ASHRAE Guideline 14-2014
(Supersedes ASHRAE Guideline 14-2002)

Measurement of Energy, Demand, and Water Savings

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Includes online access to RP-1050 and RP-1093 final reports, as well as downloadable software toolkits for analysis of building energy and environmental data.
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### NOTE

Approved addenda, errata, or interpretations for this guideline can be downloaded free of charge from the ASHRAE Web site at www.ashrae.org/technology.
This foreword is not part of this guideline. It is merely informative and does not contain requirements necessary for conformance to the guideline.

FOREWORD

Guideline 14 was developed by ASHRAE to fill a need for a standardized set of energy, demand, and water savings calculation procedures. The intent is to provide guidance on minimum acceptable levels of performance for determining energy and demand savings, using measurements, in commercial transactions. It is entirely possible to have a sale/purchase, lease, or other arrangement for energy-efficient equipment that does not involve measurements. Indeed, the vast majority of transactions are of this type. However, if the savings determination is to be based on measurements, certain minimum requirements are necessary to avoid a process that appears to be based on actual savings but might be highly inaccurate, biased, or random.

The anticipated use of ASHRAE Guideline 14 is for transactions between energy service companies (ESCOs) and their customers, and between ESCOs and utilities, where the utilities have elected to purchase energy savings. Guideline 14 is expected to provide savings results sufficiently well specified and reasonably accurate that the parties to the transaction can have adequate assurance for the payment basis. Other applications of Guideline 14 may include documenting energy savings for various credit programs (e.g., emission reduction credits associated with energy efficiency activities).

Determining savings with measurements in accordance with this guideline involves measuring postretrofit energy use and comparing that to the measured preretrofit use, adjusted or normalized, to act as a proxy for the conditions that would have prevailed had the retrofit not been performed. Therefore, determining energy savings through the use of measurements involves more than just verifying that new equipment has been installed and can function as expected, although those tasks are usually a necessary part of determining savings. In addition, energy savings cannot be claimed to be measured if no preretrofit data are available.

Sampling is often used in projects involving end-use monitoring or what is referred to here as the “retrofit isolation approach.” Informative Annex B shows procedures to calculate the added uncertainty due to sampling. Guideline 14 may be used to measure the energy savings from a utility-sponsored or contracted multiple-building energy conservation project. Applying Guideline 14 to such a project would allow the use of Annex B to calculate the measurement uncertainty directly. The net impacts of large-scale utility energy conservation programs, such as those that may involve market transformation or standard offers for purchase of conservation energy, are specifically excluded from the scope of Guideline 14, although individual and multiple-building projects within such programs are covered.

Guideline 14 primarily addresses measurements of energy and demand for determining savings. Other tasks are needed in any energy performance contract. These can include determining appropriate utility rates, inspecting and commissioning equipment, etc. Users of Guideline 14 who are interested in learning more about some of the contractual issues and types of performance contracts will find relevant discussion in the Efficiency Valuation Organization’s publication International Performance Measurement and Verification Protocol (IPMVP) available for download at www.evoworld.org.

Online Supporting Files

This guideline provides online access to supporting files. These files can be downloaded from the ASHRAE website at www.ashrae.org/G14_2014.

Included among these files are the full text of ASHRAE Research Reports RP-1050 and RP-1093, as well as software toolkits developed by ASHRAE to assist with the analysis of building energy and environmental data as described in Guideline 14.

1. PURPOSE

The purpose of this document is to provide guidelines for reliably measuring the energy, demand, and water savings achieved in conservation projects.

2. SCOPE

This document provides procedures for using measured preretrofit and postretrofit billing data (e.g., kWh, kW, Mcf, kgal) for the calculation of energy, demand, and water savings.

2.1 What Is Included. The procedures

a. include the determination of energy, demand, and water savings from individual facilities or meters;
b. apply to all forms of energy, including electricity, gas, oil, district heating/cooling, renewables, and water and wastewater; and

c. encompass all types of facilities: residential, commercial, institutional, and industrial.

