and load, or use control-system trending, and monitor the equipment over time as the equipment is operated through its range.

Each of the above techniques provides a set of data that can be used to develop or validate a relationship between the load and energy-use rate (power). These relationships may be developed from engineering principles or empirically by regression. (Please see *Regression Reference Guide* for further information.)

As an example of developing a direct relationship between a load and energy-use rate, Figure 4-1 shows the relationship derived between fan speed (percent) and fan kW for a variable speed supply fan in a university computer science building. The data were collected over a two-week period from temporarily installed kW loggers and corresponding trends of fan speed from the building's energy management system. The data were plotted in a scatter plot and a cubic polynomial relationship was fitted to the data using the least squares technique – which is common in most spreadsheet applications.

Figure 4-1: Curve Fit of Fan kW as a Function of Fan Speed



4.3. Timed Schedule

Quantifying constant hours-of-use for either constant- or variable-load equipment is generally a straightforward process. For constant loads, the number of hours that the equipment is operating must be verified. For variable loads, the number of hours within predefined load bins must be verified. A representative time period is selected over which the operating hours are measured. The monitoring period can be considered representative of the entire year if the relative distribution of hours among the bins is the same in the monitoring period as for the entire year.

As a descriptive example for a constant-load project, if an office building has regular occupancy hours that are the same all year, then a measurement period of one month may be representative of the entire year's operations. For a lighting retrofit project (assuming lighting on the interior of a building in spaces away from daylight), status loggers may be installed to determine the lighting operation hours for each day of the week. After a month of status data is collected, the average hours of operation of each day – whether it is a weekday, weekend, or holiday – is determined, and the total annual hours of operation are calculated by multiplying each day's average by the number of occurrences of those daytypes in the year (a number close to 52 in most cases), and then by adding them together.

The previous example's framework may also be used for variable-load projects with timed schedules. Consider a computer room air conditioning (CRAC) unit that operates to maintain the data center's space temperature at 70° F throughout the year. It is a split system with a condenser unit on the roof; hence, it is variable load, as the AC unit must push heat to the ambient air throughout the seasons. Since the CRAC unit duty cycles more or less frequently to meet load requirements, and the power of each on-cycle can be measured, the average hourly power can be a used to develop a regression with the ambient temperature.

Ambient temperatures and CRAC unit status signals are trended in an energy-management system. Ambient temperature bins of 5° F are defined and the number of CRAC unit operation hours within each bin is determined for a defined monitoring period. The period selected should be representative of the entire year. This means that the collected data must span as much of the operating range as possible, preferably over 90% of the range. With such representative data, then the annual operation hours of the CRAC unit in each load bin may be quantified by multiplying the bin's measurement period operation hours by the ratio of annual operation hours divided by the measurement period operation hours.

The above two examples demonstrate that the characteristics of each project's equipment has unique characteristics and insights that help determine appropriate measurement scenarios. These insights can be used to develop cost-effective monitoring plans.

4.4. Variable Schedule

Quantifying variable hours-of-use for either constant- or variable-load equipment is more dependent on the characteristics of each project's equipment. The hours-of-use may be dependent on some driving variable. For example, a chilled-water pump may have more hours-of-use in the warmer summer months than in winter months, or a building's lighting schedule may vary with the addition of daylight controls, having shorter hours of operation in summer than in winter. It is also possible that a representative period may not exist.

Regression techniques to determine the dependency of hours-of-use on an independent parameter may be used. For example, the daily hours-of-use of the chilled water pump may show a good relationship with average daily temperature. If a regression technique is used, the monitoring period should capture data over the entire range of daily pump operations and daily temperatures. This period may be less than one year. Annual energy use and savings may then be determined by extrapolation using ambient temperature data from a typical mean year weather file. The standard error of the regression may be used in savings uncertainty calculations.

5. Uncertainty

The methods described in this protocol provide a framework to determine uncertainties in the load and schedule parameters, as well as the estimated savings uncertainty. Because BPA generally does not require rigorous estimates of savings uncertainty, this chapter will only present general concepts and demonstrate how savings uncertainties may be calculated using this protocol's load and schedule framework.

The term *uncertainty* is used when the actual value of something that is measured, or estimated from an analysis, is unknown. It is a probabilistic statement about how often a specified range around the predicted value contains the actual value. The *confidence limits* define that specified range that has a certain probability of containing the true value. For example, a savings uncertainty statement may say that the savings are "500 kWh, ± 5% at the 95% confidence level." This means that with a probability of 95%, the range of 475 to 525 kWh includes the true value. A statement of "500 kWh, ± 5% at the 68% confidence level" means that with a probability of 68%, the range of 475 to 525 kWh includes the true value. Contrast the term *uncertainty* with the term *error*. Error is the difference between a measured or predicted value and the true value. A statement of the accuracy of a prediction, or *precision*, (such as ± 5%) is meaningless without an accompanying statement of its confidence level (such as 90%). (Refer to the *Glossary for M&V: Reference Guide* – a companion document to this protocol – and to statistical and experimental methods handbooks to find more information on the definitions of *uncertainty*, *error*, and *confidence limits*.[15])

Since M&V is based on measurements, physical and statistical modeling, and predictions, rigorous uncertainty analysis begins from physical measurements of the data, and propagates through the analysis, to a final estimate of savings uncertainty. When sampling of multiple similar projects is used, the savings uncertainty of each sample must be at the same confidence interval before combining to determine that population savings and uncertainty. Standard error propagation equations are shown below. In these equations, a and b are two values being combined, x is the result, k is a constant, and the symbol Δ represents the error in the value. Also, Δa is the absolute error of the value a, and $\Delta a/a$ is its relative error.

- **Addition and subtraction:** $x = a + b$; $\Delta x^2 = \Delta a^2 + \Delta b^2$
- **Multiplication and division:** $x = a \cdot b$; $(\Delta x/x)^2 = (\Delta a/a)^2 + (\Delta b/b)^2$
- **Exponential:** $x = k \cdot a^k$; $\Delta x = k \cdot \Delta a \cdot a^{k-1}$ and $x = a^{1/k}$; $\Delta x = \Delta a \cdot a^{1/k} / ka$

The following sections provide general insight on how uncertainties in the load and hours-of-use parameters may be determined. A more thorough description of uncertainty estimation is beyond

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[15] Several good sources exist. On the Internet, please consult the *Engineering Statistics Handbook* (*NIST/SEMATECH e-Handbook of Statistical Methods*).

the scope of this protocol. Refer to *ASHRAE Guideline 14 Annex B, Determination of Savings Uncertainty* for a more detailed discussion of savings uncertainty.

5.1. Constant Loads

Constant loads may be characterized by a one-time measurement, or an average of several measurements. If a one-time measurement is used, the measurement instrument's rated or calibrated accuracy is the only available information upon which to obtain an uncertainty estimate. *ASHRAE Guideline 2-2010 (RA 2014)*[16] recommends using a 95% confidence limit with instrument accuracies. For calibrated instruments, their accuracy is generally an indication of its random error, with its bias error – bias in the measurement process – having been eliminated by calibration.

An average of multiple measurements of the same parameter with a calibrated instrument reduces the overall uncertainty of the parameter's estimated value. For multiple measurements, the *standard deviation* may be used as the uncertainty estimate. This quantity must be calculated to determine whether the load may be characterized as constant. It is part of the coefficient of variation (CV) and must be less than 5%. Please refer to the suggested statistical references to determine confidence limits about the average value.

5.2. Variable Loads

Variable loads are represented by an equation, which may be derived from physical principles or from statistical modeling. Figure 5-1 shows upper and lower prediction limits about the regression line.

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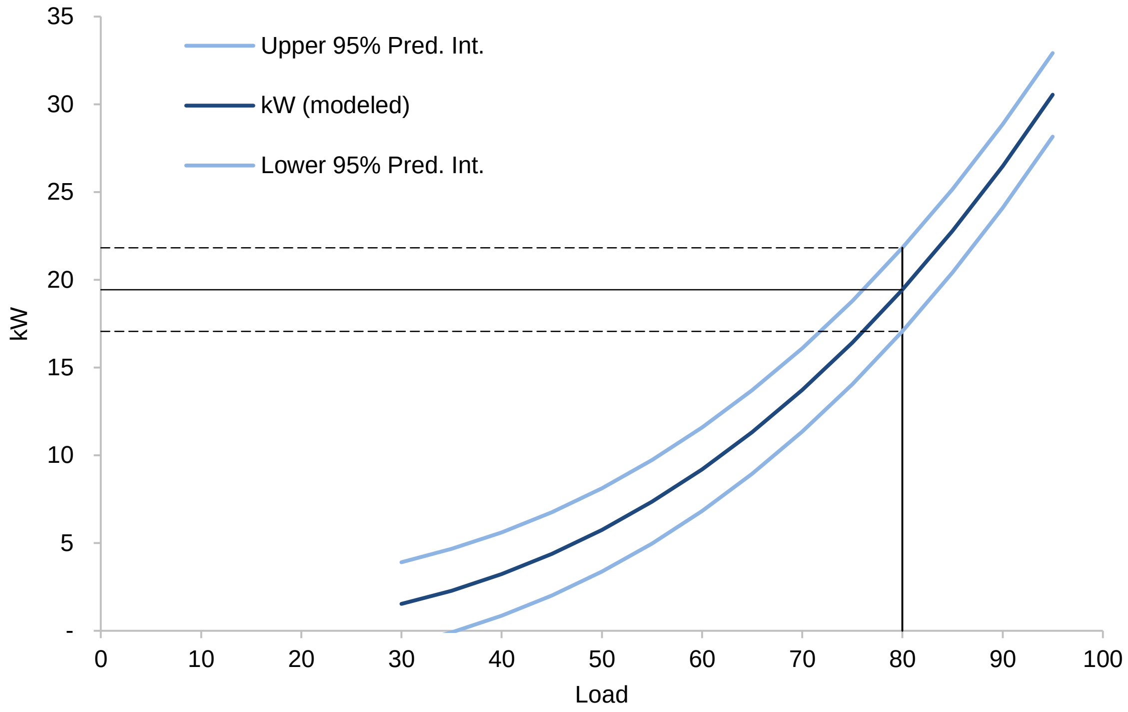
[16] *ASHRAE Guideline 2-2010 (RA 2014): Engineering Analysis of Experimental Data*.

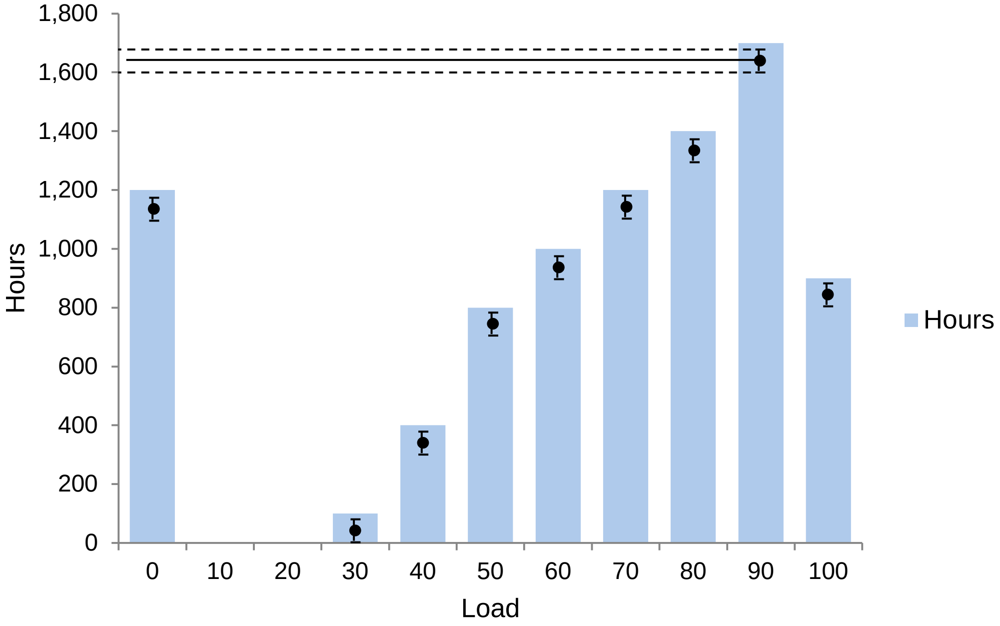
Figure 5-1: Regression Line Showing Upper and Lower Prediction Limits



5.3. Timed Schedule

For timed schedules, the total operation hours for the year are constant, whether the load is constant or variable. For variable loads, the number of hours in each load bin is constant. If operating hours are monitored throughout the year, there is very little uncertainty in the result. However, rarely is it cost-effective to monitor hours for the entire year, unless such data is already available. For these cases, a representative period of operation is selected, operation hours are measured, and annual operation hours are determined by extrapolation. Usually an average daily or average weekly number of operation hours over a representative time period are determined for each load bin (whether constant or variable load) of the load frequency distribution. These averages have associated confidence intervals, as shown in Figure 5-2, for one load bin, and are assumed to be representative of the annual daily or weekly load bin operation hours. The uncertainty of the estimated annual operation hours of each load bin is assumed to be the same as that for the representative period. Please refer to the BPA *Sampling for M&V: Reference Guide* for more information on using samples.

