BONNEVILLE POWER ADMINISTRATION

Verification by Energy Use Indexing Protocol

July 2018

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Version 2.0

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Prepared for

Bonneville Power Administration

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Contract Number 00077045

Table of Contents

1. Introduction

1.1. Purpose

Verification by Energy Use Indexing Protocol (Indexing Protocol) is one of the Measurement and Verification (M&V) protocols used by the Bonneville Power Administration (BPA). It assists the engineer in normalizing one or more independent variables that systematically affect energy use to prevent non-program changes from confounding savings estimates. For example, the method is applicable when energy use is a function of gallons of water pumped or, in an industrial situation, the number of widgets produced. This protocol is a simple application BPA's *Verification by Energy Modeling Protocol (Energy Modeling Protocol).* Savings can be large or small, but in most applications to multiple measures, the savings should not be interactive.

The protocol is adherent with *IPMVP Options B* and *C*.[1]

Originally developed in 2012, this *Indexing 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.

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:*

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1 *International Performance Measurement and Verification Protocol.*

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.

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:

- 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 *Indexing Protocol*.[7]

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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.

7 William Koran, formerly of QuEST, was the primary author of Version 1.0 of the Indexing Protocol, under Todd Amundson's direction and supported by other members of the protocol development team.

2. Overview of Method

2.1. Description

Routine changes in a building's operation or production variables can require normalizing to prevent non-program changes from confounding savings estimates. A common method to provide such normalizing is through the creation of some form of energy use index. This method estimates savings by observing changes in efficiency over time, as determined by energy use on a per-unit basis.

Reporting period savings are calculated using **Equation 1** in *Chapter 3, Algorithms*. Annual savings are calculated by multiplying the *net annual energy use* by the *calculated percentage savings*.

The most common index for commercial facilities may be energy use per square foot, per year, but other normalizing variables may be appropriate. Examples include weather (such as degree-days) and occupancy (such as hotel-room occupancy rates). Industrial facilities may often use indices related to their process, such as energy use per pound of manufactured output, per widget produced, or per gallon of fluid pumped. The time interval used for comparison may also vary depending upon the application.

2.2. Applicability

This method is applicable when the energy use affected by the efficiency measure is proportional to one or more independent variables. For example, this method may be used in industrial situations where energy use is a function of widgets produced. The method may not be applicable when energy use is significantly dependent on uncontrollable or relatively random variables, such as quality of raw materials received.

In contrast, variables must be measurable and correlated to energy for this method to be valid. It is essential that the impacts of different variables on energy use are well understood, at least on an empirical basis, and that all important non-program variables can be adequately controlled for measurement or can be normalized for this method to be used effectively. The importance of the possible independent variables should be evaluated using standard statistical methods, such as the computation of the *t-statistic* and *p-value*.

2.3. Advantages of this Protocol

Verification by energy use indexing is easily understood, at least for certain applications where factory managers or M&V professionals understand the variable(s) that drive energy use. Therefore, it meets the *International Performance Measurement and Verification Protocol* (IPMVP) requirement for a method to be transparent. If the parameters used for the indices continue to be measured over time, then the method can also be used for performance tracking.

The *Energy Use Indexing Protocol* may use simple linear regression. Since the Energy Use Index is simply a ratio, it includes the implicit assumption that energy use is linearly proportional to the normalizing variable. Therefore, it often lends itself to a visual representation of the savings in the form of a simple x-y scatter chart. As stated above, each parameter in the index – *kWh/units* – is either a total or an average aggregated over a period. In many cases, this will mean that there have been multiple measurements of kWh and multiple measurements of units. To represent the savings in a scatter chart, these measurements must occur in pairs occurring at the same time, with each pair consisting of one measurement of kWh and one measurement of units. Then a scatter chart could be created with the normalizing units on the x-axis and kWh on the y-axis.

Since this protocol is based on regression methods, it has significant related history and common use. For example, energy use has often been normalized by heating or cooling degree-days. This is an example of energy-use indexing. Other weather-related indices are similar.

This protocol can be somewhat distinct from regression methods in a specific circumstance, and in that case, indexing is a clearer, more transparent approach. *Chapter 7, Example* demonstrates this: regression requires that the independent and dependent variables be measured in concurrent pairs. If only a single point is needed to establish the slope, then the index is easily established and there is no need for a longer term of measurement for M&V. A longer baseline monitoring period may be needed to establish the run-time of equipment, for an annual extrapolation as part of energy savings forecast (ex-ante estimate), but it is not needed to establish the index. A single, one-time measurement of the independent and dependent variable may be all that is needed in the case of constant-load equipment.

2.4. Disadvantages of this Protocol

There are several possible disadvantages. A possible issue that may preclude the use of this protocol is that the independent variable(s) needed for the indices may be proprietary and/or confidential. *If the independent variable(s) driving energy use cannot be measured or obtained, this protocol cannot be used*. This is an issue with most protocols. It is not possible to use just the pre-post difference in the driving variable as a means of handling proprietary data. Without the baseline index, it would not be possible to determine the expected energy use because of the change in the driving variable.

Also, since this is, at its core, a regression-based method, independent variables that are not accounted for in the regression may introduce error or uncertainty. If the energy use is not a strong function of the independent variable(s), or if the random variation in energy use ("scatter" in the x-y chart) is significant relative to the correlation of the variables, then the protocol may produce savings estimates that have high uncertainty. Ways to reduce uncertainty are discussed in the *Uncertainty* chapter in this protocol.

Another issue is that the regression must be approximately linear over the range of interest. The *range of interest* is the range of the independent variable(s) affected by the measure. If the regression has a change point (for example, if there is a limit on the value of the energy use for values of the independent variable beyond a certain threshold), then energy indexing cannot be used unless energy use is not expected to change because of the measure for values of the independent variable beyond the threshold.

For example, HVAC energy use may be proportional to cooling degree-days. However, when cooling degree-days decrease to zero and below, the HVAC energy use may not continue to decrease – fan energy may remain constant below that point. To use energy indexing under these conditions, exclusions must be applied so that the calculations only include the range of independent variable(s) for which energy use is dependent, and it is easier to do that with other methods.