2.2 What Is not Included. The procedures do not include

a. sampling methodologies used in large-scale demand-side management programs,
b. metering standards, or
c. major industrial process loads.

3. DEFINITIONS, ABBREVIATIONS, AND ACRONYMS

3.1 General. The following definitions represent the way each term is used in ASHRAE Guideline 14.

3.2 Definitions

actual energy savings: reductions in energy, demand, or water achieved by energy conservation measures (ECMs) and determined using one of the methods described in this document.

accuracy: the capability of an instrument to indicate the true value of measured quantity. This is often confused with inaccuracy, which is the departure from the true value to which all causes of error (e.g., hysteresis, nonlinearity, drift, temperature effect, and other sources) contribute.
avoided energy use: reduction in energy use during 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.” See also, energy savings and normalized savings.

baseline: pertaining to the baseline period.

baseline adjustments: nonroutine 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 conditions: values of all relevant baseline data, including independent variables and static factors describing facility operations and design during the baseline period. This includes building characteristics and other factors that may not be explicitly defined.

baseline data: measurements and quantitative facts describing facility operations and design during the baseline period. This includes energy use or demand and parameters of facility operation, which govern energy use or demand.

baseline energy: energy use occurring during the baseline period without adjustments.

adjusted baseline energy: the energy, demand, and/or water use of the baseline period after any routine and nonroutine adjustments have been applied.

baseline period: period of time selected as representative of facility operations before retrofit.

billing data: information collected from invoices sent to an owner from the energy supplier (e.g., electric or gas bills).

billing determinants: measured quantities that a utility uses to calculate the utility invoice.

calibrated simulation: measurement and verification (M&V) approach where a simulation model is calibrated to baseline or postretrofit energy use data. See also, calibration.

calibration: (a) process of verifying the accuracy of an instrument or meter by comparing the measured output of the instrument or meter against a measurement standard or calibrated instrument; (b) process of reducing the uncertainty of a model by comparing the predicted output of the model under a specific set of conditions to the actual measured data for the same set of conditions. In both cases, calibration includes following defined procedures that identify what parameters of the instrument, meter, or model may be adjusted, determining what is an acceptable level of accuracy or uncertainty, and documenting the process and results.

coefficient of variation (CV): the ratio of the standard deviation to the mean.

coincident: occurring simultaneously or during the same interval.

confidence level: probability that any measured value will fall within a stated range of precision.
demand savings: reduction in the billing demand between the preretrofit or baseline period, and the postretrofit or reporting period, once independent variables such as weather or occupancy have been adjusted for. This term is usually applied to billing demand, to calculate cost savings, or to peak demand, for equipment sizing purposes.

degree-day: 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 64°F (18°C), for one day, it is defined that there is one heating degree-day. If this temperature difference prevailed for ten days, ten heating degree-days would be 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 (NCDC 2002).

drift (windage) (Section 7 only): cooling tower mist ejected from the tower.

energy: (a) energy, demand, or water use; (b) capability of doing work. Energy can take a number of forms, which may be transformed from one into another such as thermal (heat), mechanical (work), electrical, and chemical. Customary measurement units are kilowatts (kWs), British thermal units or kilojoules (Btus or kJ), quantity of steam (in pounds or kilograms), or volume (in gallons or litres) of hydrocarbon fuel.

energy conservation measure (ECM): installation of equipment, subsystems, or systems or modification of equipment, subsystems, systems, or operations for the purpose of improving efficiency or reducing energy and/or demand (and, therefore, energy and/or demand costs).

energy cost: see total energy cost.

energy performance contract: contract between two or more parties where payment is based on achieving specified results such as improvements in efficiency or reductions in energy costs.

energy savings: reduction in use of energy from the preretrofit baseline to the postretrofit reporting period once independent variables, such as weather or occupancy, have been adjusted for.

energy service company (ESCO): organization that designs, procures, installs, and possibly maintains one or more energy conservation measures (ECMs) at an owner’s facility or facilities.

error: the difference between the true or actual value and the value indicated by the measurement system.

random error—general category for errors that can take values above or below the average value (i.e., not systematic errors).

systemic error—persistent error that does not occur by chance.

estimate: process of determining a parameter used in a savings calculation by methods other than measuring it in the baseline and reporting periods. For the purposes of this guide-

line, equipment performance tests that are not made in the place where they are used during the reporting period are estimates.