Figure 5-2: Representations of Uncertainty in Load Frequency Distributions



5.4. Variable Schedule

For many cases, the strategy outlined above may be used to determine the uncertainty in annual operation hours. For other cases, the hours-of-use may be dependent on an external parameter, such as when the hours-of-use increase or decrease depending on the season. In such cases, a regression relationship between hours-of-use and ambient temperature may be developed. The uncertainty in the predicted hours-of-use would then be developed in the same way as in the case of variable load above.

6. Minimum Reporting Requirements

6.1. Measurement and Verification Plan

6.1.1. Essential Elements of the Measurement and Verification Plan

Proper savings verification requires planning and preparation. The IPMVP lists several requirements for a fully-adherent M&V plan.[17] The *End-Use Metering Protocol* describes methods for verifying savings in equipment and end uses. This protocol describes planning requirements, as well as specific measurement and analysis activities in the baseline and in the post-installation periods. Documenting in an M&V Plan how these requirements will be met is important so that others who subsequently become involved in the project can obtain a full understanding of the project's history and progress. The following are the essential items in documenting a savings verification plan.

- **Measurement Boundary:** Define the boundary around the equipment or end use within which the savings will be verified. This boundary can be around a specific piece of equipment, such as a pump and its motor, or a combination of equipment comprising a building subsystem, such as an air-handling system or chilled-water system.
- **Baseline Equipment and Conditions:** Document the end-use baseline systems, equipment configurations, and operational characteristics (operating practices or operation schedules that characterize load or hours-of-use). This includes equipment inventories, sizes, types, and condition. Describe any significant problems with the equipment.
- **Energy and Independent Variable Data:** Describe how equipment load is characterized and what additional parameters are required to characterize it. Describe its operating practices or operation schedules that characterize its hours-of-use. Include all energy data from spot measurements and short- or long-term monitoring from each source where data was collected. Define the baseline time period for the end use.
- **Reporting Period:** Describe the length of the reporting period and the activities that will be conducted, including data collection and sources.
- **Analysis Procedure:** Describe how the baseline and post-installation energy use or demand will be adjusted to a common set of conditions. Describe the procedures used to prepare the data. Describe the procedures used for analyzing the data and determining savings. Describe any extrapolations of energy use or savings beyond the reporting period. Describe how savings uncertainty (if required) will be estimated. Document all assumptions.

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[17] *Chapter 5, IPMVP Volume I – 2010.*

- **Option A Requirements:** For each non-key parameter, specify the basis for the estimated values used. Describe their source or sources. Describe the impact of any significant variation in the values used and what otherwise would be measured on the calculated savings.
- **Savings Verification Reports:** Describe what results will be included in the savings reports. Describe what data and calculations will be provided. Describe when savings will be reported for the project. Indicate the reporting format to be used. See the section below regarding the *Savings Verification Report* for the minimum requirements.

6.1.2. M&V Plan Additional Elements

The IPMVP describes several other elements of a good M&V plan. These items are good practice in general, but not necessary for every project. Many of them are provided here for reference and consideration for inclusion in M&V Plans written under this protocol.

- **Energy Prices:** Document the relevant energy prices to be used to value the savings. This can be a blended electric rate or a schedule of rates based on time-of-use. Note that the latter will add significant complexity to the calculations.
- **Measurement Instrument Specifications:** Document the instruments used to obtain the data used in the calculations, including their rated accuracy and range. Identify the last instrument calibration date.
- **Budget:** Estimate the budget required for the savings verification activity. Estimate labor and material (e.g., meters and instruments, associated safety equipment, etc.) costs and provide an approximate schedule for when activities will occur.
- **Quality Assurance:** Describe any quality assurance activities that will be conducted as part of this M&V project. This may include how data is validated, how IPMVP Option A estimates are checked, identifying other parties who will review the work, and so on.

6.1.3. Documentation for BPA Database

The documentation should also include the following information to support review and inclusion of the project and measure in the BPA *Energy Efficiency Central* database (*EE Central*)*:*

- Utility name
- Utility program
- Sector (commercial/industrial/residential)
- Existing building or new construction
- Site address (this will be used to establish the climate zone)
- Building type (examples: office, school, hospital)

- Building size, square feet
- Affected end uses (examples: HVAC, interior lights, exterior lights, receptacle plugs, DHW)
- Affected system (examples under HVAC: cooling plant, heating plant, HVAC fans, terminal units, controls)
- Affected equipment type (examples under cooling plant: chiller, packaged unit, cooling tower, pumps)
- Measure type (broad category)
- Measure name (specific category)

6.2. Savings Verification Report

6.2.1. General Verification Report Requirements Based on IPMVP

After the M&V calculations have been completed, the savings and actual M&V process used need to be documented.

Per the IPMVP, the *Savings Verification Report* should follow the savings verification report requirements described in the project's M&V Plan. Any deviations from the M&V Plan must be clearly described. If the M&V method followed the M&V Plan, then the information in the M&V Plan does not need to be repeated but can just reference the Plan. However, deviations from the planned method, measurement boundary, baseline characteristics, etc. necessitate new descriptions.

IPMVP Chapter 6, M&V Reporting, generally requires the following:

- Report both energy and cost savings.
- Report the data relevant to the reporting period, including the measurement period and the associated energy data and independent variables. Any changes to the observed data must be described and justified.
- Describe any non-routine baseline adjustments, including the details of how the adjustments were calculated.
- Report the energy prices or rates used in the cost-savings calculations.

In addition, actual data for baseline and post-period energy use should both be reported.

6.2.2. Additional Savings Verification Report Requirements

Load and Schedule Relationships

In the basic procedure for the *Verification by Equipment or End-Use Metering Protocol*, one of the numbered items states, "Determine the relationships between load and hours-of-use terms in the energy savings equation and other parameters, such as temperature, air or water flow, pressure, and so on." This includes the relationships of daytypes and seasons to load and hours-of-use.

These relationships are important for all protocols, not just the *End-Use Metering Protocol*. In general, if the power or energy varies with respect to ambient temperature or another independent variable, then a relationship (e.g., regression) must be developed. Schedule variations require similar considerations.

The energy modeling protocol is obviously built on these relationships, and energy indexing uses the ratio between energy and some independent driving variable – another relationship. Similarly, spreadsheet-based engineering calculations should use relationships (also described as correlations) to describe the load.

The savings verification report should clearly define loads and schedules, and their relationship to other variables:

- ➡ **For a constant load**, the load value and units should be provided, as well as how the load value was obtained. If any proxies are used to define the load, the proxies should be justified and their development described.
- ➡ **For variable load**, the load frequency distribution should be provided, along with a description of how it was obtained. For loads that can be any value, they should generally be grouped into 5 to 10 bins, but this is dependent upon how much the load varies. For example, if the load varies from 0% to 100%, 10 bins might be appropriate, but if the load only varies from 80% to 100%, then 2 to 4 bins might be appropriate.
- ➡ **For a timed schedule**, report the source for the schedule and the total annual hours.
- ➡ **For a variable schedule**, report the source for the estimate of the hours during the measurement period and the total annual hours.

Variable load information, energy models, and load correlations for engineering calculations are all similar and should be shown graphically in an x-y (scatter chart), as well as an equation or table. Load frequency distributions should be shown in both a bar chart and a table.

Savings Verification Report Information

The report should include the following information in most cases. It may be organized in this order with a separate section for each of these items, or in another order or organization that makes sense for that program or project.

1. The data for the baseline period, including the time period, monitoring intervals, and data points should be described.
2. The load and schedule for the baseline period, and any relationships associated with variable loads or schedules, should be clearly defined.
3. The impact of the ECM on the load or hours-of-use in the reporting period should be described.

4. The data for the reporting period, including the time period, monitoring intervals, and data points should be described.
5. The load and schedule, and any relationships associated with variable loads or schedules, should be clearly defined for the reporting period.
6. The equations used to estimate baseline consumption, reporting period consumption, and savings should be listed and explained.
7. Report consumption (and where relevant, demand), as well as savings, since this facilitates review and reasonableness checks.
8. As required by IPMVP, report the energy prices or rates used in the cost savings calculations.
9. Also, as required by IPMVP, report both energy and cost savings.
10. Provide verification of potential to generate savings.

Post Installation Verification of Potential to Generate Savings

IPMVP Section 4.3 requires that, "After the ECM is installed, inspect the installed equipment and revised operating procedures to ensure that they conform to the design intent of the ECM." Therefore, an IPMVP-adherent process requires evidence that the efficiency measures have the potential to generate savings. BPA may require short-term monitoring, spot measurements, production data, or other forms of verification to confirm potential.

Verification includes notation of any changes to the project subsequent to the M&V plan. If the project changed, the energy and demand savings should be recalculated based on as-installed conditions. Data and analysis from metering performed before or after installation should be included with the calculations.

In general, verification of potential to generate savings can take either of two forms:

- ➡ Installation verification
- ➡ Operational verification

Installation Verification

Installation verification is the less rigorous of the two verification methods. It demonstrates the measures were installed as planned. This demonstration may vary by measure. Project developers are required to describe the evidence and documentation they plan to provide to demonstrate that the measures were installed, and this evidence and documentation belongs in the savings verification report.

Examples of installation verification include:

- ➡ Photographs of new equipment
- ➡ Photographs of new control set-points

- Screen captures from EMCS
- Invoices from service contractors (invoices should not be the sole form of evidence, but may supplement other verification documentation).

Operational Verification

Operational verification demonstrates that in the post-installation period, the system is operating (or not operating) as modeled in the calculations. It is based on visualization of *operational* data (as opposed to *energy* data) collected during one or more site visits after the measures have been installed.

Operational verification is in addition to installation verification and documentation should include the same types of evidence as for installation verification. In addition, the data logging, control system trending, or functional tests used to establish baseline shall be repeated to demonstrate that operations have been improved. Documentation of the commissioning of the new systems or equipment can be used for operational verification.

If the collected post-installation data, test results, and/or commissioning indicate less than predicted performance, or that the measures were not installed as assumed in the savings calculations (for example, due to incorrect or partial installation, or other circumstance), either:

- Act to help the customer fully install the measure properly and then re-verify it using these procedures; or
- Use the same calculation methodology with the post-installation data to calculate a revised measure savings estimate.

Choice of Verification Method

Common, well-known measures, measures with low expected savings, and measures whose savings estimates have considerable certainty, may need only installation verification. Measures with large savings and measures with less certain savings (whose savings can vary greatly dependent upon application) typically require operational verification.

Thus, there is no hard-and-fast rule for this choice. The analyst should recommend a verification method and the evidence expected to be presented for verification when submitting calculations or simulations. The final choice of verification method and evidence will be made by the reviewer.

7. Examples

The following are representative examples of how the *End-Use Metering Protocol* may be implemented for some common project types.

7.1. Example 1: Simple Pump Motor Replacement (Option B: ECM Reduces Load)

7.1.1. Overview

Condenser water from a cooling tower in an automobile factory cools the painting process equipment and operates over two 8-hour shifts per day for 5 days per week. It does not operate on holidays. The tower has a 5-hp condenser water pump operating at constant load over these hours. Although it has several years of useful life remaining, the pump motor is eight years old and has a lower rated motor efficiency than newer models available. This motor will be replaced with a more efficient model. No changes to its operation are planned.

7.1.2. M&V Approach

The end-use metering protocol will be used to calculate and verify the savings from this pump motor replacement project.

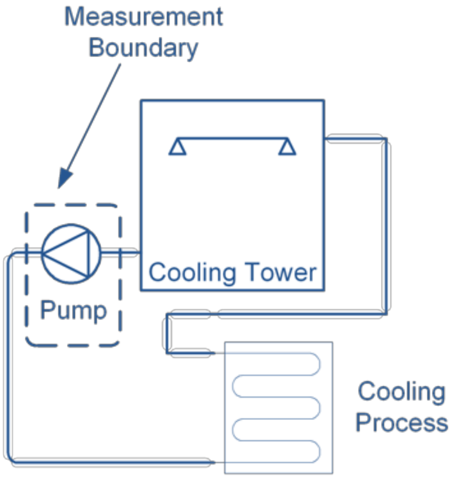
M&V Option

The *Option B: All Parameter Measurement M&V Option* will be used. Note, this method may not fully adhere to IPMVP requirements.

