

Glossary for M&V: Reference Guide

September 2011



Glossary for M&V: Reference Guide

Version 1.0

September 2011

Prepared for

Bonneville Power Administration

Prepared by

Research Into Action, Inc.

Quantum Energy Services & Technologies, Inc. (QuEST)

Stetz Consulting, LLC

Kolderup Consulting

Warren Energy Engineering, LLC

Left Fork Energy, Inc.

Schiller Consulting, Inc.

Contract Number 00044680

Table of Contents

1. Introduction.....	1
1.1. Purpose.....	1
1.2. Background.....	1
2. Glossary of Terms.....	3
3. References and Resources.....	17

1. Introduction

1.1. Purpose

This document presents a *Glossary for M&V: Reference Guide* as a complement to the Measurement & Verification (M&V) protocols used by the Bonneville Power Administration (BPA).

This document is one of many produced by BPA to direct M&V activities. The *Measurement and Verification (M&V) Protocol Selection Guide and Example M&V Plan* provides the region with an overview of all of BPA's M&V protocols, application guides, and reference guides, and gives direction as to the appropriate document for a given energy efficiency project.

Chapter 3 of this reference guide provides full citations (and web locations, where applicable) of documents referenced.

1.2. Background

In 2009, BPA contracted with a team led by Research Into Action, Inc. to assist the organization in revising the M&V protocols it uses to assure energy savings for the custom projects it accepts from its customer utilities. The team has conducted two phases of research and protocol development under the contract, Number 00044680.

In the first phase, Research Into Action directed a team comprised of:

- Quantum Energy Services & Technologies, Inc. (QuEST), led by David Jump, Ph.D., PE and assisted by William E. Koran, PE;
- Left Fork Energy, Inc., the firm of Dakers Gowans, PE;
- Warren Energy Engineering, LLC, the firm of Kevin Warren, PE;
- Schiller Consulting, Inc., the firm of Steven Schiller, PE; and
- Stetz Consulting, LLC, the firm of Mark Stetz, PE.

In the second phase, Research Into Action directed a team comprised of:

- David Jump, Ph.D., PE, William E. Koran, PE, and David Zankowsky of QuEST;
- Mark Stetz, PE, CMVP, of Stetz Consulting;
- Erik Kolderup, PE, LEED AP, of Kolderup Consulting; and
- Kevin Warren, PE, of Warren Energy Engineering.

The Research Into Action team was led by Jane S. Peters, Ph.D., and Marjorie McRae, Ph.D. Assisting Drs. Peters and McRae were Robert Scholl, Joe Van Clock, Mersiha Spahic, Anna Kim, Alexandra Dunn, Ph.D., and Kathleen Gygi, Ph.D.

For BPA, Todd Amundson, PE, directed the M&V protocol research and development activities. Mr. Amundson was working under the direction of Ryan Fedie, PE, and was assisted by BPA engineers. Mr. Amundson coordinated this work with protocol development work undertaken by the Regional Technical Forum. In addition, Mr. Amundson obtained feedback from regional stakeholders.

2. Glossary of Terms

Accuracy: An indication of how close the measured value is to the true value of the quantity in question. Accuracy is not the same as precision.

Adjusted-Baseline Energy: The energy use of the baseline period, adjusted to a different set of operating conditions.

Algorithm for Savings Determination: The procedures to be followed for converting all relevant measured data and facts from the post-retrofit period to energy or demand savings using the baseline model.

Adjusted R-Squared (\bar{R}^2): A modification of R^2 that adjusts for the number of independent variables in a model. Adjusted R^2 only increases if the additional independent variables improve the model more than by random chance. It is calculated by taking R^2 and dividing it by the associated degrees of freedom. Or as described below:

$$\bar{R}^2 = 1 - \frac{MSE}{MST}$$

Autocollinearity: The correlation of values in a time series with prior and future values. It is calculated as:

$$\rho = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}}$$

Avoided Energy Use: 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. *Cost avoidance* is the monetary equivalent of *avoided energy use*. Both are commonly called *savings*. *Normalized savings* is another type of savings.

Baseline: Pertaining to the baseline period.

Baseline Adjustments: The non-routine adjustments arising during the reporting period from changes in any energy-governing characteristic of the facility within the measurement boundary, except the named independent variables used for routine adjustments.