Another point regarding the treatment of energy indexing as a regression: *It only estimates savings for a change in the regression slope*, because the energy indexing approach implicitly assumes that the y-intercept is the same for the pre and post cases, typically zero. Therefore, this protocol cannot be used for measures where the regression slope does not change, since that would not result in any change to the index.

Finally, if there is more than one continuous independent (normalizing) variable, this method will be much less transparent – in this case, a clearer regression method should be used. If there is one continuous variable and one or more categorical variables, an energy use indexing method may still be appropriate. *Categorical variables* are variables that have discrete values and are not continuous. For example, *daytype* could be a categorical variable. Creating temperature bins makes a categorical variable out of a continuous variable (see the following chapter).

2.5. Energy Use Indexing vs. Energy Modeling

The *Energy Use Indexing Protocol* is a simple application BPA's *Energy Modeling Protocol*. The Protocol Selection Flowchart in the BPA *M&V Protocol Selection Guide* suggests using the *Energy Use Indexing Protocol* when the following conditions are met:

- Energy use is dependent on weather or another continuous variable
- Linear regression slopes to zero use (that is, the model intercept is near zero)

Figure 2-1 shows a process that is an excellent candidate for Energy Use Indexing. It plots the daily energy use (kWh) of an individually-metered machine against the quantity of raw material used (tons) each day. There is a clear linear relationship between the energy used and the amount of material processed. Based on both a visual inspection of the trend and an understanding of the plant operations, we would expect the daily energy use of this process to be near zero if no material were processed. An 'index' of kWh-per-ton is a useful metric to describe the energy intensity of this process.

Figure 2-1: Good Candidate for Indexing

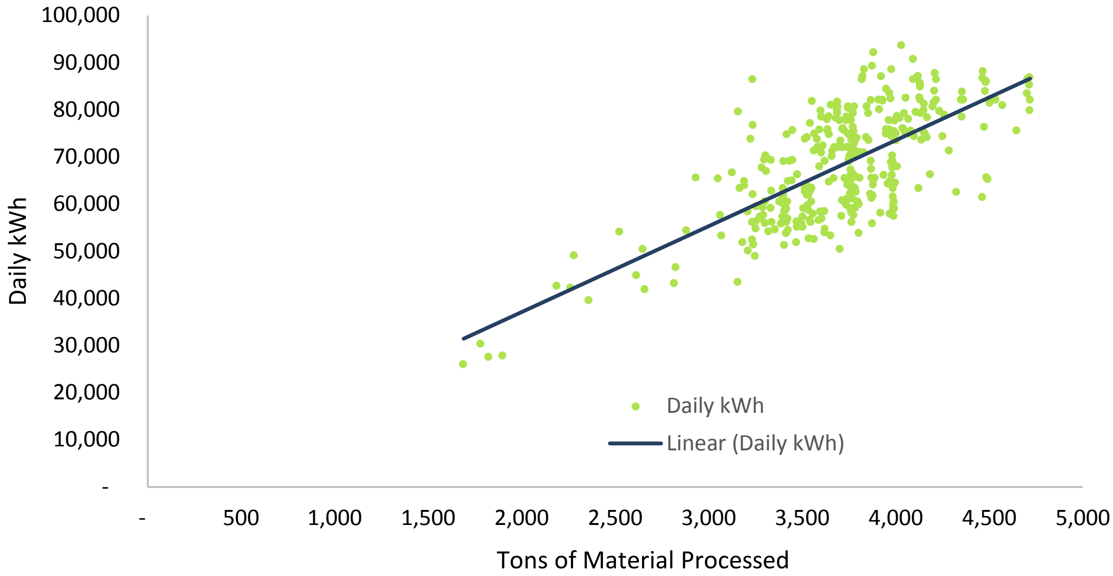


Figure 2-2 plots data from the same facility. However, the consumption data is from the facility meter instead of the machine of interest. While the linear trend between energy use (kWh) and material processed (tons) is present, the trend does not slope to zero use. Recall from Section 2.4 that *Energy Use Indexing* only captures changes in slope. Visual inspection of the trend line suggests that daily kWh consumption would be approximately 30,000 kWh if tons were equal to zero. A regression intercept is needed to capture this value, so this project would be better suited for the *Energy Modeling Protocol*.