Measurement Boundary

The measurement boundary is drawn around the pump as shown in Figure 7-1. Since the water flow will not be changed, the only impact of this measure on energy use will be on the electric energy use. Electric energy use of the pump motor is the only savings to be verified during this M&V analysis (no gas savings, etc.).

Figure 7-1: System Sketch



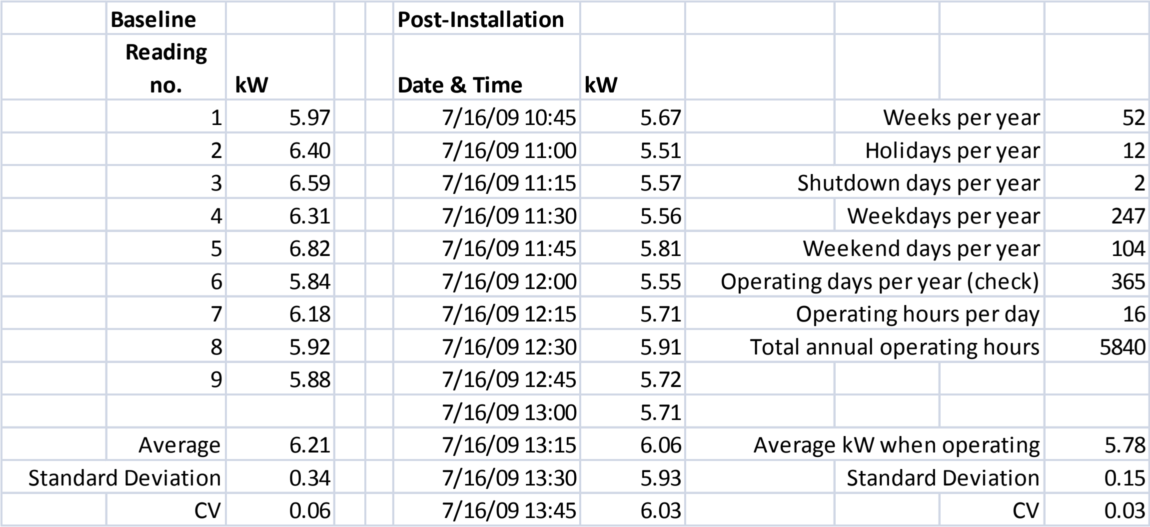
Baseline Period

This pump and motor operate at constant load for a known amount of time. To verify constant load operation, a handheld wattmeter is used to read the power demand of the pump. Several one-minute interval readings are made with the wattmeter while the instrument is attached to the pump's motor control center circuits.

Post-Installation Period

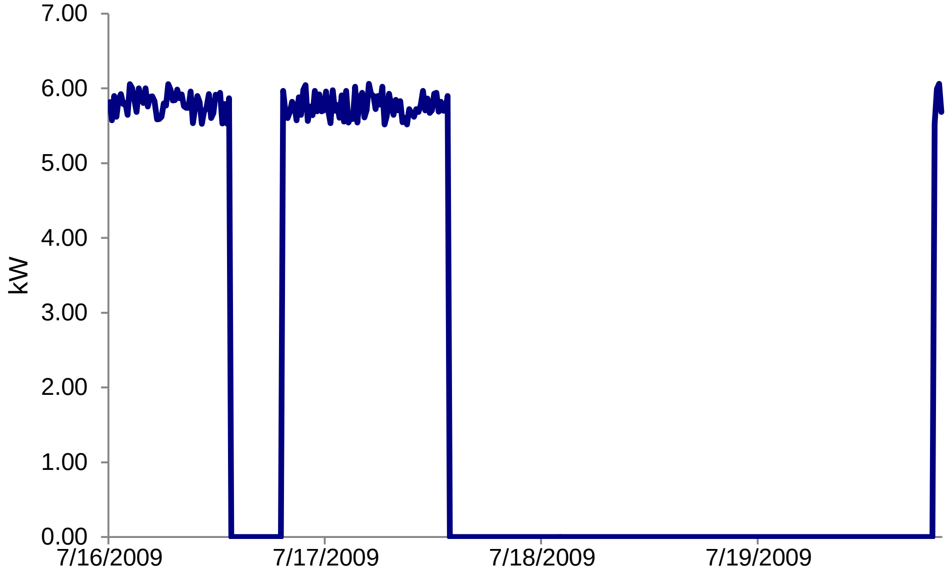
After the motor has been replaced, both the new wattage and operation schedule are measured. A power logger is placed on the motor's power circuits in the motor control center and set to record its power at 15-minute intervals for two weeks, spanning two weekends of non-operation. Both the time and power readings are uploaded to a spreadsheet. Figure 7-2 shows a portion of the spreadsheet with the measured baseline and post-installation data. A time series chart in Figure 7-3 shows a snapshot of operation over one of the monitored weekends, confirming 16 hours per day of weekday operation, and no operation during the weekend.

Figure 7-2: Energy Data



	Baseline				**Post-Installation**					
	Reading no.	**kW**			**Date & Time**	**kW**				
	1	5.97			7/16/09 10:45	5.67			Weeks per year	52
	2	6.40			7/16/09 11:00	5.51			Holidays per year	12
	3	6.59			7/16/09 11:15	5.57			Shutdown days per year	2
	4	6.31			7/16/09 11:30	5.56			Weekdays per year	247
	5	6.82			7/16/09 11:45	5.81			Weekend days per year	104
	6	5.84			7/16/09 12:00	5.55			Operating days per year (check)	365
	7	6.18			7/16/09 12:15	5.71			Operating hours per day	16
	8	5.92			7/16/09 12:30	5.91			Total annual operating hours	5840
	9	5.88			7/16/09 12:45	5.72				
					7/16/09 13:00	5.71				
	Average	6.21			7/16/09 13:15	6.06			Average kW when operating	5.78
	Standard Deviation	0.34			7/16/09 13:30	5.93			Standard Deviation	0.15
	CV	0.06			7/16/09 13:45	6.03			CV	0.03

Figure 7-3: Chart Representation



7.1.3. Algorithm

The baseline category is CLTS. Both load and operating schedule are constant. The number of operating hours each year is constant. The pump motor power will be measured in the baseline period.

Replacing the pump motor with a more efficient motor only reduces the motor power. The operating schedule does not change. The post-installation category is also CLTS. The pump motor kW and operating schedule were measured over a two-week period. Annual energy use is calculated by **Equation 1**, from Table 3-2:

- **Equation 1:** $kWh_{saved} = (kW_{base} - kW_{post})HRS_{post}$

7.1.4. Annual Savings

- ➡ The total operating hours are shown in the spreadsheet: 5,840 hours
- ➡ The energy savings are calculated to be (6.21 – 5.78) * 5,840 = 2,511 kWh.

7.2. Example 2: Automobile Factory Paint Shop Exhaust Fans (Option A: ECM Reduces Schedule)

7.2.1. Overview

Exhaust fans in the paint shop at an automobile factory operated continuously throughout two 8-hour work shifts (6:00 am to midnight) during each work week. There were four days of maintenance downtime in the previous year. There were four paint booths within the shop, each with 60-hp constant speed fans. The factory's engineering staff implemented controls in each paint shop to monitor air quality and shut the fans off when the paint shop was not used, and air quality was at acceptable levels. This resulted in the exhaust fans being operated only when needed as cars were cycled through the paint shop and significantly reduced the number of operation hours per year.

7.2.2. M&V Approach

The end-use metering protocol was used to calculate and verify the savings from this paint shop controls project.

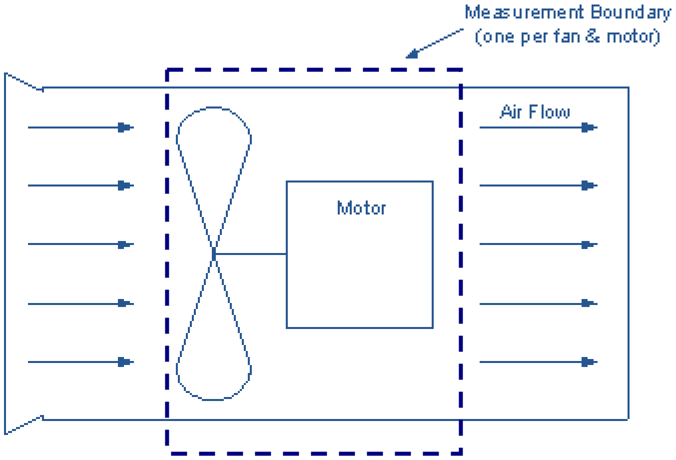
M&V Option

The *Option A: Key Parameter Measurement M&V Option* was used. The key parameter was the number of operation hours of the exhaust fans. Exhaust fan power will be estimated based on motor nameplate data and a spot measurement on each fan.

Measurement Boundary

A measurement boundary was drawn around each exhaust fan, as shown in Figure 7-4. Exhaust fan motors were operated at constant speed during each shift of factory operation. The exhaust fan motors will not be affected by the planned changes. The only effect of the ECM was to reduce the hours of operation.

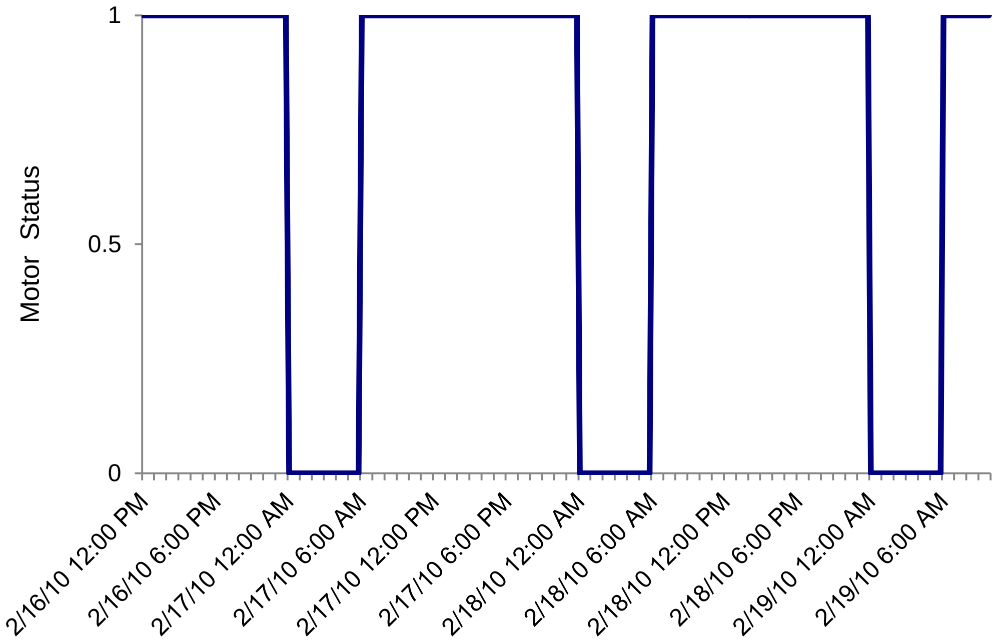
Figure 7-4: System Sketch



Baseline Period

The baseline equipment was operated under a constant load timed schedule system (CLTS). The motor and fan were operated at a constant load for a known amount of time. The nameplate horsepower rating from each fan motor was collected; the brake horsepower was calculated and compared against a spot measurement of each fan's power use when operating. This verified the engineering assumption of each fan's power draw. The fan operation schedule was verified using a motor status logger on each of the four fans; logging was conducted over a 2-week period to verify that the fans operated continuously over both work shifts each working day. Results of the baseline motor status logging are shown in Figure 7-5.