Baseline Data: The measurements and facts describing facility operations and design during the baseline period. This will include energy use or demand and parameters of facility operation that govern energy use or demand.

Baseline Energy: The energy use occurring during the baseline period without adjustments.

Baseline Model: The set of arithmetic factors, equations, or data used to describe the relationship between energy use or demand and other baseline data. A model may also be a simulation process involving a specified simulation engine and set of input data.

Baseline Period: The period of time chosen to represent operation of the facility or system before implementation of an ECM. This period may be as short as the time required for an instantaneous measurement of a constant quantity, or long enough to reflect one full operating cycle of a system or facility with variable operations.

Billing Data: Metered data obtained from the electric or gas meter used to bill the customer for energy used in a particular billing period.

Binomial Distributions: A population consisting of items that can only occupy one of two states (i.e., present/absent, on/off, or pass/fail).

Building Commissioning: Building commissioning provides documented confirmation that the building systems as constructed function in accordance with the intent of the building designers and satisfy the owner's operational needs.

Building Envelope: The assembly of exterior partitions of a building that enclose conditioned spaces through which thermal energy may be transferred to or from the exterior, unconditioned spaces, or the ground.

Calibration: 1) The process of comparing the output or results of a measurement or model with that of some standard, determining the deviation and relevant uncertainty, and adjusting the model accordingly. 2) An adjustment of a measurement instrument to ensure the information it provides is accurate.

Categorical Variables: Variables that have discrete values and are not continuous.

Change Model: A type of billing analysis designed to explain changes in energy usage. This can take the form of having the change in energy consumption (pre versus post) as the dependent variable (e.g., December pre-retrofit usage – December post-retrofit usage) or having consumption as the dependent variable and pre-retrofit consumption as one of the independent variables.

Climate Thermal Zone (CTZ): A geographical area in the state that has particular weather patterns. These zones are used to determine the type of building standards that are required by law.

Coefficient of Variation (CV): An indication of how much variation or randomness there is within any given data set. It quantifies the variation relative to the average and is dimensionless. The higher it is, the more variation there is relative to the average. It is defined as the ratio of the standard deviation to the average:

$$CV = \frac{\sigma}{x}$$

Commissioning: A process for achieving, verifying, and documenting the performance of equipment to meet the operational needs of the facility within the capabilities of the design, and to meet the design documentation and the owner’s functional criteria, including preparation of operating personnel.

Confidence Interval: The range of values expected to contain the true value with a specific probability. The probability is referred to as the confidence level.

Confidence Level: The probability that the true value resides within the confidence interval.

Continuous Variables: Variables that are numeric and can have any value within the range of encountered data.

Constant: A term used to describe a physical parameter which does not change during a period of interest. Minor variations may be observed in the parameter while still describing it as constant. The magnitude of variations that are deemed to be “minor” must be reported in the M&V Plan.

Coefficient of Performance (COP): A parameter that represents the efficacy of a cooling or heat pump system. It is the dimensionless ratio of energy transferred to the input energy into the system in common units.

$$COP = \text{Energy Transferred} / \text{Energy Input}$$

Coefficient of Variation of the Root-Mean Squared Error [CV(RMSE)]: A measure that describes how much variation or randomness there is between the data and the model, calculated by dividing the *Root-Mean Squared Error (RMSE)* by the *average energy use*. It is calculated as:

$$CV(RMSE) = \frac{1}{y} \left[\frac{\sum (y_i - \hat{y})^2}{(n - p)} \right]^{1/2}$$

Degree Day: A degree-day is a measure of the heating or cooling load on a facility created by outdoor temperature. When the mean daily outdoor temperature is one degree below a stated reference temperature such as 18°C, for one day, it is defined that there is one heating degree-day. If this temperature difference prevailed for ten days, there would be ten heating degree-days counted for the total period. If the temperature difference were to be 12 degrees for ten days, 120 heating degree-days would be counted. When the ambient temperature is below the reference temperature, it is defined that heating degree-days are counted. When ambient temperatures are above the reference, cooling degree-days are counted. Any reference temperature may be used for recording degree-days, though it is usually chosen to reflect the temperature at which a particular building no longer needs heating or cooling.