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

full-time equivalent: 1 for each 1 person per 8-hour shift. Visitors are calculated as average number of daily visitors.

independent variables: factors affecting the energy used in a facility that change regularly but which are outside the control of energy conservation measures (e.g., weather or occupancy). See also, routine adjustments and static factors.

instrument: device used to measure a physical quantity.

interactive effects: energy effects created by an energy conservation measure but not measured within the measurement boundary. Examples include the cooling energy savings and heating penalty that result when lighting energy use is reduced.

inverse method: approach to modeling energy use that develops an empirical relationship between a set of independent variables such as weather and actual measured energy, demand, and/or water use.

kWh: 3412 Btu.

least squares method: a data-fitting method that minimizes the sum of squared residuals, a residual being the difference between an observed value and the fitted value provided by a model.

marginal price: cost of one additional unit of a commodity billed under a complex rate schedule.

mean: the most widely used measure of the central tendency of a series of observations; the “average” value of a data set, determined by adding up the individual data points and dividing by the total number of these data points.

mean bias error (MBE): an indication of overall bias in a regression model.

measure: to use an instrument or meter to assess a physical quantity.

measured data: data collected using an instrument or meter.

measurement: (a) the act of collecting data using an instrument or meter; (b) data collected using an instrument or meter; (c) a calculated value that is derived directly from measurements.

measurement and verification (M&V): determination of actual energy, demand, and water savings achieved by one or more energy conservation measure(s). Savings cannot be directly measured because they represent the absence of energy use. Instead, actual savings are determined by comparing measured use before and after implementation of a project and making appropriate adjustments for changes in conditions.

measurement and verification plan (M&V plan): document describing in detail the proposed M&V activities, procedures,
and methods that will be used to determine the actual energy savings.

**measurement boundary:** notional boundary drawn around equipment and/or systems to segregate those that are relevant to savings determination from those that are not. All energy uses of equipment or systems within the measurement boundary must be measured or estimated, whether or not the energy uses are within the boundary.

**meter:** device used to measure energy, demand, or water use. See also *utility meter*.

**metered data:** energy, demand, or water use data collected over time using an instrument or meter.

**metering:** the act of collecting energy, demand, or water data at a facility using an instrument or meter.

**model:** mathematical representation or calculation procedure used to predict the energy used in a building or facility. Models may be based on equations that specifically represent the physical processes (simulation models) or may be the result of statistical analysis of energy use data (regression models). See also *inverse method*.

**regression model:** mathematical model based on statistical analysis of some measured data.

**simulation model:** model based on first-principles engineering methods that provides information on the energy using systems in a building (e.g., heating, ventilation, and air conditioning; lighting; occupancy; plug loads; building envelope). The model, along with weather data, serves as the input data for a specific computer building energy simulation program. When run, the computer simulation program will predict the energy use and demand in the described building for a time interval specified in the simulation model. Depending on the kind of simulation program and how it is set up to run, various kinds of output may be produced. (Refer also to Section 5.3)

**monitoring:** gathering data over time to evaluate equipment or system performance (e.g., chiller electric demand, inlet evaporator temperature and flow and outlet evaporator temperature, condenser inlet temperature, ambient dry-bulb temperature and relative humidity or wet-bulb temperature for use in developing a chiller performance map (kW/ton vs. cooling load and condenser inlet temperature).

**net determination bias test:** savings resulting from applying the baseline period’s independent variable data to algorithms for savings determination. Data so applied must reflect all exclusions or adjustments to actual measured data as documented for the baseline model.