Figure 2-2: Poor Candidate for Indexing

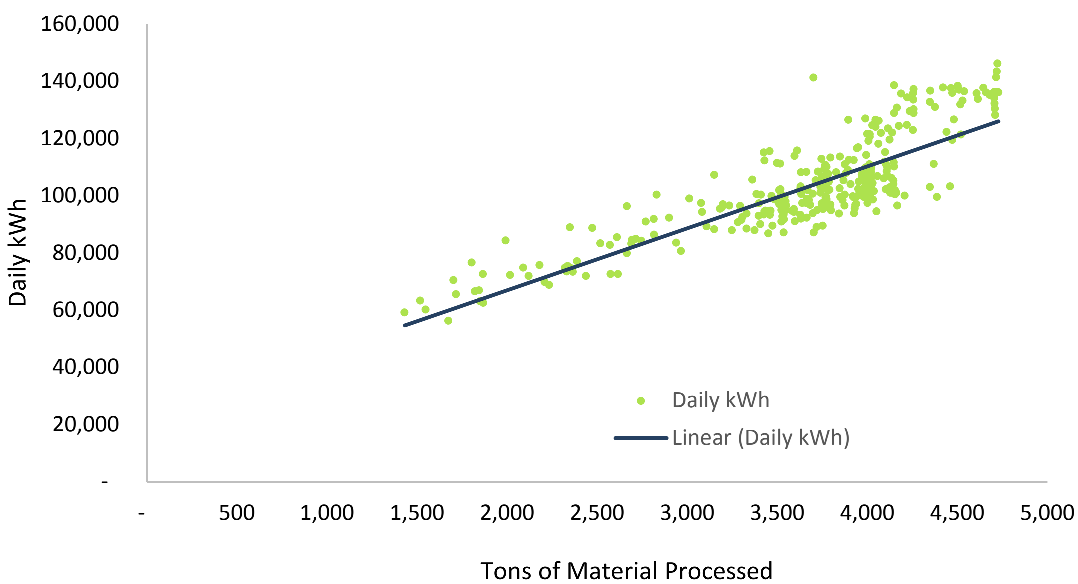
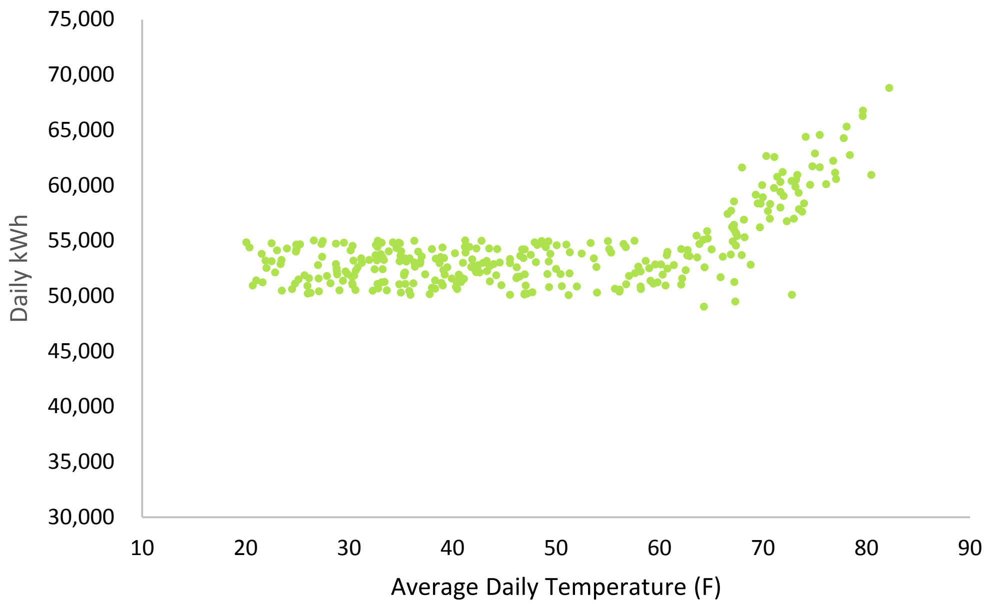


Figure 2-3 shows another site that would be a poor choice for *Energy Use Indexing* and would be better-suited for the *Energy Modeling Protocol*. In Figure 2-3, the daily facility loads (kWh) are plotted against ambient temperature (F). The relationship between energy use and temperature has a distinct linear trend that slopes towards the origin when temperatures are above 60 degrees (F). However, when average daily temperatures are below 60 degrees (F) the electric energy consumption does not vary in response to temperature. A linear change point model is better equipped to capture the differing slopes in the heating and cooling temperature ranges.

Figure 2-3: Poor Candidate for Indexing



3. Algorithms

3.1. Basic Procedure

A baseline is established by determining a pre-measure *energy-use-per-unit*. This may be done with utility billing data and data on output, or another use index if the billing data provide sufficient resolution, or with submetering of the affected equipment and measurement or acquisition (from external sources) of the normalizing variable(s).

Categorical variables may be relevant to the savings estimate. If so, the practitioner would need to develop separate energy-use indices for each value of a categorical variable.

For example, if a plant produces two types of widgets and the energy use per widget is not the same for each type, then separate indices will be needed. Each index could still use **Equation 1** to estimate the savings, and the total savings would be estimated by summing the results of **Equation 1** for each type of widget. Similarly, if energy use differs by daytype (for example, weekdays and weekends often have different rates of energy use), separate indices may be needed for each daytype. If the measurement interval is monthly, then there may be different numbers of weekdays and weekends in the month, even for months with the same number of days.

The basic index model equation is:

- **Equation 1:** $actual\ savings\ (kWh) = ((kWh/units)_{base} - (kWh/units)_{post}) \times units$

  where:

  - *Actual savings* refers to savings occurring during the reporting period.
  - *Units* is the normalizing variable, such as square feet, widgets produced, etc. The number of units must be measured over the same time period (and at the same intervals) as the corresponding energy use.
  - Each parameter (kWh, units) in the ratio, kWh/units, is either a total or an average aggregated over a period of time. Alternatively, the ratio may be the slope of a regression with units as the independent variable and kWh (or other energy use measure) as the dependent variable.

3.2. Equations

- **Equation 1:** $actual\ savings\ (kWh) = ((kWh/units)_{base} - (kWh/units)_{post}) \times units$
- **Equation 2:** $percentage\ savings = ((kWh/units)_{base} - (kWh/units)_{post}) \div (kWh/units)_{base}$
- **Equation 3:** $per\text{-}unit\ savings = (kWh/units)_{base} - (kWh/units)_{post}$

Notice that **Equation 1** uses *units* rather than $units_{base}$ or $units_{post}$. The choice of what to use for the 'units' multiplier in **Equation 1** is dependent upon whether the project or program uses the *avoided energy use* or the *normalized savings* approach to estimate savings.

Section 5.4.1 and 5.4.2. of *IPMVP Core Concepts 2016* discusses two types of savings: *avoided energy use* and *normalized savings*.

- **Avoided Energy Use (Reporting Period Basis Savings):** The reduction in energy use that occurred in the reporting period, relative to what would have occurred if the facility had been equipped and operated as it was in the baseline period, but under reporting period operating conditions. **Equation 1** uses $units_{post}$ for the *units* multiplier.
- **Normalized Savings (Fixed Conditions Basis Savings):** The reduction in energy use or cost that occurred in the reporting period, relative to what would have occurred if the facility had been equipped and operated as it was in the baseline period, but under a normal set of conditions. **Equation 1** can use one of various definitions for the *units* multiplier. These units describing "normal conditions" or "fixed conditions" could be calculated as the long-term average value of units, a projection of normal conditions during the mechanical life of the project, or the units under the conditions of any chosen period other than the reporting period, including the baseline period. Units under baseline period conditions are typically used when the ex-ante predicted savings were developed based on those conditions.