Demand: The rate of energy use. Many utilities base a portion of their bills on the highest (or peak) demand they measure during each billing period. Peak demand values are sometimes referred to as simply *demand*. Electrical demand is normally expressed in kilowatts (kW). The sum of monthly billed kW quantities can be expressed in units of *kW-months*. See also *Demand Ratchet*.

Demand Savings: The reduction in the demand from the pre-retrofit baseline to the post-retrofit demand, once independent variables (such as weather or occupancy) have been adjusted for.

Demand Side Management (DSM): The methods used to manage energy demand, including energy efficiency, load management, fuel substitution, and load building.

Dependent Variable: The response that is measured. A dependent variable changes because of the independent variable.

Effective Useful Life (EUL): An estimate of the median number of years that the measures installed under a program are still in place and operable.

Efficiency: The ratio of the useful energy delivered by a dynamic system (such as a machine, engine, or motor) to the energy supplied to it over the same period or cycle of operation. The ratio is usually determined under specific test conditions.

Energy Conservation Measure (ECM): An activity or set of activities designed to increase the energy efficiency of a facility, system, or piece of equipment. ECMs may also conserve energy without changing efficiency. Several ECMs may be carried out in a facility at one time, each with a different thrust. An ECM may involve one or more of: physical changes to facility equipment, revisions to operating and maintenance procedures, software changes, or new means of training or managing users of the space, or operations and maintenance staff. An ECM may be applied as a retrofit to an existing system or facility, or as a modification to a design before construction of a new system or facility.

Energy Consumption: The amount of energy consumed in the form in which it is acquired by the user. The term excludes electrical generation and distribution losses.

Energy Cost: The total cost for energy, including such charges as base charges, demand charges, customer charges, power factor charges, and miscellaneous charges.

Energy Efficiency Improvement: Reduced energy use for a comparable level of service resulting from the installation of an energy efficiency measure or the adoption of an energy efficiency practice.

Energy Efficiency Measure: Installation of equipment, subsystems or systems, or modification of equipment, subsystems, systems, or operations on the customer side of the meter for the purpose of reducing energy and/or demand (and, hence, energy and/or demand costs) at a comparable level of service.

Energy Management System: A control system (often computerized) designed to regulate the energy consumption of a building by controlling the operation of energy-consuming systems, such as the heating, ventilation, and air conditioning (HVAC), lighting and water heating systems.

Energy Performance Contract: A contract between two or more parties where payment is based on achieving specified results, such as reductions in energy costs or payback of investment within a stated period.

Energy Services Company (ESCO): A firm that provides services of design and construction of ECMs under an energy performance contract.

Error: The deviation of a measurement from the true value.

Estimate: A process of determining a parameter used in a savings calculation through methods other than measuring it in the baseline and reporting periods. These methods may range from arbitrary assumptions to engineering estimates derived from the manufacturer’s rating of equipment performance. Equipment performance tests that are not made in the place where they are used during the reporting period are estimates, for purposes of adherence with IPMVP.

Ex-Ante Savings Estimate: Administrator-forecasted savings used for program and portfolio planning purposes. Derivation is from the Latin for *beforehand*.

Ex-Post Evaluation Estimated Savings: Savings estimates reported by the independent evaluator after the energy impact evaluation and the associated Measurement and Verification efforts have been completed. Derivation is from the Latin for *from something done afterward*.

Facility: A building or industrial site containing several energy-using systems. A wing or section of a larger facility can be treated as a facility of its own if it has meters that separately measure all of its energy.

Finite Population Correction Equation: When calculating sample size, the finite population correction equation reduces the number of samples required (n) when the population size is small (N) relative to the number of samples (n) assuming a very large population. It is calculated as:

$$n^* = \frac{Nn}{N+n}$$

Fixed Conditions Basis: Conditions other than those of the reporting period that may be used as the basis for adjustment. The conditions may be those of the baseline period, some other arbitrary period, or a typical, average or “normal” set of conditions. Adjustment to a fixed set of conditions reports a style of savings which could be called *normalized savings* of the reporting period. In this method, energy data of the reporting period and possibly of the baseline period are adjusted from their actual conditions to the common fixed (or *normal*) set of conditions selected.

Fractional Savings Uncertainty: The uncertainty divided by the savings, where uncertainty is measured as the quantity of savings from the upper confidence limit to the lower confidence limit surrounding a savings estimate.

Heterogeneous Population: A population in which all members have similar characteristics and can be considered of the same type.