Figure 7-5: Baseline Operation – Fan EXH 23



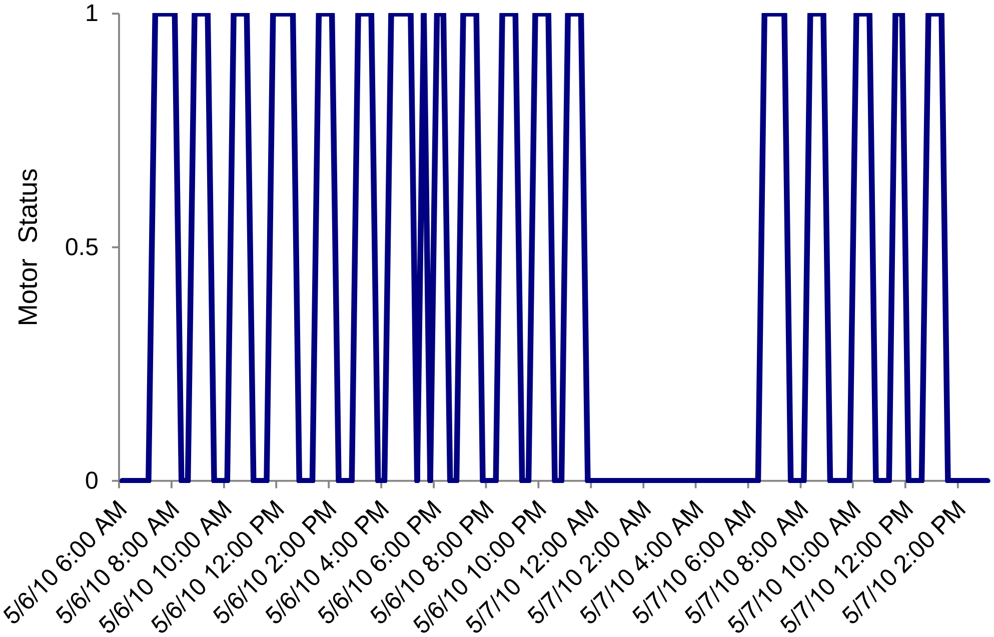
Post-Installation Period

After the controls are installed, the equipment will still operate as a constant load; however, the operation schedule will change to a variable schedule system (CLVS) while the exhaust fans cycle on and off as the cars cycle through the paint shop.

Each fan motor's power use when operating will be verified that it is unchanged, using a spot measurement of fan motor power. The exhaust fan schedule will be monitored by installing motor status loggers on each fan motor for one-month duration. In addition, the paint shop logs of cars entering and leaving the shop during the monitoring period will be obtained.

Results of the monitoring and paint shop log review are shown in Figure 7-6.

Figure 7-6: Post-Installation Operation – Fan EXH23



7.2.3. Algorithm

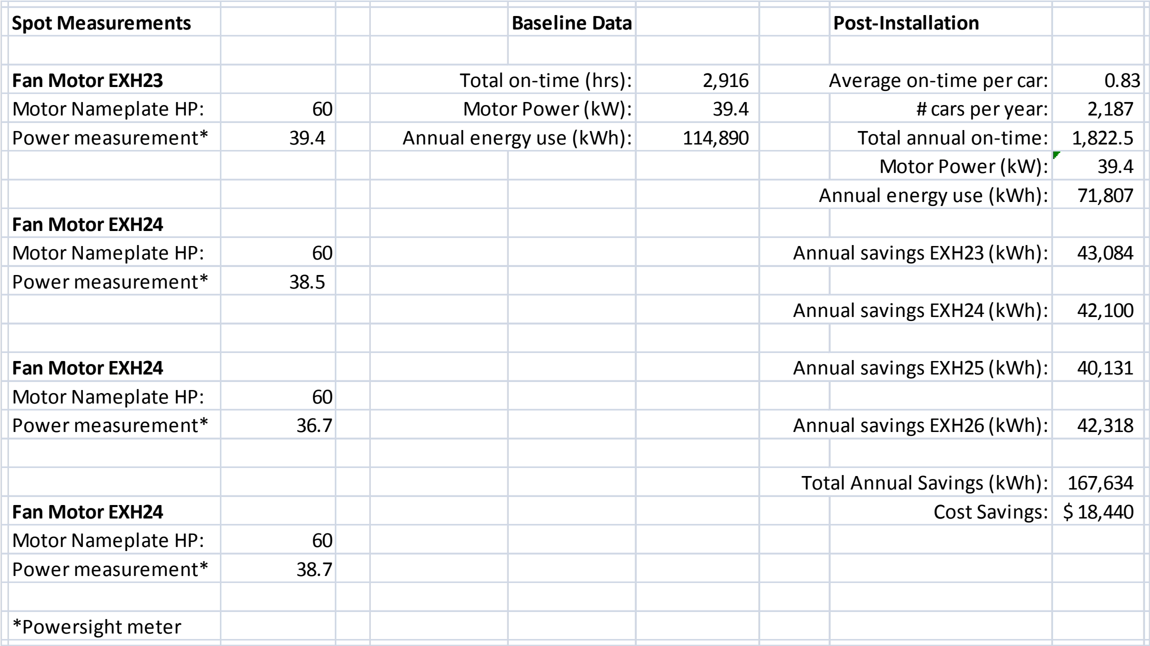
The baseline category is CLTS. The controls upgrade only affects hours of operation – enabling and operating the exhaust fans only as cars are cycled through the paint shop. The post-installation category is CLVS. The 60-hp fan motors were measured with a one-time spot measurement in the baseline period, while the fan operation hours were measured over a two-week period using motor status loggers on each exhaust fan. It was found that in the post-installation period, the fans operated 0.83 hours per car. The annual post-installation operation hours were found by consulting the paint shop log books and counting the number of cars painted per year. Annual energy use is calculated from **Equation 2**, from Table 3-2:

- **Equation** $kWh_{saved} = kW_{base} \cdot HRS_{base} - kW_{base} \sum_{i} HRS_{post,i}$ **2:**

7.2.4. Annual Savings

The baseline motor power data and annual savings calculation are shown in Figure 7-7. Annual operation hours were reduced from 2,916 to 1,822.5 hours per year. This resulted in an annual electric energy savings of 167,623 kWh and cost savings of over $18,000 per year.

Figure 7-7: Savings Calculations



Spot Measurements		Baseline Data		Post-Installation	
Fan Motor EXH23		Total on-time (hrs):	2,916	Average on-time per car:	0.83
Motor Nameplate HP:	60	Motor Power (kW):	39.4	# cars per year:	2,187
Power measurement*	39.4	Annual energy use (kWh):	114,890	Total annual on-time:	1,822.5
				Motor Power (kW):	39.4
				Annual energy use (kWh):	71,807
Fan Motor EXH24					
Motor Nameplate HP:	60			Annual savings EXH23 (kWh):	43,084
Power measurement*	38.5				
				Annual savings EXH24 (kWh):	42,100
Fan Motor EXH24				Annual savings EXH25 (kWh):	40,131
Motor Nameplate HP:	60				
Power measurement*	36.7			Annual savings EXH26 (kWh):	42,318
				Total Annual Savings (kWh):	167,634
Fan Motor EXH24				Cost Savings:	$ 18,440
Motor Nameplate HP:	60				
Power measurement*	38.7				
*Powersight meter					

7.3. Example 3: Supply Fan IGV to VSD Conversion (Improved Fan Efficiency)

7.3.1. Overview

Supply air to an office building is provided by a variable volume reheat system with mechanical cooling that operates Monday to Friday from 6:00 am to 10:00 pm. The volume of air is varied by dampers in the variable air volume (VAV) boxes. As the dampers close, the inlet guide vanes (IGV) also close down to maintain duct static pressure, reducing the flow of air though the fan, and the fan motor uses less energy. The supply fan uses a 30-hp motor and flows 35,100 CFM with the IGV wide open. The IGV will be replaced by a variable speed drive (VSD) which will reduce the fan motor’s consumption at a given flow.

7.3.2. M&V Approach

The end-use metering protocol will be used to calculate and verify the savings from this IGV to VSD conversion project.

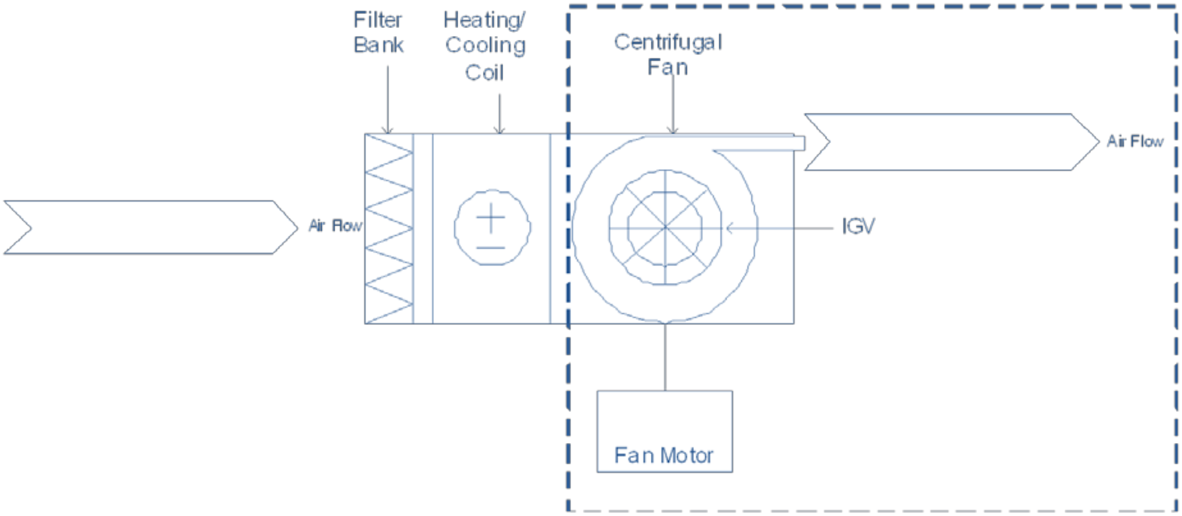
M&V Option

The *Option B: All Parameter Measurement M&V Option* will be used.

Measurement Boundary

The measurement boundary is drawn around the fan and motor as shown in Figure 7-8. Since the air flow will not be changed, the only impact of this measure will be on the electric energy use. Electric energy use of the fan motor is the only savings to be verified during this M&V analysis (no gas savings, etc.).

Figure 7-8: System Sketch



Baseline Period

The fan operates to maintain its required flow to maintain space conditions, so the air-flow rate will be used as the load variable. The fan and motor operate at variable flow, spending unknown amounts of time at each flow rate, but with total operation hours for the year known. Total known operation hours are based on the daily HVAC operation schedule and the number of operating days per year. This system is a variable load, timed schedule (VLTS) system.

The effect of the VFD will be to lower the kW required to produce the required air flow. In the baseline period, only the power/flow-rate relationship will be determined.

To verify variable load operation in this instance, a handheld flow meter is used to read the flow, and the IGV position at each flow is recorded, as the flow is modulated by the zone terminal box dampers. Figure 7-9 shows the relationship between flow and power and Figure 7-10 shows a portion of the spreadsheet with the measured baseline data.