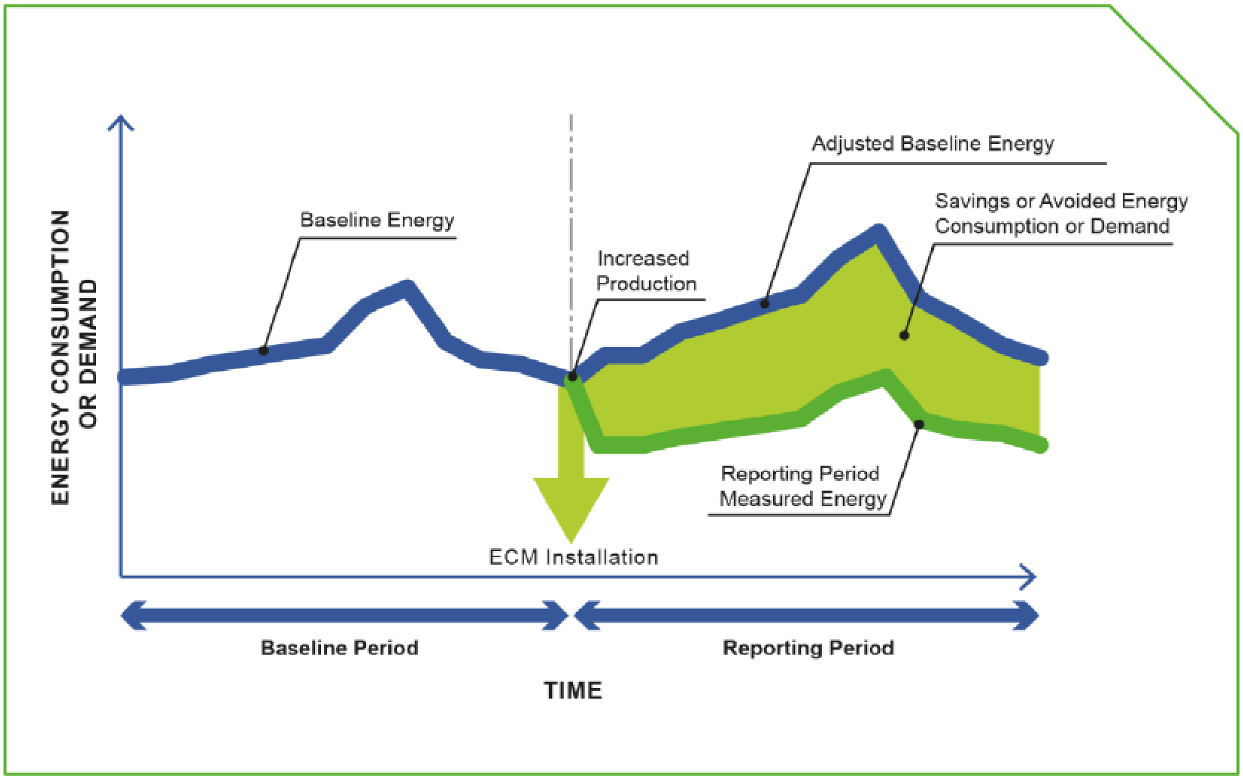
3.2.1. Example of Avoided Energy Use Approach

In *Section 4.1*, *IPMVP 2012* describes how the baseline is adjusted to post conditions using the *avoided energy use* approach:

> *"To properly document the impact of the ECM, its energy effect must be separated from the energy effect of the increased production. The 'baseline energy' use pattern before ECM installation was studied to determine the relationship between energy use and production. Following ECM installation, this baseline relationship was used to estimate how much energy the plant would have used each month if there had been no ECM (called the "adjusted-baseline energy"). The saving, or 'avoided energy use' is the difference between the adjusted-baseline energy and the energy that was actually metered during the reporting period."*

This is shown in Figure 3-1, which is taken from *Section 5 of IPMVP Core Concepts 2016*:

Figure 3-1: Example Energy History



Consider the following hypothetical example of the *avoided energy use* approach (Table 3-1):

Table 3-1: Example Using Avoided Energy Use Approach

	Base	Post	Percent Savings
kWh	10,000	8,000	
Units	400	500	
kWh/units	25	16	36%

Using **Equation 1**, the Actual Savings would be calculated as follows:

- ➡ Actual savings (kWh) = $((\text{kWh/units})_{base} - (\text{kWh/units})_{post}) \times \text{units}_{post}$
- ➡ Actual savings (kWh) = (25 – 16) × 500 = 4,500

Using **Equation 2**, the Percentage Savings would be:

- ➡ Percentage savings (kWh) = $((\text{kWh/units})_{base} - (\text{kWh/units})_{post}) \div (\text{kWh/units})_{base}$
- ➡ Percentage savings (kWh) = (25 – 16) ÷ 25 = 36%

Using **Equation 3**, the Per-Unit Savings would be calculated as follows:

- ➡ Per-Unit Savings (kWh/unit) = $(\text{kWh/units})_{base} - (\text{kWh/units})_{post}$
- ➡ Per-Unit Savings (kWh/unit) = (25 – 16) = 9 kWh/unit

We can check **Equation 1** by taking the extra step to adjust the baseline to the post conditions and then calculating the savings:

Keeping the index (kWh/units) the same, the baseline kWh is adjusted to reflect the units produced in the post period (Table 3-2):

Table 3-2: Actual Savings Verified Through Baseline Adjustment Method

	Base	Post	Percent Savings
kWh	12,500	8,000	
Units	500	500	
kWh/units	25	16	36%

Now the savings can be directly calculated as *12,500 – 8,000 = 4,500 kWh*. This matches the value shown by **Equation 1**.

The typical *avoided energy use* approach is a subset of the *normalized savings* approach. The *normalized savings* approach uses both the baseline period and post period models to predict energy use for a *fixed set of conditions*. The *avoided energy use* approach uses the set of post conditions as the fixed set of conditions. The baseline model is used to predict energy use using the conditions observed in the post period.

The *avoided energy* use style of savings is somewhat simpler, since it is a subset of the normalized savings approach. The post period represents reality; it is not modeled. The savings so estimated represent the true savings achieved over the post period, within the accuracy of the baseline model.