Homogeneous Population: A population in which members have different characteristics and thus there are subpopulations of different types.

Homoscedasticity: (Also known as *homogeneity of variance*). Homoscedasticity generally means that all data in a model have the same variance. Within linear regression, this means that the variance around the regression line is the same for all values of the dependent variable.

Incentives: Financial support (e.g., rebates, low-interest loans) to install energy efficiency measures. The incentives are solicited by the customer and based on the customer's billing history and/or customer-specific information.

Independent Variable: A factor that cannot be controlled, and is expected to change regularly and have a measurable impact on the energy use of a system or facility.

Interactive Effects: Energy effects created by an ECM, but not measured within the measurement boundary.

International Performance Measurement and Verification Protocol (IPMVP): The IPMVP provides an overview of current best practice techniques available for verifying results of energy efficiency, water efficiency, and renewable energy projects in commercial and industrial facilities. It may also be used by facility operators to assess and improve facility performance. The IPMVP is the leading international standard in Measurement and Verification protocols. It has been translated into ten languages and is used in more than 40 countries.

IPMVP Options: IPMVP provides four Options for determining savings associated with Energy Conservation Measures (Options A, B, C, and D). The choice among the Options involves many considerations, including the location of the measurement boundary. Options C and D are appropriate for determining savings at the facility level. If only the performance of the measure itself is of concern, a *Retrofit Isolation* technique may be more suitable (Options A or B).

IPMVP Option A, Retrofit Isolation – Key Parameter Measurement: 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. When applying this protocol to new construction ECMs where there is no baseline equipment for measurement, the relevant building code or standard may be used to define estimated parameters.

IPMVP Option B, Retrofit Isolation – All Parameter Measurement: Savings are determined by field measurement of the energy use of the ECM-affected system. Measurement frequency ranges from short-term to continuous, depending on the expected variations in the savings and the length of the reporting period.

IPMVP Option C, Whole Facility: (Also known as the *Whole Building Metered Approach*.) Savings are determined by measuring energy use at the whole facility or sub-facility level. Continuous measurements of the entire facility's energy use are taken throughout the reporting period.

IPMVP Option D, Calibrated Simulation: (Also known as the *Whole Building Calibrated Simulation Approach*.) Savings are determined through the use of computer simulation software to predict facility or sub-facility energy use. A simulation model must be *calibrated* so that it predicts an energy pattern that approximately matches actual metered data. Option D is the primary *M&V* approach for assessing *energy* efficiency inclusions in new *facility* designs.

Mean: The most widely used measure of the central tendency of a series of observations. The Mean (\bar{Y}) is determined by summing the individual observations (Y_i) and dividing by the total number of observations (n), as follows:

$$\bar{Y} = \frac{1}{n} \sum Y_i$$

Mean Bias Error (MBE): (Also known as the *Normalized Mean Bias Error* or the *Net Determination Bias Test*.) The Mean Bias Error is an indication of overall bias in a regression model. Positive MBE indicates that regression estimates tend to overstate the actual values. It is calculated as:

$$NMBE = \frac{1}{y} \sum (y_i - \hat{y}_i) / (n - p)$$

Mean Model: (Also known as a *Single Parameter Model*.) A model that estimates the mean of the dependent variable.

Measure: 1) (n) an action or system modification intended to reduce energy use. 2) (v) the process of quantifying a physical parameter using instruments.

Measurement and Verification (M&V): The process of using measurements to reliably determine actual savings created within an individual facility by an energy management program. Savings cannot be directly measured, since they represent the absence of energy use. Instead savings are determined by comparing measured use before and after implementation of a project, making appropriate adjustments for changes in conditions.

M&V Plan: A well-defined and implemented M&V Plan encourages comprehensive project design by including all M&V costs in the project's economics. It increases the transparency and credibility of reports on the outcome of efficiency investments, and can be the basis for documenting performance in a transparent manner and subjected to independent verification.

Measurement Boundary: 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.

Measurement System Verification: The full range of checks and tests carried out to determine if all installed measurement system components, subsystems, systems, and interfaces between systems function in accordance with the measurement plan. Also used to ascertain the as-installed uncertainty of the measurement system.

Metering: Collection of energy data over time at a facility through the use of measurement devices.