**nonroutine adjustments:** calculations used to account for changes in static factors within the measurement boundary since the baseline period. When nonroutine adjustments are applied to the baseline energy, they are sometimes referred to simply as *baseline adjustments*.

**normalization:** adjustment of the baseline or postinstallation energy use to reflect a common set of conditions.

**normalized savings:** reduction in energy use or cost during a 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.

**performance contract:** binding agreement between two parties prescribing the specific performance criteria range and magnitude of achievement required of equipment, subsystems, or systems; provided by one party for the benefit and use of the other.

**postretrofit period:** time following a retrofit during which savings are to be determined. This term is synonymous with *reporting period*.

**precision:** (a) indication of the closeness of agreement among repeated measurements of the same physical quantity; (b) amount by which a measured value is expected to deviate from the true value. Precision is expressed as a plus/minus tolerance. Any precision statement about a measured value should include a confidence statement. For example, a meter’s precision may be rated by the meter manufacturer as ±10% with a 95% confidence level. See also *accuracy* and *uncertainty*.

**process water:** water used in a manufacturing or production process.

**proxy:** 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.

**r squared (r²):** a measure of the extent to which variations in the dependent variable from its mean value are explained by the regression model.

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

**reporting period:** period of time following implementation of an energy conservation measure when savings reports adhere to the guideline. 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.

**resolution:** smallest indicated increment in the value of a measured quantity that can be measured and reported by a recording instrument. Resolution is not related to accuracy, precision, or uncertainty.
**retrofit:** energy conservation measure or measures installed and/or implemented as a single project at a specific time. Although retrofit refers to work done in existing facilities, in the context of this guideline, retrofit is synonymous with energy conservation measures and may be used when referring to new construction.

**retrofit isolation:** savings measurement approach defined in this document that determines energy, demand, and/or water savings for a specific system. Retrofit isolation may be performed using energy measurements through the use of measurements to isolate the energy flows for the systems under consideration.

**routine adjustments:** adjustments to account for changes in selected independent variables within the measurement boundary since the baseline period. The methodology for routine adjustments must be defined in the measurement and verification plan by a specific formula or algorithm.

**savings:** general term referring to reductions in energy, demand, or water use or costs. See also, actual energy savings.

**savings determination:** see measurement and verification.

**standard deviation:** the square root of the variance.

**standard error:** the standard deviation divided by the square root of the number of observations.

**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:** a metric used to establish the reliability of a prediction when a model is used to predict a value for a given independent variable. The reliability of the prediction is measured by the standard error of the estimate.

**static factors:** those characteristics of a facility that 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.

**statistically valid sample:** randomly selected sample where the actual uncertainty of the sample measurements is equal to or less than the targeted precision for the specified confidence interval.

**system:** one or more pieces of equipment (e.g., fan, pump, motor) working together (e.g., heating system or electrical circuit).

**t-statistic:** a measure of the probability that the value (or difference between two values) is statistically valid.

**therm:** 100,000 Btu.

**time of use:** pricing structures for some forms of energy, especially electricity, include different prices for different times of day and weekends to encourage consumers to shift or reduce consumption at peak demand times.

**total energy cost:** total cost for energy obtained by applying the billing determinants to the rate or price schedule. This may include base charges, demand charges, customer charges, power factor charges, miscellaneous charges, etc.

**uncertainty:** range or interval of doubt surrounding a measured or calculated value within which the true value is expected to fall within some degree of confidence. See also precision and accuracy.

**uncertainty analysis:** (a) procedure or method by which the uncertainty of a measured or calculated value is determined; (b) process of determining the degree of confidence in the true value when using measurement procedures and/or calculations.

**utility:** supplier of energy or water to a facility. For the purposes of this guideline, a utility includes all entities responsible for providing both the commodity (energy and/or water) and services related to delivering the commodity to the facility, which may include storage, transmission, distribution, and metering. This includes regulated utilities, commodities suppliers, and internal groups that supply steam, hot water, or chilled water.