Figure 7-9: Relationship between Power and Flow

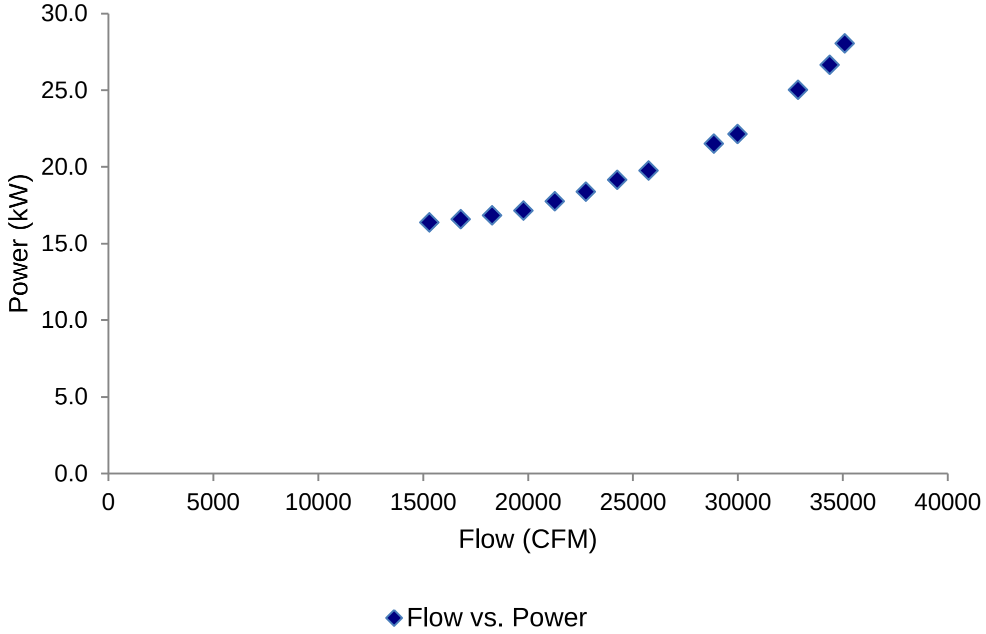


Figure 7-10: Baseline Energy Data

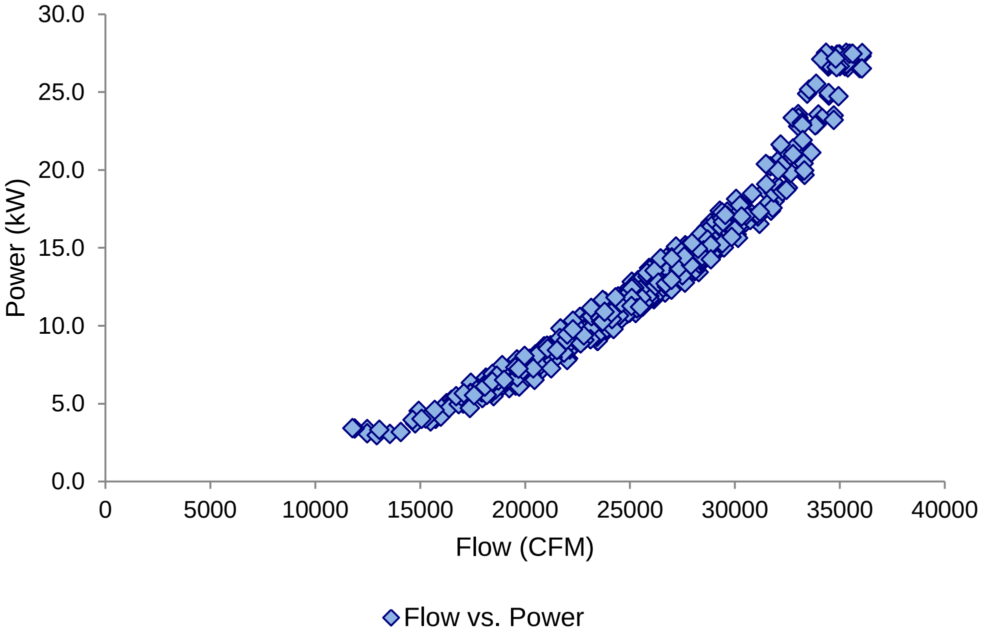
Baseline Reading No.	IGV Position	Flow	kW
1	0.40	15309	16.4
2	0.45	16800	16.6
3	0.50	18291	16.8
4	0.55	19782	17.1
5	0.60	21273	17.7
6	0.65	22764	18.4
7	0.70	24255	19.1
8	0.75	25746	19.8
9	0.80	28866	21.5
10	0.85	29982	22.1
11	0.90	32867	25.0
12	0.95	34376	26.7
13	1.00	35100	28.0
		Average kW	20.4
	Standard Deviation		4.0
		CV	0.2

Post-Installation Period

After the IGV have been replaced with a VFD, a new power-flow curve must be determined. The load frequency distribution of the number of hours at each flow bin must also be determined. The system has not changed categories; it is still a VLTS system.

After the IGV has been replaced, the new wattage, flow, and VSD speed are spot measured over a number of operating points. A new power-flow curve is developed, as shown in Figure 7-11.

Figure 7-11: Post-Installation Power versus Flow Curve



Ambient temperature and VFD speed are trended in the building's control system. The trended VFD speed is converted to air flow using a relationship between VFD speed and air-flow rate determined from the collected test data – which follows the one-to-one relationship of the affinity laws. A regression relationship between the flow and ambient temperature is developed. A load frequency distribution is developed from a typical mean year (TMY) weather file for the local climate zone, and the regression relationship is used to convert ambient temperature to air-flow rate. The data are shown in Figure 7-12, the resulting load frequency distribution is shown in Figure 7-13.

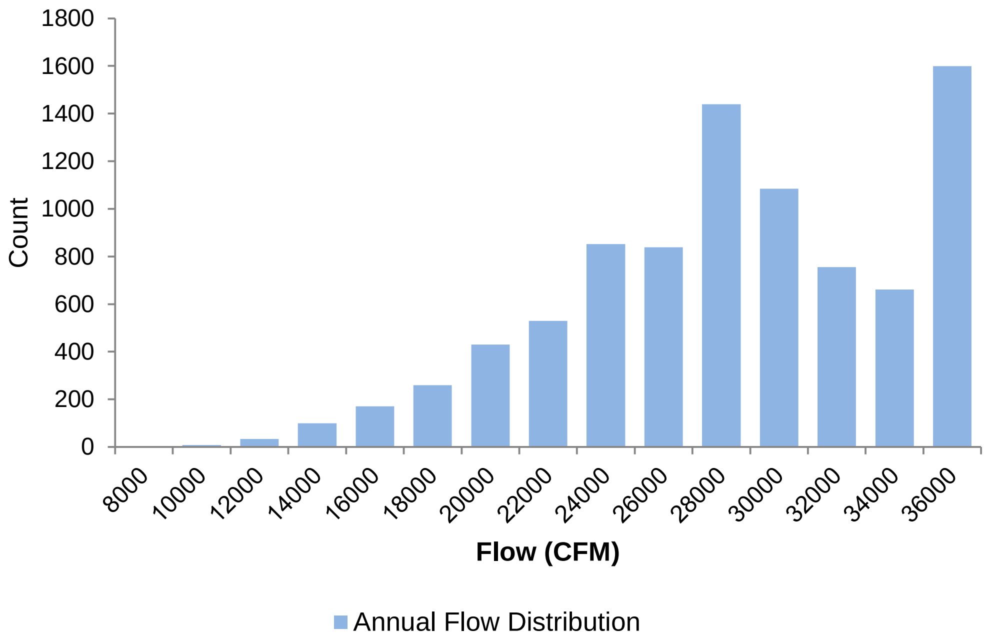
Figure 7-12: Post-Installation Energy Data

Post-Install Reading No.	VSD Speed	Flow	kW
1	0.40	14040	3.4
2	0.45	15698	4.2
3	0.50	17455	5.2
4	0.55	19503	6.7
5	0.60	21106	8.2
6	0.65	22815	9.8
7	0.70	24570	11.3
8	0.75	26431	12.9
9	0.80	27985	14.3
10	0.85	29566	16.1
11	0.90	31623	18.8
12	0.95	33224	21.5
13	1.00	35100	27.0
		Average kW	12.3
		Standard Deviation	7.1
		CV	0.6

Trends Date/Time		OAT	VSD Speed	Flow	kW
4/1/2009 16:00	16	50	0.64	22221	9.9
4/1/2009 17:00	17	50	0.64	21957	9.1
4/1/2009 18:00	18	50	0.64	22807	9.2
4/1/2009 19:00	19	50	0.64	21876	9.5
4/1/2009 20:00	20	49	0.62	21918	8.8
4/1/2009 21:00	21	49	0.62	21243	8.7
4/2/2009 6:00	6	64	0.92	31564	20.3
4/2/2009 7:00	7	61	0.86	31184	16.5
4/2/2009 8:00	8	59	0.82	29177	15.9
4/2/2009 9:00	9	58	0.80	28547	14.4
4/2/2009 10:00	10	56	0.76	26499	13.0
4/2/2009 11:00	11	54	0.72	25581	11.8
4/2/2009 12:00	12	53	0.70	24490	11.5
4/2/2009 13:00	13	49	0.62	22621	9.3
4/2/2009 14:00	14	50	0.64	22168	9.8
4/2/2009 15:00	15	51	0.66	23398	10.4
4/2/2009 16:00	16	50	0.64	21806	9.1
4/2/2009 17:00	17	47	0.58	21027	8.0
4/2/2009 18:00	18	42	0.48	16265	5.0
4/2/2009 19:00	19	37	0.38	12481	3.4
4/2/2009 20:00	20	37	0.38	12481	3.1
4/2/2009 21:00	21	37	0.38	12939	3.0
4/3/2009 6:00	6	71	1.00	34574	27.2
4/3/2009 7:00	7	73	1.00	35231	27.4

Weeks Per Year	52
Hours Per Day	16
Weekdays Per Year	261
Total Annual Operating Hours	4,176
Average kW when operating	12.9
Standard Deviation	5.735141
CV	0.444079
Annual Electric Consumption (based on extrapolation)	133,518

Figure 7-13: Load Distribution Chart



7.3.3. Algorithm

Both the baseline and post-installation load characteristics were measured. The hours of operation at various loads were measured for a short time period and annual hours were determined through a relationship with ambient temperature.

Replacing the IGVs with a VSD improves the efficiency of the fan, which only reduces the motor power required. The hours of operation at each flow are determined from the post-installation period, so that baseline and post-installation energy use are determined from the same set of conditions. Annual energy use is calculated by **Equation 3**, from Table 3-3 using the histogram of flow from the post-installation case:

- **Equation 3:** $kWh_{saved} = \sum_i \left[\left(kW_{base,i} - kW_{post,i} \right) \cdot HRS_{post,i} \right]$

7.3.4. Annual Savings

The calculations of energy savings are shown in Figure 7-14.

Figure 7-14: Savings Calculations

		Baseline		Post-Installation		
Flow		Energy		Energy		Savings
Bin	*Frequency*	*kW*	*kWh*	*kW*	*kWh*	*kWh*
8000	0	14.4	-	0.8	-	-
10000	8	15.1	120	1.3	10	110
12000	34	15.6	530	2.0	66	463
14000	99	16.0	1,583	2.7	272	1,312
16000	171	16.3	2,795	3.7	630	2,165
18000	259	16.7	4,321	4.8	1,237	3,083
20000	430	17.1	7,332	6.0	2,591	4,740
22000	530	17.5	9,274	7.4	3,941	5,334
24000	852	18.1	15,400	9.0	7,674	7,726
26000	838	18.8	15,777	10.7	9,004	6,773
28000	1439	19.8	28,496	12.7	18,205	10,291
30000	1085	21.1	22,840	14.7	15,980	6,860
32000	755	22.6	17,077	17.0	12,820	4,257
34000	661	24.6	16,231	19.4	12,828	3,403
36000	1599	26.9	43,024	22.0	35,198	7,826
			184,799		120,457	64,342

7.4. Example 4: Constant Volume Blower to Variable Volume

7.4.1. Overview

A waste water treatment plant has one blower system serving four aeration basins. Each aeration basin has five zones. The basins' treatment process follows the aerated grit removal and primary sedimentation treatment processes. In the basins, the primary effluent undergoes aerobic biological treatment from the blower system, which consists of four 125-hp multi-stage centrifugal blowers. Typical blower operation requires two blowers to maintain dissolved oxygen (DO) levels, meaning that the other two are cycled into operation every other month. The blowers move air into a common manifold that transports the air to the aeration basins to maintain an average DO level of 2.0 mg/l across the 5th zone of each basin. Currently there are no controls or control valves for balancing the air flow and the ponds/zones have independently fluctuating DO levels. Consequently, the plant maintains an average DO value, which is only slightly representative of the DO values in each pond. By installing motorized valves and additional DO sensors, the blower system can be better controlled to maintain the set point evenly across all five zones in each of the four ponds while using less power.

7.4.2. M&V Approach

The end-use metering protocol will be used to calculate and verify the savings from this constant volume to variable volume conversion project.

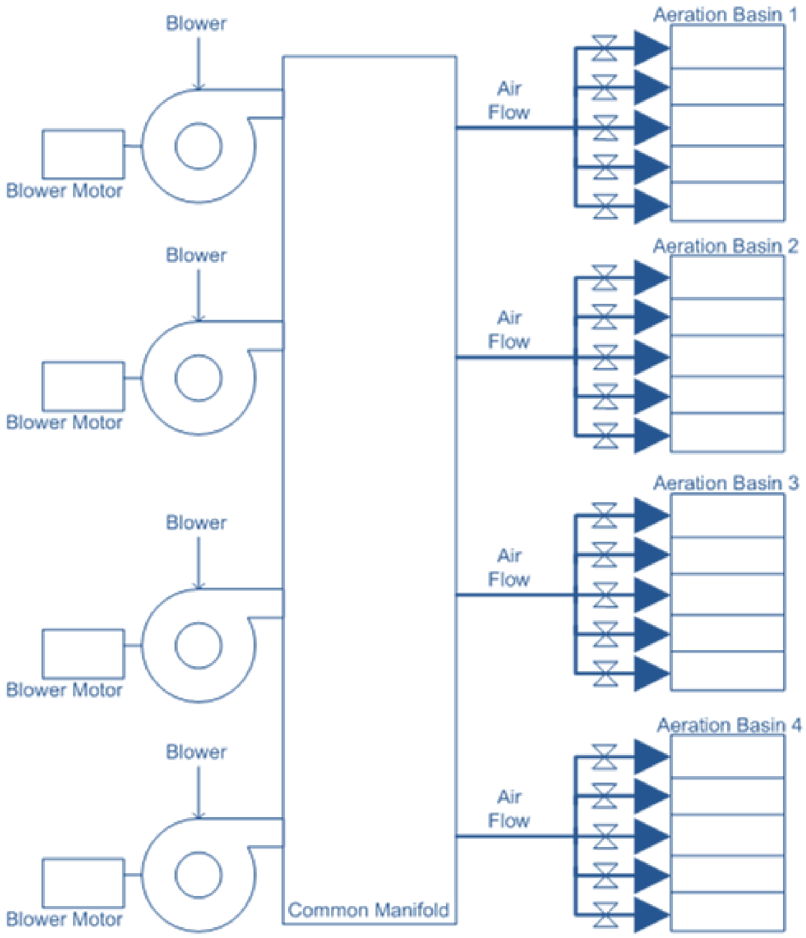
M&V Option

The *Option B: All Parameter Measurement M&V Option* will be used.