Model: A mathematical representation or calculation procedure that is used to predict the energy use and demand in a building or facility. Models may be based on equations that specifically represent the physical processes (see *simulation model*) or may be the result of statistical analysis of energy-use data (see *regression model*).

Monitoring (Equipment or System): Gathering of relevant measurement data over time to evaluate equipment or system performance. For example, one might measure chiller electric demand, inlet evaporator temperature and flow, outlet evaporator temperature, condenser inlet temperature, and ambient dry-bulb temperature and relative humidity or wet-bulb temperature for use in developing a chiller performance map – such as kW/ton vs. cooling load and kW/ton vs. condenser inlet temperature.

Net Determination Bias Test: The savings resulting from applying the baseline period's independent variable data to the algorithms for savings determination. The data so applied must reflect all exclusions or adjustments to actual measured data as documented for the baseline model. See *Mean Bias Error*.

Normal distribution: A continuous and symmetric population distribution in which the frequency of occurrence decreases exponentially as values deviate from the mean (or central) value. It is also referred to as a *Gaussian* or *bell curve*. Most continuous populations are normal.

Normalized 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. These normal conditions may be a long-term average or those of any other chosen period of time other than the reporting period. Normal conditions may also be set as those prevailing during the baseline period, especially if they were used as the basis for predicting savings. If conditions are those of the reporting period, the term *avoided energy use*, or just *savings*, is used instead of *normalized savings*.

Outliers: Data points that do not conform to the typical distribution. An outlier appears to deviate markedly from other members of the same sample.

Over-Specified Model: A model with added independent variables that are not statistically significant or are possibly correlated with other independent variables.

p-value: The probability that a derived value is due to random chance. A small *p-value* indicates that a result has a low probability of being due to selecting non-representative samples. See *t-statistic*.

Peak Demand: The maximum level of metered demand during a specified time period, such as a billing month, or during a specified peak demand period, such as weekdays from 8 AM to 8 PM.

Performance Contracts: A binding agreement between two parties prescribing the range and magnitude of achievement required of equipment, a subsystem, or a system, which is provided by one party for the benefit and use of the other.

Post-Retrofit Period: The time following a retrofit during which savings are to be determined.

Precision: The indication of the closeness of agreement among repeated measurements; a measure of the repeatability of a process. Any precision statement about a measured value must include a confidence level. A precision of 10% at 90% confidence means that we are 90% certain the measured values are drawn from samples that represent the population and that the “true” value is within $\pm 10\%$ of the measured value. Because precision does not account for bias or instrumentation error, it is not an indication of accuracy.

Projected Baseline: The baseline energy use or demand applied to the post-retrofit period and conditions.

Proxy: A measured parameter substituted in place of direct measurement of an energy parameter, where a relationship between the two has been proven on site. For example, if a relationship has been proven between the output signal from a variable speed drive controller and the power requirements of the controlled fan, this output signal is a proxy for fan power.

Quasi-Random Sampling: A sampling technique in which each k^{th} element is selected from the population until the desired number is achieved.

R-Squared (R^2): (Also known as the *Coefficient of Determination*.) This measure indicates the extent to which variations in the dependent variable from its mean value are explained by the regression model. Examination of R^2 is the first step in assessing the reliability of a model. It is calculated as:

$$R^2 = 1 - \frac{SS_{error}}{SS_{total}}$$

Random Number Generator: A computer algorithm that generates quasi-random numbers that can be used for sample selection or for other purposes. Note that computers cannot generate truly random numbers and that algorithms may generate results with either uniform or quasi-normal population distributions.

Range of Interest: The range of the independent variable(s) affected by the measure.

Regression Analysis: A mathematical technique that extracts parameters from a set of data to describe the correlation of measured independent variables and dependent variables (usually energy data).

Regression Model: A mathematical model based on statistical analysis where the dependent variable is regressed on the independent variables which are said to determine its value. In so doing, the relationship between the variables is estimated statistically from the data used. A simple linear regression is calculated as:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i \text{ where } i = 1, \dots, n$$

Reliability: When used in energy evaluation, refers to the likelihood that the observations can be replicated.

Reporting Period: The period of time following implementation of an ECM when savings reports adhere to IPMVP. This period may be: as short as the time for an instantaneous measurement of a constant quantity; long enough to reflect all normal operating modes of a system or facility with variable operations; the length of the financial payback period for an investment; the duration of a performance measurement period under an energy performance contract; or indefinite.