**utility meter:** meter used by a utility to measure billing determinants to calculate monthly charges for energy, demand, and/or water at a facility. More than one utility meter may be installed at a facility. If a utility combines data from several meters to calculate a single bill, the meters may be treated as a single meter.

**utility tariff:** document describing how utility bills will be determined for a particular customer. Regulated utilities publish the rate tariffs for most classes of customers, but rates that are negotiated with large customers may be confidential.

If the commodity is supplied by an entity different from the entity that delivers it to the customer, that portion of the utility costs may be determined by a separate contract. For the purposes of this guideline, the utility tariff refers to all documents that define how the utility or suppliers calculate their invoices to the facility.

**variance:** a measure of the extent to which observed values differ from each other (i.e., variability or dispersion), found by averaging the squares of the individual deviations from the mean.

**whole-facility metered approach:** savings measurement approach defined in 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.

### 3.3 Abbreviations and Acronyms

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<tbody>
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<td>3D</td>
<td>three dimensional</td>
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<tr>
<td>AC</td>
<td>alternating current</td>
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<tr>
<td>AGA</td>
<td>American Gas Association</td>
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<tr>
<td>AHRI</td>
<td>Air-Conditioning, Heating, and Refrigeration Institute</td>
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<tr>
<td>AHU</td>
<td>air-handling unit</td>
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<tr>
<td>ANSI</td>
<td>American National Standards Institute</td>
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<td>ASME</td>
<td>American Society of Mechanical Engineers</td>
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<td>Btu</td>
<td>British thermal unit</td>
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<td>BWM</td>
<td>box-whisker-mean</td>
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<td>Abbreviation</td>
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<tr>
<td>cfm</td>
<td>cubic feet per minute (ft³/min)</td>
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<td>COP</td>
<td>coefficient of performance</td>
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<tr>
<td>CT</td>
<td>current transformer</td>
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<td>CV(RMSE)</td>
<td>coefficient of variation of the root-mean-square error</td>
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<td>CV(STD)</td>
<td>coefficient of variation of the standard deviation</td>
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<td>DAS</td>
<td>data acquisition system</td>
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<td>DC</td>
<td>direct current</td>
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<td>DOE</td>
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<td>ECM</td>
<td>energy conservation measure</td>
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<td>energy management and control system</td>
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<td>ESCO</td>
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<td>evapotranspiration</td>
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<td>gpd</td>
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<td>gpm</td>
<td>gallons per minute (gal/min)</td>
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<td>higher heating value</td>
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<td>horse power</td>
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<td>HRSG</td>
<td>heat-recovery steam generator</td>
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<td>HVAC</td>
<td>heating, ventilating, and air conditioning</td>
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<td>inch-pound</td>
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<td>integrated circuit</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standardization (Organisation Internationale de Normalisation)</td>
</tr>
<tr>
<td>kVA</td>
<td>kilovolt-ampere</td>
</tr>
<tr>
<td>kVAR</td>
<td>kilovolt-ampere reactive</td>
</tr>
<tr>
<td>kW</td>
<td>kilowatt</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt-hour</td>
</tr>
<tr>
<td>M&amp;V</td>
<td>measurement and verification</td>
</tr>
<tr>
<td>MBE</td>
<td>mean bias error</td>
</tr>
<tr>
<td>LNG</td>
<td>liquid natural gas</td>
</tr>
<tr>
<td>MSE</td>
<td>mean square error</td>
</tr>
<tr>
<td>NCDC</td>
<td>National Climatic Data Center</td>
</tr>
<tr>
<td>NIST</td>
<td>National Institute of Standards and Technology</td>
</tr>
<tr>
<td>NMBE</td>
<td>normalized mean bias error</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>PF</td>
<td>power factor</td>
</tr>
<tr>
<td>ppmw</td>
<td>parts per million by weight</td>
</tr>
<tr>
<td>PRISM</td>
<td>Princeton Scorekeeping Method</td>
</tr>
<tr>
<td>PT</td>
<td>potential transformer</td>
</tr>
<tr>
<td>RE</td>
<td>relative error</td>
</tr>
<tr>
<td>RTD</td>
<td>resistance temperature detector</td>
</tr>
<tr>
<td>SaaS</td>
<td>software as a service</td>
</tr>
<tr>
<td>SI</td>
<td>International System (Le Système International d’Unités)</td>
</tr>
<tr>
<td>TS</td>
<td>time schedule</td>
</tr>
<tr>
<td>UFM</td>
<td>ultrasonic flowmeter</td>
</tr>
<tr>
<td>USB</td>
<td>universal serial bus</td>
</tr>
<tr>
<td>VAV</td>
<td>variable air volume</td>
</tr>
<tr>
<td>VBDD</td>
<td>variable-base degree-day</td>
</tr>
<tr>
<td>VSD</td>
<td>variable-speed drive</td>
</tr>
<tr>
<td>WCM</td>
<td>water conservation measure</td>
</tr>
</tbody>
</table>
Section 4 defines the minimum requirements and common elements of each of the three approaches, describes the criteria used to select an approach, and ongoing management of the measurement and verification (M&V) process. This section also provides a brief overview of how energy savings are used to calculate cost savings. A detailed description of each approach, including the elements unique to each approach, is provided in Section 6.