Measurement Boundary

The measurement boundary is drawn around the blowers, their motors, and the aeration ponds as shown in Figure 7-15. By reducing the blower system's output as appropriate for maintaining DO levels, this measure saved electric energy. Electric energy use of the blower motors was the only savings to be verified during this M&V analysis (no gas savings, etc.).

Figure 7-15: System Sketch (not to scale)



Baseline Period

The blowers were operated to provide the air required to maintain the average DO level across the 5th zone of each basin, so the air flow rate was used as the load variable. The blowers and motors operated at variable flow, spending unknown amounts of time at each flow rate, but with total operation hours for the year known. Total known operation hours were 8,760, because the plant had to run continuously to maintain the system balance. This system is a variable load, timed schedule (VLTS) system.

The effect of the additional valves and DO sensors was to lower the kW required by reducing the required air flow. In the baseline period, the power/flow-rate relationship was determined, as was the load frequency distribution for the number of hours at each flow rate. The procedure for determining the load curve (power versus flow) and load frequency distribution in the baseline period is outlined below:

- Spot measure power, pressure, and blower speed. For each blower, this will identify a point on the blower's performance curve.

- Trend blower speeds and ambient temperatures in the plant’s control system. The trend period was two months.
- Calculate the power for each trended point based on the affinity law and trended speeds.
- Calculate the air flows through the blowers for the trend period based on the manufacturer’s blower curve and the spot measurements. From this data, a correlation between blower speed and ambient temperature was developed. Since blower speed is proportional to air flow and the rate of dissolved oxygen consumed by the pond’s bacteria, and thus required air flow, varies with ambient temperature, a relationship between flow and temperature, and annual weather data, will be used to develop the load frequency distribution.

Figure 7-16 shows a portion of the spreadsheet with the measured baseline data.

Figure 7-16: Baseline Energy Data

Baseline					Trends								
Reading No.	VSD Speed	pressure (psig)	kW	Deg F	Date/Time	OAT	VSD Speed	Flow	kW				
Blower 1	0.85	5.25	68.6	70	2/1/2009 0:00	53	0.94	2561	212.3				
Blower 2	0.85	5.25	70.2	70	2/1/2009 1:00	48	0.97	2669	238.1				
			138.8		2/1/2009 2:00	44	0.99	2637	220.5				
					2/1/2009 3:00	40	1.00	2695	220.2	Total Annual Operating Hours			8,760
					2/1/2009 4:00	39	1.00	2565	222.6				
					2/1/2009 5:00	38	1.00	2574	201.4			Average kW when operating	202.2
					2/1/2009 6:00	38	1.00	2607	228.0			Standard Deviation	17.86
					2/1/2009 7:00	37	1.00	2667	197.0			CV	0.09
					2/1/2009 8:00	41	1.00	2574	200.4				
					2/1/2009 9:00	52	0.95	2576	192.5				
					2/1/2009 10:00	54	0.93	2512	190.3				
					2/1/2009 11:00	60	0.90	2458	187.8				
					2/1/2009 12:00	63	0.89	2354	186.4				
					2/1/2009 13:00	64	0.88	2299	193.9				
					2/1/2009 14:00	64	0.88	2336	188.9				
					2/1/2009 15:00	64	0.88	2423	184.0				
					2/1/2009 16:00	63	0.89	2377	173.3				
					2/1/2009 17:00	60	0.90	2492	205.6				
					2/1/2009 18:00	57	0.92	2404	183.5				
					2/1/2009 19:00	52	0.95	2455	218.7				
					2/1/2009 20:00	47	0.97	2551	221.5				
		Average kW	69.4		2/1/2009 21:00	45	0.99	2676	201.7				
	Standard Deviation		1.141		2/1/2009 22:00	45	0.99	2586	236.3				
		CV	0.016		2/1/2009 23:00	44	0.99	2602	192.6				

Post-Installation Period

After the motorized valves, additional DO sensors, and controls were installed, the power-flow relationship remained the same; however, a new load frequency distribution of hours at a given flow bin was determined. In the baseline, due to a lack of DO feedback, the blowers over-ventilated the ponds. In the post-installation period, the flow rate will be lowered while still maintaining the required DO level.

The system pressure set point has remained constant throughout this period, so with a new set of power measurements, the flow can be determined from the blower curves, as it was in the baseline. The load frequency distribution was determined in the same way as it was in the baseline. The system has not changed categories; it is still a VLTS system. A portion of the data gathered for the post-installation period can be seen in Figure 7-17 below.

Figure 7-17: Post-Installation Energy Data

Post-Install					Trends									
Reading No.	VSD Speed	pressure (PSI)	kW		Date/Time	OAT	VSD Speed	Flow	kW					
Blower 1	0.53	5.25	25.7		8/20/2009 0:00	55	0.72	1944	171.9					
Blower 2	0.53	5.25	26.3		8/20/2009 1:00	55	0.72	1875	144.2					
			52.1		8/20/2009 2:00	56	0.71	1957	149.0					
					8/20/2009 3:00	56	0.71	1849	129.1				Total Annual Operating Hours	8,760
					8/20/2009 4:00	55	0.72	2012	179.4					
					8/20/2009 5:00	55	0.72	1938	145.4				Average kW when operating	131.5
					8/20/2009 6:00	55	0.72	1833	172.8				Standard Deviation	28.23159
					8/20/2009 7:00	55	0.72	1822	152.9				CV	0.214615
					8/20/2009 8:00	57	0.69	1900	158.2					
					8/20/2009 9:00	64	0.59	1607	139.4					
					8/20/2009 10:00	71	0.51	1272	82.0					
					8/20/2009 11:00	71	0.51	1319	108.8					
					8/20/2009 12:00	75	0.46	1153	93.2					
					8/20/2009 13:00	74	0.47	1264	107.3					
					8/20/2009 14:00	74	0.47	1160	110.8					
					8/20/2009 15:00	73	0.49	1285	96.0					
					8/20/2009 16:00	69	0.53	1464	129.6					
					8/20/2009 17:00	66	0.57	1504	107.9					
					8/20/2009 18:00	62	0.62	1674	155.8					
					8/20/2009 19:00	57	0.69	1759	131.7					
					8/20/2009 20:00	56	0.71	1819	129.7					
		Average kW	34.7		8/20/2009 21:00	56	0.71	1811	170.0					
		Standard Deviation	15.0296		8/20/2009 22:00	56	0.71	1919	173.9					
		CV	0.4331		8/20/2009 23:00	56	0.71	1873	148.1					

The baseline and post-installation power/load relationships, and load frequency distributions are shown in Figure 7-18 and Figure 7-19 below.

Figure 7-18: Post-Installation Power versus Flow Curve

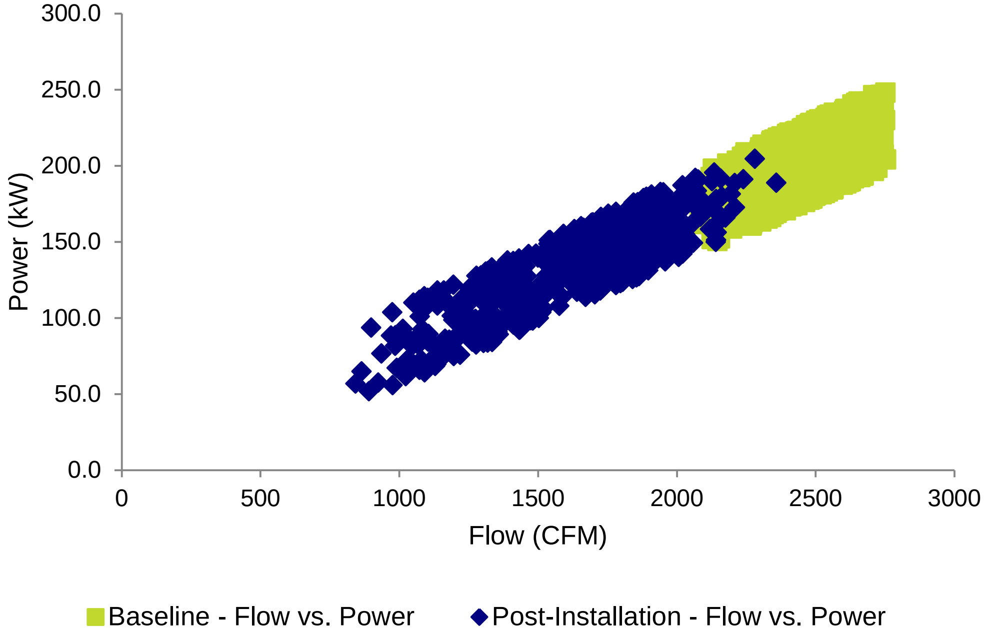
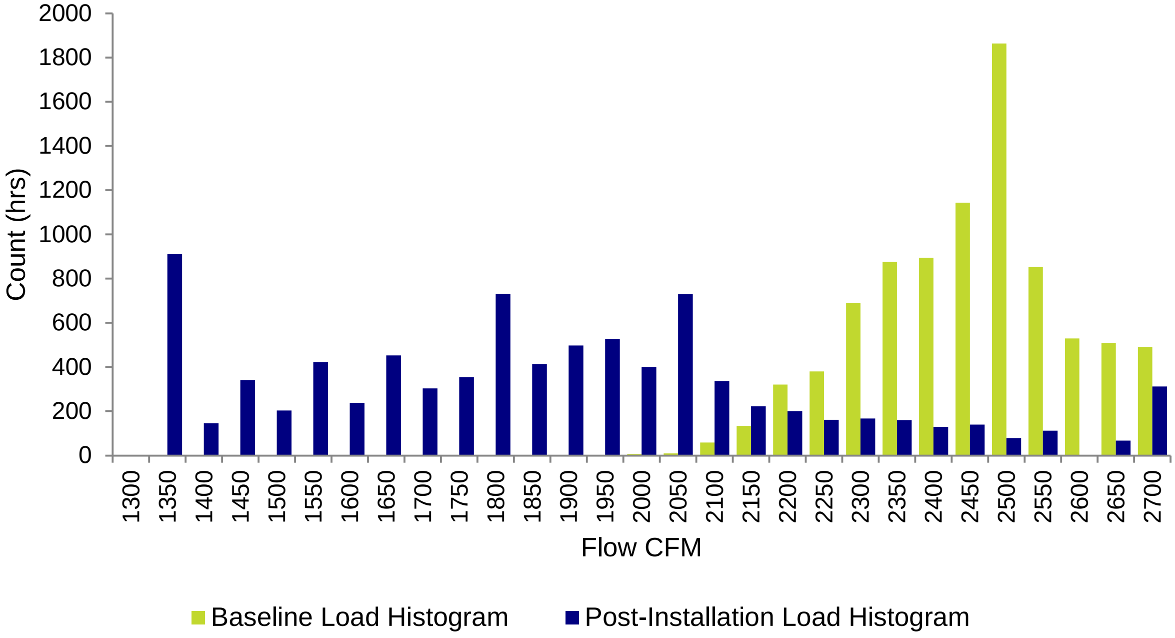


Figure 7-19: Load Distribution Chart



7.4.3. Algorithm

Both the baseline and post-installation load characteristics (load and schedule) were measured. The hours of operation at various loads were measured for a two-month period in both the baseline and the post.

Annual energy use is calculated by **Equation 4**, from Table 3-3 using the histogram of flow from the post-installation case:

- **Equation** $kWh_{saved} = \sum_{i} \left[kW_{base,i} \cdot HRS_{base,i} - kW_{post,i} \cdot HRS_{post,i} \right]$ **4:**

7.4.4. Annual Savings

The calculations of energy savings are shown in Figure 7-20.