3.2.2. Discussion of the Normalized Savings Approach

The *normalized savings* approach does not estimate the actual savings achieved over the post period, as does the avoided energy approach, but it has the benefit that the savings estimated can be directly compared with any ex-ante savings estimates if the *fixed conditions* are the same as those used in the ex-ante estimates.

So, for estimates of actual savings, the *avoided energy use approach* is recommended if savings are to be estimated retrospectively after a complete cycle of conditions – typically a year – has occurred in the post period. However, if typical or average savings are to be estimated (for example, if savings for a year are to be forecast prior to obtaining a full year of post-implementation data, or if reimbursements or incentives are to be paid based on expected long-term savings), it may be appropriate to use a *normalized savings* approach. When performing a *normalized savings* analysis, it is good practice to also perform an *avoided energy* *use* analysis and compare the savings estimates to the fixed conditions to ensure they make sense directionally.

Commonly, the continuous independent variable used in the *Indexing Protocol* is a quantity describing production levels (such as tons of material used, gallons of water pumped, widgets produced etc.). Facility staff claims that production levels are expected to increase or decrease significantly should be thoroughly vetted and documented before the levels are used as the basis for *normalized savings*. Typically, production levels should be normalized to the conditions observed in the baseline and post periods, such as the baseline conditions, an average of the baseline and reporting periods, or a projection of normal conditions of the mechanical life of the project. It can be more challenging to develop normalized levels of these facility-specific parameters than to do so for weather variables.

3.3. Non-Routine Events

An underlying assumption of the *Indexing Protocol* is that the only change in facility operation during the baseline and reporting periods is the absence and presence of the ECM being analyzed. Sometimes this assumption is violated and a significant one-time change unrelated to the ECM occurs within the measurement boundary.[8] A change to static factors that affects energy use is a "non-routine events," or NRE. When an NRE occurs, the practitioner must adjust the savings to isolate savings due to installed measures, and not be assessing usage changes due to both the measures and NREs. NREs can include adjustments in facility equipment or operations, including (but not limited to) renovations, facility expansion, equipment addition or removal, and changes to occupancy type or schedule.

NREs can:

- Add or remove load;
- Be permanent or temporary;
- Be another ECM not incented by the program;[9]
- Occur in the baseline period, the reporting period, or at the time of the ECM installation
  - Understanding the timing is important to developing an appropriate adjustment
  - When an NRE occurs in the baseline period, the NRE and proposed adjustment should be documented in the M&V Plan. The M&V plan should also describe in general terms how NREs in the reporting period will be treated, if observed.

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8 The measurement boundary is a notional boundary drawn around equipment and/or systems to segregate those which are relevant to savings determination from those which are not. All energy uses of equipment or systems within the measurement boundary must be measured or estimated, whether the energy uses are within the boundary or not. For a fuller discussion, see the *Energy Modeling Protocol.*

9 ECMs either non-incented or incented under other programs.

  - When NREs occur in the implementation or reporting period, the Savings Report should document how they were identified and the approach used to account for the effects in the savings estimate.

- ➡ Be independent of the ECM, or have interactions with the ECM.
  - An example of an ECM that is independent of an NRE is a process motor upgrade in a manufacturing facility that also installed LED lighting throughout the plant. If a whole-building energy model is being used, the reduction in lighting load will influence the model, but is unrelated to the improved efficiency of the process motors. Even though the ECM and NRE are independent of one another, because the NRE lies within the measurement boundary, an adjustment is needed.
  - An example of an interaction between an ECM and NRE is an HVAC upgrade in a facility that undergoes an expansion. If the expanded footprint would have been served by the existing system absent the ECM, the expansion can be expected to increase the savings attributable to the ECM. Whether or not the ECM is credited with this increase (or decrease) in savings is governed by program policy and procedures.

The distinction between an NRE and an outlier is not always clear and requires professional judgment based on an understanding of facility operation. A temporary NRE – such as a labor strike or equipment failure – can be handled similarly to an outlier. With justification, data from the affected period can be removed from the model provided it does not lead to excessive data gaps or poor coverage of operating conditions. A permanent NRE can be thought of as “the new normal.” In the case of a permanent NRE, data from the affected period should not be removed. Instead, the effect of the NRE should be removed from the model-based savings estimate. Section 3.7 of the Energy Modeling Protocol contains additional guidance on identify and accounting for NREs.

4. Uncertainty

Regression analysis yields estimates, predictions that will not be 100% accurate. Thus, modelers speak of the uncertainty of the estimates, that is, uncertainty in the predicted *y-value*. Uncertainty in regression analysis results from three principal sources:

- Measurement uncertainty or measurement error,
- Coverage error, and
- Regression uncertainty or model uncertainty.

4.1. Measurement Uncertainty

Measurement uncertainty has two principal components: *measurement bias* and *measurement precision*. *Bias* relates to issues of calibration and accuracy; *precision* relates to the magnitude of random variation that occurs when multiple measurements are made. (See BPA's reference guides *Sampling for M&V* and *Regression for M&V* for fuller discussion of these concepts.) The concept of measurement uncertainty as it relates to regression analysis pertains to the independent variables, as any measurement error in the dependent variable contributes to model uncertainty, with the error contributing to the model residual.

Instruments for acquiring measurements should be of sufficient resolution and precision that the uncertainties in measurements are small relative to the regression uncertainty. Measurement bias due to measuring equipment error should be eliminated through calibration, and careful instrumentation design and installation should be used to minimize other measurement bias errors. Installation criteria for accurate measurement, such as the need for a straight duct of a specific number of equivalent duct diameters for a flow measurement, may be important.

Note that, even though an installation limitation may introduce the same bias to the pre and post periods, the fact that the bias is the same may not mean that the savings estimate is not biased. Whether or not there is a savings bias is dependent upon the type of bias (that is, additive or multiplicative) and how the measurement is mathematically used.