Sections 4.1 and 4.2 define and summarize the common elements of the three approaches for savings measurement. Section 4.3 defines the mandatory elements of any savings determination activity claiming compliance with this guideline.

Section 4.3 also contains Table 4-2, which summarizes mandatory requirements for compliance with this guideline for each approach, including prescriptive- and performance-based requirements for the whole-facility approach.

Section 4.4 outlines the steps in selecting and designing a project-specific M&V process and presents additional issues to be considered when selecting an approach. Section 4.5 provides recommendations for ongoing management of the M&V process.

Section 4.5 outlines how energy savings are typically calculated and how this affects the selection and design of the M&V process.

4.1 Approaches. The three approaches to determining savings (Table 4-1) use similar concepts in savings computation. They differ in how they measure actual energy use and demand quantities to be used in savings determination.

4.1.1 Retrofit Isolation Approach. The retrofit isolation approach measures the energy use and relevant independent variables of the individual systems and equipment affected by the retrofit. Measurements of baseline and postinstallation energy use are required. The duration of the measurements must be sufficient to capture the full range of operating conditions. Normalization of the measured energy use is usually required to account for differences in the operating conditions and to extrapolate measurements taken over a short period of time to represent annual energy use. The measurements may be normalized to the conditions during the baseline period or the actual postinstallation operation conditions. If neither baseline nor postinstallation conditions are representative of typical operating conditions, it may be necessary to define and use “normal” operating conditions. Both inverse methods and calibrated component simulations may be used to normalize savings. Savings are determined by comparing the normalized baseline and postinstallation energy use.

Savings derived from isolated and metered systems may be used as the basis for determining savings in similar but un-metered systems within the same facility, provided they are subjected to similar operating conditions throughout the baseline and postretrofit periods.

4.1.2 Whole-Facility Approach. The whole-facility approach uses the measured energy use of a building or an entire facility to determine savings. The building or facility energy use may be measured by the utility meter or by a separate submeter for the building or buildings to be evaluated. This approach may involve the use of monthly utility billing data or data gathered more frequently from the utility meter or existing submeters. Data regarding other statistically significant independent variables, such as weather, must be collected during the same period. If weather data are not available from an on-site source, data collected by government weather stations may be used.

A baseline model of facility energy use as a function of the independent variables is developed using inverse methods. The model is validated to ensure it is representative of baseline conditions. Savings are determined by comparing the baseline energy use calculated using the baseline model and the measured postinstallation values of the independent variables with the measured postinstallation energy use.