Figure 7-20: Savings Calculations

		Baseline		Post-Installation		
Flow		Energy		Energy		Savings
Bin	*kW*	*Frequency*	*kWh*	*Frequency*	*kWh*	*kWh*
1300	106.2	0.0	-	0.0	-	-
1350	110.3	0.0	-	910.0	100,395	(100,395)
1400	114.4	0.0	-	145.0	16,590	(16,590)
1450	118.5	0.0	-	341.0	40,407	(40,407)
1500	122.6	0.0	-	203.0	24,884	(24,884)
1550	126.7	0.0	-	422.0	53,454	(53,454)
1600	130.8	0.0	-	239.0	31,250	(31,250)
1650	134.8	0.0	-	452.0	60,948	(60,948)
1700	138.9	0.0	-	303.0	42,095	(42,095)
1750	143.0	0.0	-	354.0	50,627	(50,627)
1800	147.1	0.0	-	731.0	107,530	(107,530)
1850	151.2	0.0	-	413.0	62,440	(62,440)
1900	155.3	0.0	-	498.0	77,325	(77,325)
1950	159.4	0.0	-	528.0	84,141	(84,141)
2000	163.4	7.0	1,144	401.0	65,541	(64,397)
2050	167.5	9.0	1,508	729.0	122,129	(120,621)
2100	171.6	59.0	10,125	337.0	57,835	(47,709)
2150	175.7	134.0	23,544	223.0	39,182	(15,637)
2200	179.8	321.0	57,712	201.0	36,137	21,575
2250	183.9	380.0	69,872	162.0	29,788	40,085
2300	188.0	689.0	129,505	167.0	31,389	98,115
2350	192.0	876.0	168,233	160.0	30,727	137,505
2400	196.1	894.0	175,342	130.0	25,497	149,845
2450	200.2	1144.0	229,050	140.0	28,031	201,019
2500	204.3	1864.0	380,824	79.0	16,140	364,684
2550	208.4	852.0	177,549	112.0	23,340	154,209
2600	212.5	530.0	112,613	0.0	-	112,613
2650	216.6	509.0	110,231	68.0	14,726	95,504
2700	220.6	492.0	108,559	312.0	68,842	39,717
			1,755,810		1,341,391	414,420

7.5. Example 5: Plywood Plant Compressed Air System Upgrade Project

The following example illustrates how to apply the *Verification by Equipment or End Use Metering Protocol* to determine savings for a comprehensive upgrade of an air compressor system at a plywood plant. The capital project's energy efficiency measures were projected to substantially improve the plant's air compressor system's efficiency. From an audit that recommended compressed air system upgrades, savings were expected to be over 200,000 kWh. Measurement of key parameters prior to, and after implementation, were needed over a full range of operating conditions to verify system performance improvements and quantify energy savings. On this basis the *Verification by Equipment or End Use Metering Protocol* was selected.

7.5.1. Introduction

The plant's original compressed air system consisted of two separate compressor systems each with a 250 HP single-stage rotary screw air compressor, a 1,250 SCFM (standard cubic feet per minute) dual-tower desiccant air dryer and related equipment. The compressor systems were located on opposite sides of the plant. During an energy audit, energy use data was collected from multiple pieces of equipment and numerous energy efficiency measures (EEMs) were identified.

From the audit and data collected on the compressed air system, it was determined that energy use was high because:

- The compressor systems were oversized for the plant requirements
- Inlet modulation control was used to adjust compressor capacity
- Supply air pressure was maintained higher than needed because of high 'cleanup' pressure drop and little dry storage in the system
- The distribution header system had little storage capacity and the piping was not looped
- The air dryers operated in a timed regeneration mode, purge air requirements and heater energy were at maximum

Efficiency Measure

To improve air compressor system efficiency, the audit recommendation proposed that the two compressor systems be moved to a dedicated room to be built in the north end of the plant. There were multiple steps taken to improve compressor system efficiency:

- A new VFD-controlled air compressor replaced one of the existing compressors, one compressor was used to meet a base load of compressed air, and the VFD controlled compressor used to meet fluctuating plant demand. During non-production hours, only the VFD controlled compressor was used to meet compressed air demands. Sequencing controls were added to assure the power used was sufficient to meet the compressed air demand without over pressurizing the system.

- The controls on the desiccant air dryers would be switched from a timed mode to a sequence that monitored moisture loading of the desiccant beds in the dryers.
- Two 1060 gallon receivers would be added to the dry side of the system, with one in the new compressor room and the other in the southwest side of the plant. The original dry air receiver served as a third unit and remained in its current location.
- The two receivers at the end of the loop would be connected, closing the loop in the header system, using 3” diameter piping. This increased the amount of available compressed air capacity throughout the plant.

The audit report estimated 595,000 kWh in annual electric savings.

Assessment

The compressor systems operated continuously to maintain a quasi-constant air pressure in the headers and receivers. Compressor power and inlet air flow modulated to meet the pressure requirement. While power, air flow and pressure fluctuated as equipment was used in the plant, on average the power, flow, and pressure were expected to remain constant to meet plant compressed air demand. This was confirmed by analysis of the pressure, flow, and power data collected during the audit process.

The efficiency upgrades described above would improve overall compressed air plant efficiency, meaning that the effect of the retrofit would be to reduce the power required to maintain the same supply pressure in the compressed air system. Because there was data collected in the baseline phase available, and savings were over 200,000 kWh, the *Verification by Equipment or End Use Metering Protocol* was selected.

For this approach, the measurement boundary was drawn around the compressor systems, and they were considered a constant load, timed schedule (CLTS) system. The impact of the efficiency upgrade would be to reduce the load, while the schedule remained unchanged. Note that this distinction of constant load was only applied over daily operations.

The system power, airflow, and dry pressure was monitored over time in the baseline and in the post-installation periods. This was an *Option B: All Parameter Measurement* approach according to IPMVP, however this method may not fully adhere to IPMVP requirements, as the M&V procedure used assumptions to estimate annual savings based on the monitoring period data.

The equation used to determine savings was:

$$kWh_{saved} = \left(kW_{base} - kW_{post}\right) HRS_{post}$$

The following sections describe how the data was collected and analyzed, and what assumptions were made to verify savings for this project.

7.5.2. Baseline Period

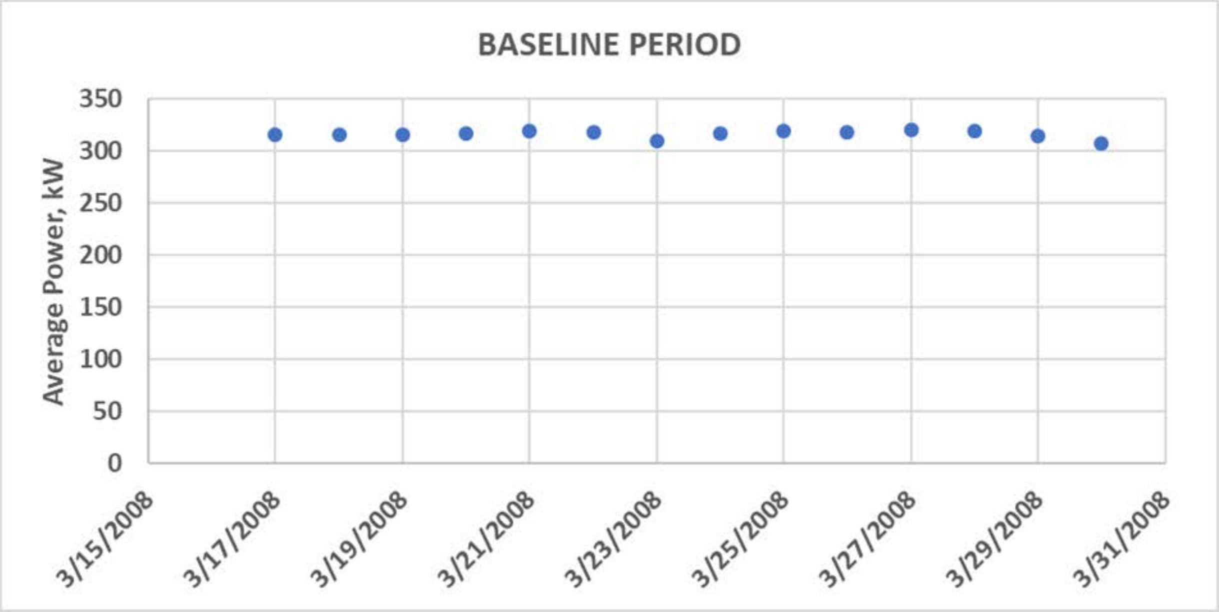
Data Collected

As described above, the baseline data was the same data as had been collected for the energy audit. Data loggers were used to log the air receiver pressure, air flow, and power consumed by the compressor and electric heater of each compressor system. The data was collected over two weeks with a recording interval of 30 seconds. While this data collection frequency is higher than needed for M&V purposes, it was needed at this frequency to analyze system operational performance.

Analysis

The data was retrieved from the loggers and exported for spreadsheet analysis. The data was checked for issues with data quality (missing values, repeated values, and outliers). No data quality issues were found. Average values of pressure, flow, and power were determined for each day of the monitoring period. A chart of the baseline power consumption over time is shown in Figure 7-21, confirming that baseline power demand may be considered constant.

Figure 7-21: Baseline Power over Monitoring Period



The average values for the entire monitoring period were also determined, along with the standard deviation, expressed in measurement units and as a percentage of the average. The standard deviation was used to assess how much variation in power there was about the average value for the baseline period. For this period, it was 2% which met the 5% criterion recommended by the protocol for systems to be considered constant load. This analysis is shown in the savings spreadsheet, Figure 4.

During the baseline monitoring period, plant personnel reported that plant operations and production rates were normal as would be expected throughout the year.

Key assumptions used in this analysis were:

- Plant operations and production rates would be consistent throughout the year as represented by the conditions during the baseline monitoring period.
- The retrofit would cause a reduction in air flow requirements of 110 ACFM (actual cubic feet per minute) due to the reduced purge requirements for desiccant regeneration.

M&V Plan Developed

The M&V Plan developed for this project described the plant, and its compressed air system. Based on the *Verification by End Use Metering Protocol* and using the BPA Custom Project Calculator, it described the baseline operations of the air compressors with support based on analysis of the monitored data, the impact of the EEM, and the planned verification activities in the post-installation period. It described the equations to be used to quantify savings, what data would be measured and monitored in the post-installation period, how the data would be analyzed to quantify the parameters in the savings equations, and the resulting savings. The M&V Plan addressed important considerations that influence savings, such as how to address the case if plant production rates deviated from normal operations.

7.5.3. Post-Implementation Period

Verification Activities

A site visit was made to verify that all the specified equipment was installed and operating per the manufacturer’s specifications.

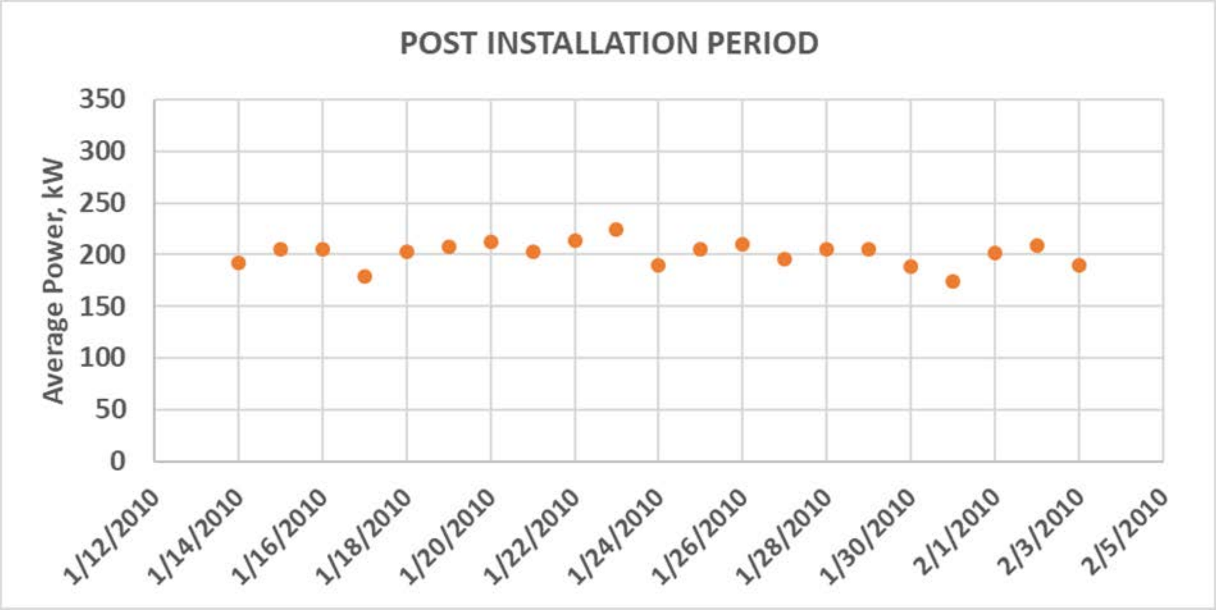
Data Collected

During the site visit, data loggers were installed to monitor and record receiver pressure, airflow, and compressor and electric heating power for the upgraded compressed air system. In this case the monitoring period was extended to three weeks. The data was collected and inspected for data quality issues. It was found that the tower pressure on one of the air dryers failed near the end of the monitoring period (it was later repaired), however enough data was collected to complete the analysis.