As applicable and possible, utility meters should be used for energy-use measurements. By M&V convention, utility meter data is considered to have zero uncertainty for savings estimates. Similarly, data from a nearby National Oceanic and Atmospheric Administration (NOAA) weather station should be used for weather measurements, but such measurements should be verified to be representative of the conditions at the treated building. NOAA sites are far less likely to have biases or inaccuracies due to solar effects and sensor calibration errors than site measurements.

For a thorough discussion of measurements, refer to *Section 6, Instrumentation*, and *Annex A, Physical Measurements*, within *ASHRAE Guideline 14, Measurement of Energy, Demand, and Water Savings*.

4.2. Coverage Error

Coverage error occurs when an M&V data set does not fully "cover" the range of conditions that drive energy use, that is the full range of building or system operating conditions. Measurements should be conducted for a sufficient period to capture a significant range of the index variable. Beyond that, no definitive criteria can be provided regarding the sufficiency of shorter-term data for annual extrapolation. *ASHRAE Research Project 1404, Measurement, Modeling, Analysis and Reporting Protocols for Short-term M&V of Whole Building Energy Performance* provides some guidance.

In a production environment, the consistency of production will determine this length of time. When weather is the independent variable, the season and climate will determine the length of time necessary. If seasonal variations in weather are minor, a relatively short time may be possible and still cover a wide range of conditions. If seasonal variations are significant, longer periods (up to a year) may be advisable.

Measurements of energy use and the indexing variable(s) must cover the same time periods.

4.3. Regression Uncertainty

Regression uncertainty (in this case, index uncertainty, also referred to as savings uncertainty) results both from modeling errors – explanatory variables are omitted from the model or an incorrect functional form is specified – and because people's unpredictable behaviors affect energy use. Uncertainty in regression typically refers to the uncertainty in the output from a regression; uncertainty in the regression coefficients is typically referred to in a more explicit manner as the *uncertainty of the slope*.

A goal of any M&V plan should be to minimize uncertainty in the savings estimate (regression uncertainty). More specifically, the goal should be to make the uncertainty small relative to the savings. *ASHRAE Guideline 14-2014, Annex B* refers to this as the *fractional savings uncertainty (FSU)*.[10]

Generally, factors that affect regression modeling uncertainty include:

- ➡ Number of points used in the baseline regression
- ➡ Number of points in the post-installation period
- ➡ Number of significant independent variables included in the regression

One way to reduce the fractional savings uncertainty is to use more data. Gathering data over a longer period, and/or at more frequent intervals, will generally reduce the uncertainty. Note, though, that as data is gathered at more frequent intervals, this will increase serial autocorrelation

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[10] Refer to *ASHRAE Guideline 14-2014, Annex B: Determination of Savings Uncertainty* for a more detailed discussion of savings uncertainty than is provided here.

– each reading becomes more significantly related to the prior reading. Uncertainty estimates must account for this autocorrelation. Costs may be affected by increasing the length of time required to collect data or monitoring additional variables.

Another way to reduce the fractional savings uncertainty is to include more relevant independent variables. The *t-statistic* and *p-value* should be used to check for the relevance of additional independent variables. If multiple continuous independent variables are significant, the practitioner should not use the *Indexing Protocol*. However, the uncertainty in an index model can sometimes be reduced by including one or two categorical variables (discussed more subsequently). Note that the categorical variables may be different in the baseline and post scenarios, and care should be taken to check their significance.

As with all M&V protocols, the emphasis on accuracy needs to be balanced against the level of savings and cost. Parametric analyses may be exercised on the M&V methodology, or if measurement uncertainty is a minimum, then factors affecting regression uncertainty may be assessed to determine the amount of effort and cost needed to increase accuracy.

4.4. Using a Categorical Variable to Estimate Uncertainty

The *Energy Use Indexing Protocol* is a simple application of the *Energy Modeling Protocol*. Because of the simplified model structure, it is well-suited to a model estimated from a dataset combining both the baseline and reporting period data and including a categorical variable set equal to 1 in the post period and 0 in the baseline period. This approach is favored by economists and statisticians for modeling many types of processes and treatment effects. In the context of Energy Use Indexing, it allows the per-unit savings and uncertainty to be estimated in a single step.

Figure 5-1 illustrates the relationship between daily energy use (kWh) and production (widgets) for a hypothetical manufacturing plant. This project is a good candidate for Energy Use Indexing because the trend line approaches the origin (that is, consumption is near zero when production is near zero) for both the baseline and reporting periods.

Figure 5-1: Scatterplot of Baseline and Reporting Period

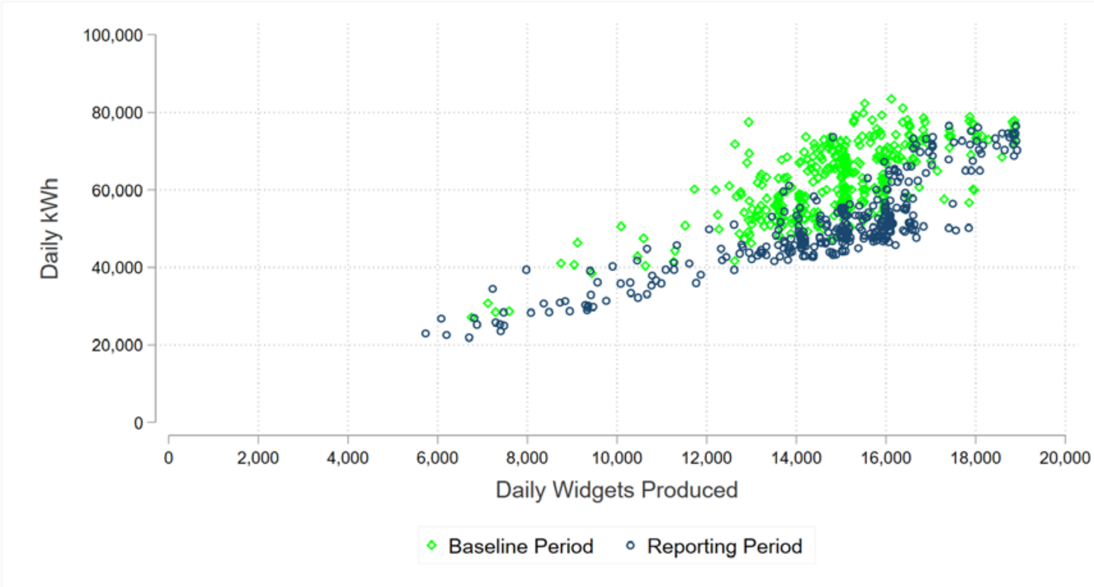

Table 5-1 summarizes the data set and calculates the (kWh/units) index for the baseline and reporting periods as well as the percent savings.