Residual: Is the difference between the observed (or actual) and predicted value of the dependent variable.

$$\hat{\epsilon} = y_i - \hat{y}_i$$

Retrofit: Energy conservation measure or measures installed and/or implemented as a single project at a specific time.

Retrofit Isolation: The savings measurement approach defined in IPMVP Options A and B, and ASHRAE Guideline 14 that determines energy or demand savings through the use of meters to isolate the energy flows for the system(s) under consideration.

Rigor: The level of expected reliability. The higher the level of rigor, the more confident we are the results of the evaluation are both accurate and precise (i.e., reliable). That is, *reliability* and *rigor* are treated as synonymous.

Root Mean Squared Error (RMSE): (Also known as the *Standard Error of the Estimate*.) When a model is used to predict a value for given independent variable(s), the reliability of the prediction is measured by the standard error of the estimate. The RMSE is calculated as:

$$RMSE(\hat{\theta}) = \sqrt{MSE(\hat{\theta})} = \sqrt{E((\hat{\theta} - \theta)^2)}$$

Sampling: The process of identifying which and how many items to measure, and evaluating the results to assess reliability.

Simple Random Sampling: A sampling technique that draws representative samples from a single population where any sample is expected to be representative of the whole population.

Simulation Model: An assembly of algorithms that calculates energy use for a facility based on engineering equations and user-defined parameters.

Simple Random Sampling: Draws representative samples from a single population where any sample is expected to be representative of the whole population.

Standard Deviation (s): The square root of the variance, which brings the variability measure back to the units of the data. (With variance units in kWh^2 , the standard deviation units are kWh.) The sample standard deviation (s) is defined as:

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{(n-1)}}$$

Standard Error (SE): The standard deviation divided by \sqrt{n} . This measure is used in estimating precision. SE is defined as:

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

Standard Error of the Coefficient: The standard error of each coefficient in a regression model defines the range where the “true” value lies.

Standard Error of the Estimate: (Also known as the *Root Mean Squared Error*.) When a model is used to predict a value for given independent variable(s), the reliability of the prediction is measured by the standard error of the estimate. The *Root Mean Squared Error* (RMSE) is calculated as:

$$RMSE(\hat{\theta}) = \sqrt{MSE(\hat{\theta})} = \sqrt{E((\hat{\theta} - \theta)^2)}$$

Static Factors: Those characteristics of a facility which affect energy use within the chosen measurement boundary, but which are not used as the basis for any routine adjustments. These characteristics include fixed, environmental, operational, and maintenance characteristics. They may be constant or varying.

Stratified Sampling: A sampling technique used when the population is not homogeneous and needs to be segregated by some defining characteristic. Sample sizes in each stratum are determined by that stratum’s contribution to the overall variance such that the total sample size is minimized.

Sufficiency: A judgment as to whether the model is sufficiently accurate to verify the expected energy savings. The quality of a baseline model is not, by itself, adequate to determine its appropriateness. One makes the judgment by assessing the *fractional savings uncertainty*, which compares the uncertainty in the model with the magnitude of expected savings. The M&V profession has not established a criterion for this. In general, the uncertainty of savings should be much smaller than the savings. With the required confidence level and an expected savings percentage, a maximum acceptable *coefficient of variation of the root-mean squared error* [CV(RMSE)] can be calculated for the model.

System: A combination of equipment and/or controls, accessories, interconnecting means, and terminal elements working together to perform a specific function, such as HVAC, service water heating or illumination.

t-statistic: A measure of the probability that the value (or difference between two values) is statistically valid. The calculated t-statistic can be compared to critical *t-values* from a *t-table*. The t-statistic is inversely related to the *p-value*; a high t-statistic ($t > 2$) indicates a low probability that random chance has introduced an erroneous result. The t-statistic is calculated as:

$$t_{\hat{\beta}} = \frac{\hat{\beta} - \beta_0}{s.e.(\hat{\beta})}$$

Tons: A unit of cooling energy equal to 12,000 BTU/hr. The term derives from the amount of cooling that 1 ton of ice can provide in a 24-hour period.

Uncertainty: The range or interval of doubt surrounding a measured or calculated value within which the true value is expected to fall within some stated degree of confidence.