4.1.3 Whole-Building Calibrated Simulation Approach. The whole-building calibrated simulation approach involves the use of a computer simulation tool to create a model of energy use and demand of the facility. This model, which is typically of preretrofit conditions, is calibrated against actual measured energy, demand, and/or water consumption data. In some cases, additional data regarding the operation of the building and/or the energy use of specific systems or loads are used to refine and calibrate the model. The calibrated model is then used to determine the energy use, demand, and/or water use of the postretrofit conditions.

Simulations of existing buildings are usually calibrated against baseline data and then used to determine postinstallation energy use. In cases where baseline data do not exist, the simulations are calibrated after implementation, and the calibration adjustments are applied to the baseline model. Calibrating a simulation model to baseline and postinstallation measurements is not recommended because it is difficult to determine which postinstallation calibration adjustments should be applied to the baseline model. Savings are deter-

### TABLE 4-1 Approaches to Determining Savings

<table>
<thead>
<tr>
<th>Approach</th>
<th>Measurement Boundary</th>
<th>Measurements Required</th>
<th>Analysis Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retrofit isolation</td>
<td>Equipment or systems affected by retrofit</td>
<td>• Baseline energy use</td>
<td>• Inverse methods; include regression analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Postinstallation energy use</td>
<td>• Calibrated component models</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Significant independent variables</td>
<td></td>
</tr>
<tr>
<td>Whole-facility metering</td>
<td>Building or facility</td>
<td>• Baseline energy use</td>
<td>• Inverse methods; include regression analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Postinstallation energy use</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Significant independent variables</td>
<td></td>
</tr>
<tr>
<td>Calibrated simulation</td>
<td>Building or facility</td>
<td>• Baseline energy use OR postinstallation energy use</td>
<td>• Building simulation models</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Significant independent variables</td>
<td></td>
</tr>
</tbody>
</table>
4.2 Common Elements of all Approaches. Common elements of the three approaches for determining savings are presented below. Unique elements are presented in Sections 5.1 through 5.3.

4.2.1 Selecting Relevant Independent Variables. Independent variables are variables that directly or indirectly determine the energy use or demand of the system and which change during the baseline and/or postinstallation period. The most significant independent variables must be identified, measured over the periods of interest, and then considered in any savings computation. Examples of significant independent variables include, but are not limited to the following:

a. Weather (including outside air temperature, humidity, solar radiation, cloud cover, precipitation, wind, etc.)
b. Occupancy (including building or facility use, population, operating hours, etc.)
c. Production level and process operating conditions (for industrial facilities)

The measurement methodology, the duration, and frequency of measurements of independent variables depends on the availability of the data, the fraction of expected savings, and the desired level of uncertainty in determining savings. This guideline requires that the key independent variables be accurately quantified. If this is not technically or economically feasible, it may be impossible to verify savings with an acceptable level of uncertainty.

Independent variables for retrofit isolation techniques include the parameters that directly or indirectly influence the energy use of the equipment or systems affected by the retrofit. Whole-building or facility techniques require evaluation of all parameters that affect energy use or demand of the facility or building as a whole, including the energy use of equipment or systems not affected by the retrofit.

Determining which independent variables are relevant requires a thorough understanding of how the system (retrofit isolation methods) or facility (whole-facility methods) uses energy and how the retrofit will affect energy use and demand. All independent variables should be evaluated to determine which variables are most significant. The relevance of independent variables used as inputs to empirical modeling techniques (i.e., inverse methods) can be evaluated quantitatively using the \( F \) and \( t \)-statistics for each variable. Identifying the most relevant independent variables for engineering models (e.g., hourly building simulations) requires a sensitivity analysis. Documented experience with similar projects (i.e., similar facilities, systems, retrofits, climates, and rate structures) allows the sensitivity analysis to consider the variables that are likely to have the greatest impact. Adjustments for changes in known independent variables are discussed in Section 4.2.8.2.