Table 5-1: Energy Consumption, Production, and Percent Savings

	Baseline	Reporting	Percent Savings
kWh	21,772,144	17,091,622	
Units	5,179,381	4,927,787	
kWh/units	4.20	3.47	17.5%

To estimate the change in the index (slope), a convenient approach is to structure the data so that it includes a column for the daily kWh usage, the daily widget production, and a categorical variable named "Post" equal to 1 for all records in the reporting period and 0 for all rows in the baseline period. Next, create an interaction term between the "Post" indicator variable and the continuous independent variable (widgets). In this example, the new variable is named "Post*Widgets." In the baseline period, this term is multiplied by zero, so it is equal to zero. In the reporting period, the "Post*Widgets" term is multiplied by 1, so it is equal to the number of daily widgets.

The regression model for this approach takes the form: $Daily\ kWh = \beta_1 + \beta_2 * Widgets + \beta_3 * Post * Widget + \varepsilon$

Where:

β_1 = the model intercept

β_2 = the energy use index in the baseline period (kWh/unit)

β_3 = the change in the energy use index in the reporting period (per-unit savings)

ε = the model error term

Figure 5-2 shows the regression output from this hypothetical data set as analyzed by the Microsoft Excel Regression function.[11]

Figure 5-2: Regression Output

Regression Statistics	
Multiple R	0.8460
R Square	0.7156
Adjusted R Square	0.7148
Standard Error	6427.5145
Observations	685

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	70905273671	3.5453E+10	858.1484	5.9371E-187
Residual	682	28175427222	41312943.1		
Total	684	99080700893			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-54.7631	1617.4133	-0.0339	0.9730	-3230.471	3120.945
Widgets	4.2013	0.1098	38.2569	0.0000	3.986	4.417
Post*Widgets	-0.7227	0.0329	-21.9572	0.0000	-0.7874	-0.6581

- The Intercept coefficient echoes a visual examination of the data and suggests that energy consumption would be statistically indistinguishable from 0 kWh at a production level of zero widgets. The Widgets coefficient is equal to the $kWh/units_{base}$ discussed in Section 3 and shown in Table 5-1. The Post*Widgets coefficient is negative, being equal to the per-unit change in the reporting period, that is $((kWh/units)_{post} – (kWh/units)_{base})$.To calculate avoided energy use, multiply the per-unit savings (0.7227 kWh/widget) by the number of widgets produced in the reporting period.
- To calculate normalized savings, multiply the per-unit savings by the expected number of widgets produced in a period of interest (fixed conditions).

While the coefficient of Post*Widgets represents the change in energy index (kWh/unit), its standard error represents the uncertainty of the estimate. The uncertainty can be calculated using the standard error of the coefficient and the t-statistic for the desired confidence level.[12] The

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[11] The regression function in Excel is one of the tools in the Data Analysis Add-In.

[12] For data sets with a large number of observations (large number of degrees of freedom), the z-statistic will approximate the t-statistic and can be used instead. For monthly data sets the t-statistic should be calculated using the number of observations and the degrees of freedom. Chapter 5 of the *Regression Reference Guide* includes guidance on calculating t-statistics.

calculation for this example is shown below using a 90% confidence level. The sign of the coefficient is converted to a positive value to represent per-unit *savings*.

$$Fractional\ Savings\ Uncertainty\ (FSU) = \frac{SE * t\text{-}statistic}{Coefficient}$$

$$Fractional\ Savings\ Uncertainty\ (FSU) = \frac{0.0329 * 1.645}{0.7227} = 7.49\%$$

The default Excel regression output provides the 95% confidence interval. If 95% is the desired confidence level, the FSU can be computed dividing the difference between the upper or lower bound and the coefficient by the regression coefficient.

$$Fractional\ Savings\ Uncertainty\ (FSU) = \frac{-0.6581 - (-0.7227)}{0.7227} = 8.94\%$$

5. Minimum Reporting Requirements

5.1. Measurement and Verification Plan

5.1.1. 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.[13] The *Energy Use Indexing 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 affected by the ECMs. Document equipment configurations, operational characteristics (operating practices or operation schedules that characterize its hours of use), and equipment inventories, sizes, types, and conditions.
- **Energy and Independent Variable Data:** Include all energy data from spot measurements and short- or long-term monitoring from each source. Describe:
  - The parameters needed to characterize equipment load,
  - The sources of the energy and independent variable data and the time interval at which they are monitored,
  - The start and duration of monitoring for both the baseline and post-installation periods, and
  - Any needed corrections to the data.
- **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

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13 *Chapter 7, IPMVP Core Concepts – 2016*.

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.

- **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.

5.1.2. 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 (such as meters and instruments, and associated safety equipment) 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.

5.1.3. 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 reporting system*:*

- 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)

5.2. Savings Verification Report

5.2.1. 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.

5.2.2. Additional Savings Verification Report Requirements

Load and Schedule Relationships

Determine the relationships between load and continuous variables such as temperature, air or water flow, pressure, and so on. This includes the relationships of indicator variables such as daytypes and seasons to energy consumption. 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.

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 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:

- Take action 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 fixed 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 reviewer will make the final choice of verification method and evidence.

6. Example

This example applies the protocol with the measurement boundary at the equipment level.

6.1. Overview

Company ABC operates an industry-leading aggregates and construction services company in the Willamette Valley, one of several they own and operate in the Pacific Northwest region. The equipment under study is the crusher water-supply pumps at the main pumping station. All the pumps are on one meter. Over the last year, energy use has totaled 887,200 kWh, with an average demand of 227.4 kW and a peak demand of 252.8 kW. There are no data available for the water demand at the crusher or the submeter data for each of the four pumps.