Analysis

Average daily pressures, air flows and power consumed were determined for each day of the post-installation monitoring period. The average pressure, air flow, and power for the entire monitoring period was also determined. A chart of the post-installation power consumption over time is shown in Figure 7-22, confirming that although there is more variation, the post-installation power may be considered constant.

Figure 7-22: Post-Installation Power over Monitoring Period



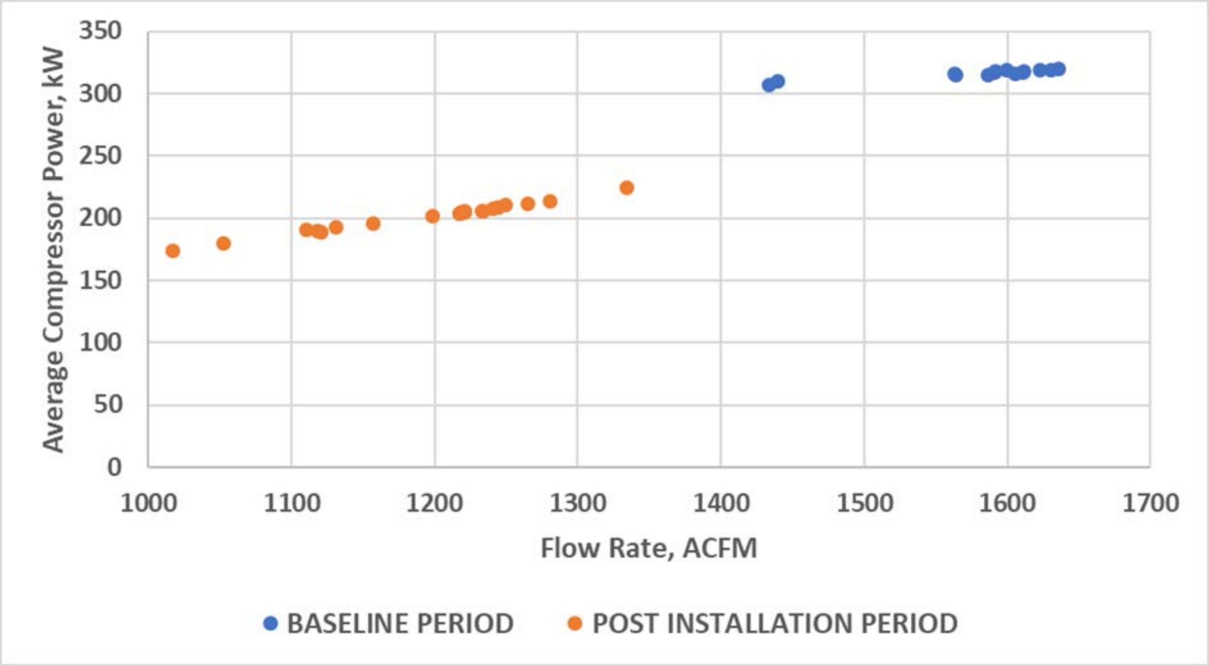
The demand (flowrate) on the compressors were expected to decrease because of two factors:

1) 110 ACFM because of reduced purge demands of the desiccant dryers
2) 68.2 ACFM from a planned reduction of the system pressure

Plant operations also changed as reported by the plant personnel. This was also shown by the data collected in the post-installation monitoring period, as shown by the difference between the baseline and post-installation average flowrates of 383.0 ACFM, which was greater than the expected 178.2 ACFM effect described above.

Savings for the EEM could not be determined by direct comparison of energy use in the baseline and post-installation period because the energy use in each period was under different operating conditions. Figure 7-23 shows that the baseline and post installation power are slightly linear with flow rate.

Figure 7-23: Baseline and Post-Installation Power versus Air Flowrate.

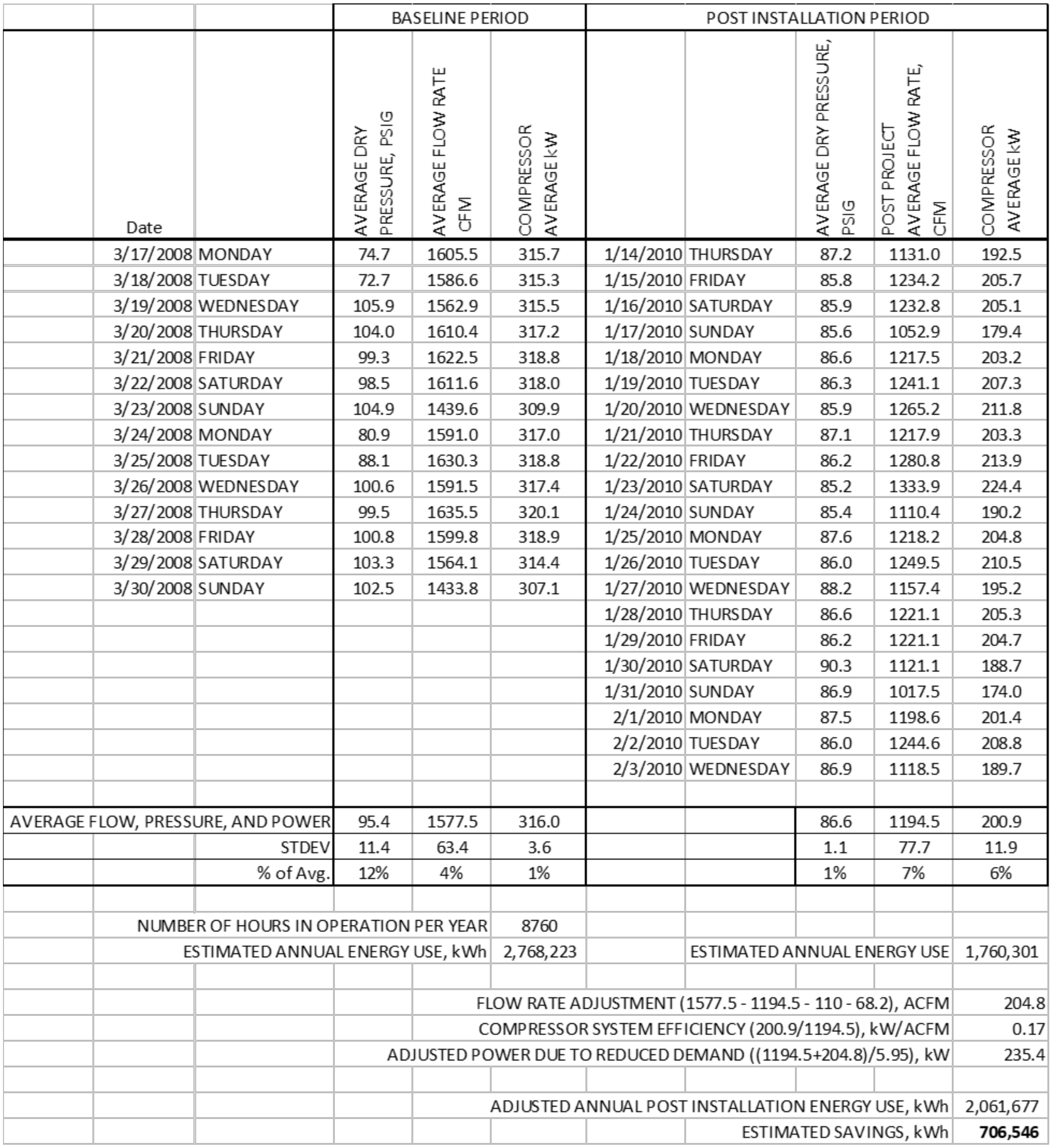


Based on its relationship with flowrate, the post-installation power was adjusted to compensate for the decreased demand by determining what the power would have been under baseline demand conditions. This was done by adding the 204.8 ACFM (383 – 178.2) to the post-installation average flow rate, then multiplying by the ratio of the average power to the average flow rate of the new system.

Savings Results

Once the average baseline and post-installation power were determined, the annual energy savings were estimated for the typical plant operation conditions, assuming continuous operation for all hours of the year. Figure 7-24 provides an annotated spreadsheet of this calculation procedure, once all the data were collected. The final verified savings were 706,500 kWh.

Figure 7-24: Savings Estimation Spreadsheet



			BASELINE PERIOD			POST INSTALLATION PERIOD				
	Date		AVERAGE DRY PRESSURE, PSIG	AVERAGE FLOW RATE CFM	COMPRESSOR AVERAGE kW			AVERAGE DRY PRESSURE, PSIG	POST PROJECT AVERAGE FLOW RATE, CFM	COMPRESSOR AVERAGE kW
	3/17/2008	MONDAY	74.7	1605.5	315.7	1/14/2010	THURSDAY	87.2	1131.0	192.5
	3/18/2008	TUESDAY	72.7	1586.6	315.3	1/15/2010	FRIDAY	85.8	1234.2	205.7
	3/19/2008	WEDNESDAY	105.9	1562.9	315.5	1/16/2010	SATURDAY	85.9	1232.8	205.1
	3/20/2008	THURSDAY	104.0	1610.4	317.2	1/17/2010	SUNDAY	85.6	1052.9	179.4
	3/21/2008	FRIDAY	99.3	1622.5	318.8	1/18/2010	MONDAY	86.6	1217.5	203.2
	3/22/2008	SATURDAY	98.5	1611.6	318.0	1/19/2010	TUESDAY	86.3	1241.1	207.3
	3/23/2008	SUNDAY	104.9	1439.6	309.9	1/20/2010	WEDNESDAY	85.9	1265.2	211.8
	3/24/2008	MONDAY	80.9	1591.0	317.0	1/21/2010	THURSDAY	87.1	1217.9	203.3
	3/25/2008	TUESDAY	88.1	1630.3	318.8	1/22/2010	FRIDAY	86.2	1280.8	213.9
	3/26/2008	WEDNESDAY	100.6	1591.5	317.4	1/23/2010	SATURDAY	85.2	1333.9	224.4
	3/27/2008	THURSDAY	99.5	1635.5	320.1	1/24/2010	SUNDAY	85.4	1110.4	190.2
	3/28/2008	FRIDAY	100.8	1599.8	318.9	1/25/2010	MONDAY	87.6	1218.2	204.8
	3/29/2008	SATURDAY	103.3	1564.1	314.4	1/26/2010	TUESDAY	86.0	1249.5	210.5
	3/30/2008	SUNDAY	102.5	1433.8	307.1	1/27/2010	WEDNESDAY	88.2	1157.4	195.2
						1/28/2010	THURSDAY	86.6	1221.1	205.3
						1/29/2010	FRIDAY	86.2	1221.1	204.7
						1/30/2010	SATURDAY	90.3	1121.1	188.7
						1/31/2010	SUNDAY	86.9	1017.5	174.0
						2/1/2010	MONDAY	87.5	1198.6	201.4
						2/2/2010	TUESDAY	86.0	1244.6	208.8
						2/3/2010	WEDNESDAY	86.9	1118.5	189.7
AVERAGE FLOW, PRESSURE, AND POWER			95.4	1577.5	316.0			86.6	1194.5	200.9
		STDEV	11.4	63.4	3.6			1.1	77.7	11.9
		% of Avg.	12%	4%	1%			1%	7%	6%
	NUMBER OF HOURS IN OPERATION PER YEAR				8760					
	ESTIMATED ANNUAL ENERGY USE, kWh				2,768,223		ESTIMATED ANNUAL ENERGY USE			1,760,301
				FLOW RATE ADJUSTMENT (1577.5 - 1194.5 - 110 - 68.2), ACFM						204.8
				COMPRESSOR SYSTEM EFFICIENCY (200.9/1194.5), kW/ACFM						0.17
			ADJUSTED POWER DUE TO REDUCED DEMAND ((1194.5+204.8)/5.95), kW							235.4
				ADJUSTED ANNUAL POST INSTALLATION ENERGY USE, kWh						2,061,677
							ESTIMATED SAVINGS, kWh			**706,546**

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