Uncertainty Analysis: 1) A procedure or method by which the uncertainty of a measured or calculated value is determined. 2) The process of determining the degree of confidence in the true value when using a measurement procedure(s) and/or calculation(s).

Variance (S^2): A measure of the extent to which observed values differ from each other (i.e., variability or dispersion), such that the greater the variability, the greater the uncertainty in the mean. Variance, the most important measure of variability, is found by averaging the squares of the individual deviations from the mean. The reason these deviations from the mean are squared is to eliminate the negative values (when a value is below the mean) so they do not cancel out the positive values (when a value is above the mean). Variance is computed as follows:

$$S^2 = \frac{\sum(Y_i - \bar{Y})^2}{n - 1}$$

Verification: 1) “The process of examining a report prepared by others to comment on its suitability for the intended purpose.” [Quoted from the IPMVP Glossary.] A third-party review of the savings estimation measurements, analysis approaches, and conclusions. 2) Providing evidence collected after implementation that the efficiency measure has been properly installed, is operating correctly, and has the potential to generate savings. Most references in the BPA protocols refer to the latter definition. Verification can be *Operational Verification*, which is preferred, or just *Installation Verification*, which is a subset of Operational Verification. Implementation Verification methods in the BPA protocols include surveys, inspections, photographs, spot measurements, short-term metering, and functional testing. For large and complicated measures, commissioning reports may be reviewed and used as part of the evidence that the measure has the potential to generate savings.

Weighted Regression: A form of regression used when data do not have equal weight in a model because the error is not constant across all observations.

Whole Building Calibrated Simulation Approach: The savings measurement approach defined in IPMVP Option D and ASHRAE Guideline 14, which involves the use of an approved computer simulation program to develop a physical model of the building in order to determine energy and demand savings. The simulation program is used to model the energy used by the facility before and after the retrofit. The pre-or post-retrofit models are developed by calibration with measured energy use, and demand data and weather data.

Whole Building Metered Approach: The savings measurement approach defined in IPMVP Option C and ASHRAE Guideline 14 that determines energy and demand savings through the use of whole facility energy (end-use) data, which may be measured by utility meters or data loggers.

z-statistic: (Also known as the *Standard Score*.) The z-statistic indicates how many standard deviations an observation or datum is above or below the mean. It is a dimensionless quantity derived by subtracting the population mean from an individual raw score and then dividing the difference by the population standard deviation.

$$z = \frac{x - \mu}{\sigma}$$

3. References and Resources

- ASHRAE. 2002. *ASHRAE Guideline 14-2002 – Measurement of Energy and Demand Savings*. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers.
Purchase at: http://www.techstreet.com/cgi-bin/detail?product_id=1645226.
- Brase, Charles Henry, and Corrinne Pellillo Brase. 2009. *Understandable Statistics: Concepts and Methods* (Ninth Ed.). New York, N.Y.: Houghton Mifflin Company.
- Cochran, William Gemmill. 1977. *Sampling Techniques* (Third ed.). Hoboken, N.J.: John Wiley & Sons, Inc.
- De Leeuw, Edith D., Joop Hox, and Don A. Dillman (editors). 2008. *International Handbook of Survey Methodology*. Mahwah, N.J.: Lawrence Erlbaum Associates.
- IPMVP. 2010. *International Performance Measurement and Verification Protocol Volume 1: Concepts and Options for Determining Energy and Water Savings*. EVO 10000 – 1:2010. Washington, D.C.: Efficiency Valuation Organization.
Available at: http://www.evo-world.org/index.php?option=com_form&form_id=38.
- Kish, Leslie F. 1965. *Survey Sampling*. New York, N.Y.: John Wiley & Sons, Inc.
- PJM Forward Market Operations. 2010. *PJM Manual 18B: Energy Efficiency Measurement and Verification*. Revision: 01, Effective Date: March 1, 2010. Norristown, Penn.: PMJ Interconnection.
- Schaeffer, Richard L., William Mendenhall III, and R. Lyman Ott. 2006. *Elementary Survey Sampling* (Sixth Ed.). Pacific Grove, Calif.: Duxbury Press.
- TecMarket Works Team. *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals*, April 2006. San Francisco, CA: California Public Utilities Commission.
Available at: www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/EM+and+V.
- Thompson, Steven K. 2002. *Sampling*. (Second Ed.) New York, N.Y.: John Wiley & Sons, Inc.