The conservation target process is the crusher supply-water pumps. Two vertical turbine pumps, one 125-hp and one 100-hp, draw water from a pond at a near continuous rate through underground piping to the crusher plant. The 125-hp and 100-hp pumps operate under manual on/off controls. The crusher plant is estimated to be about 800 feet from the pumping station. The crusher requires a relatively high-pressure supply and its current supply volume is inadequate, based on interviews with plant personnel.

This project was designed to reduce overall energy consumption at the main pump station and improved supply conditions at the crusher. To accomplish this, it was recommended that the pumping station be consolidated into one 75-hp energy-efficient pump (3,200 GPM/75 TDH), optimized to deliver 3,200 gallons per minute. Existing delivery lines will be examined in an attempt to eliminate the leaks that have limited historic flows. Additionally, this measure includes the installation of two booster pumps located close to the required end uses. These pumps will help ensure that properly pressurized water is delivered to the wash stations. These include one 60-hp (1,200 GPM, 180 TDH, 80 psi) just beyond the manifold to supply the crusher screen and one 15-hp (400 GPM, 90 TDH, 40 psi) at the classifier location.

Actual installed equipment included:

- One new energy-efficient 75-hp Vertical Turbine pump
- Miscellaneous installation equipment, including conduit, wire, and mounting hardware
- Varying lengths of new stainless steel and PVC discharge pipe and fittings
- One new energy-efficient 15-hp in-line booster pump
- One new energy-efficient 60-hp booster pump

6.2. M&V Approach

Overall energy savings will be measured by comparing the energy use per unit (kWh/kilo-gallon) efficiency before and after the project. This is an energy indexing approach as described in this protocol.

The measurement and verification plan for this project will rely on two sets of data monitoring sessions – one to provide pre-project data on energy consumption and system flow rates and a second to develop the efficiency metric. Additional variables, including pressure and flow, were also monitored. This data helped verify the post-project operating conditions of the main pump station, crusher-screen booster pump, and classifier-screen booster pump.

6.2.1. M&V Option

An Option B system approach was used for the energy use associated with water provided by the pumping station.

The measurement and verification team chose an energy efficiency metric, or index (kWh/kgal) to determine the savings amount for a full year. The savings were determined on a *fixed conditions* basis and the fixed conditions were selected to be the historic flows at the crusher. Since historic flows at the crusher were not measured, the historic energy use of the pumping station, from the pump station electric meter, was used as a proxy variable. The baseline monitored data was used to correlate the pumping station energy use to flow.

6.2.2. Measurement Boundary

The measurement boundary includes all the pumps and the electric meter is the measurement device. No other energy-using devices are on the meter.

6.2.3. Baseline Period

Baseline period data was collected to develop the baseline energy models. The baseline periods for each meter, their analysis time interval, and number of points are shown in Table 7-1.

Table 7-1: Baseline Period

Meter	From	To	Interval	Unit
Electricity	August 21, 2008 11:45 AM	August 27, 2008 8:45 PM	10 minutes	Amps

6.2.4. Post-Installation Modeling Period

After the new equipment was installed and operational, post-installation energy use and flow data was collected. Table 7-2 summarizes the post-installation monitoring period.

Table 7-2: Post-Installation Monitoring Period

Meter	From	To	Interval	Unit
Electricity	July 31, 2009 10:00 AM	August 18, 2009 1:40 PM	5 minutes	kW

6.3. Energy Indexing

The purpose of the baseline monitoring period was to establish the run-time of the pumps, so that the annual energy use could be estimated for the ex-ante savings estimate. Pump performance testing was accomplished at the time of typical operating conditions. However, only a single pair of measurements was needed to establish the index for the purposes of M&V, as shown in Table 7-3.

Table 7-3: Baseline Energy Index

Pump	Operating kW	Operating Gallons per Minute	Operating Gallons per Hour	Energy Index: kWh per 1,000 Gallons
125-hp	70.4	1,200	72,000	
100-hp	55.0	750	45,000	
Total	**125.4**	**1,950**	**117,000**	**1.072**

This index was used in conjunction with the utility bills to establish the annual historic water use, which was the fixed conditions basis for the savings (Table 7-4):

Table 7-4: Annual Water Use

Month	kWh	Gallons Calculated	Energy Index: kWh per 1,000 Gallons
Nov-07	81,000	75,574,163	
Dec-07	69,680	65,012,440	
Jan-08	83,520	77,925,359	
Feb-08	70,000	65,311,005	
Mar-08	64,640	60,310,048	
Apr-08	69,400	64,751,196	
May-08	68,720	64,116,746	
Jun-08	81,960	76,469,856	
Jul-08	94,680	88,337,799	
Aug-08	58,080	54,189,474	
Sep-08	77,200	72,028,708	
Oct-08	68,320	63,743,541	
Total	**887,200**	**827,770,335**	**1.072**

6.3.1. Post-Installation Modeling

Again, just a single pair of measurements was needed to establish the post-installation index (Table 7-5).

Table 7-5: Post-Installation Energy Index

Pump	Operating kW	Operating Gallons per Minute	Operating Gallons per Hour	Energy Index: kWh per 1,000 Gallons
75-hp Pump Station	52.6	2,775	166,500	
Booster Pumps	41.8	2,775	166,500	
Total	**94.4**	**2,775**	**166,500**	**0.567**

6.4. Annual Savings

Savings were estimated by adjusting post-installation energy use to the historic conditions. This was done simply by multiplying the post-installation index times the baseline water use, in gallons (Table 7-6).

Table 7-6: Company ABC's Willamette Valley Plant Annual Energy Savings

Phase	Water Use: 1,000 gallons	Energy Use Index: kWh per 1,000 gallons	Energy Use: kWh
Baseline	827,770	1.072	887,200
Post	827,770	0.567	469,318
Savings		**0.505**	**417,882**

7. References and Resources

ASHRAE. 2014. *ASHRAE Guideline 14-2014 – Measurement of Energy, Demand, and Water Savings*. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

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DOE\BP-4353 • July 2018