The known independent variables rarely account for all of the variation in energy use or demand. Unaccounted for variables, including changes to the facility or its operation that go unnoticed and variables that cannot be accurately measured or quantified, are a primary source of uncertainty in any computed savings (see Section 4.2.11).

Parameters that may affect energy use but do not change during the baseline period are referred to as static factors. Static factors may include conditioned area, internal office, and process loads. Some parameters, such as occupancy levels and operating hours, may be independent variables for some projects (e.g., a hotel or industrial process) and static factors for others (e.g., correctional facilities). Adjustments for changes in static factors are discussed in Section 4.2.8.3.

4.2.2 Selecting the Baseline Period. The baseline period must include data across the full range of expected operating conditions, modes, and independent variables. Where possible, the baseline operating conditions should be similar to the expected operating conditions for the postretrofit period, to minimize bias or error from unaccounted for factors.

The baseline period is typically the period immediately before the retrofit is analyzed or proposed and should represent one or more complete operating cycles to minimize bias. For example, a facility that operates on an annual cycle in response to weather should have a baseline period of a full year, or several complete years. If data cannot be obtained for less than a full cycle of operation (e.g., 12 months for a facility with weather-dependent loads), shorter periods that are representative of each operating mode (e.g., one month in each season) may be acceptable if the data collection interval is reduced (e.g., from monthly to hourly). In all cases, care must be taken to ensure that the baseline period is representative of typical conditions and does not over- or underemphasize particular operating conditions.

If multiple years are included in the baseline period, each year must be evaluated independently to determine if the pattern of energy use or demand has changed during the period being evaluated. Evaluating several years of preretrofit data can help determine if there are long-term changes in the building energy use and indicate the magnitude of the change. For example, a gradual increase in the internal electrical loads (also referred to as “load creep”) is common in many types of buildings and over time can obscure the impact of the retrofit. Even if the underlying cause cannot be precisely determined, the impact of these long-term changes needs to be addressed in the M&V plan so that the retrofit performance can be accurately evaluated.

The baseline period shall be agreed to by both parties and shall be documented in the M&V plan.

4.2.3 Documenting Baseline Conditions. Baseline conditions include all of the parameters that can affect the energy use of systems inside the measurement boundary, including both independent variables and static factors. The relevant independent variables (see Section 4.2.1) shall be measured during the baseline period and documented in the detailed M&V plan. Measurement and analysis of independent variables is described in Sections 5 and 6. Static factors are usually identified at the same time as the independent variables, but the precise impact of static factors on energy use or demand is typically unknown.

Accurate and complete documentation of the baseline conditions inside the measurement boundary is necessary for developing accurate baseline models and establishing baseline conditions for calculating normalized savings. Nonrou-
tine adjustments require documentation of the static factors before and after the retrofit.

All static factors that may affect the energy use of the systems inside the measurement boundary shall be documented during the baseline and reporting periods. Procedures for collecting and documenting this information shall be mutually agreed to by all parties and included in the detailed M&V plan. The baseline values for all static factors that may affect energy use shall be recorded and documented in the M&V plan. If the static factors depend on the mode of operation and/or the time period or season, they must be documented for all conditions. Examples of static factors that need to be documented, include, but are not limited to

a. equipment nameplate and performance data;
b. occupancy, including population levels or density, schedule or patterns, and the use of the building;
c. HVAC equipment operating schedules and setpoints;
d. boiler and chiller plant control strategies, including sequencing, setpoints, and reset schedules;
e. lighting system operating hours and light levels;
f. miscellaneous equipment (e.g., office equipment) operating schedules, load profiles, and control strategies;
g. process loads, production levels, or other plant equipment energy use or load profiles;
h. conditioned space/volume;
i. energy use and operating conditions of equipment and systems not affected by the retrofit; and
j. maintenance activities, including the nature and timing of any equipment failures that have a material impact on energy use.

Note that some parameters may be independent variables for some retrofits and static variables for others (e.g., populations).

Baseline conditions shall be recorded for all the energy-using systems served by the meters to be used in the savings determination. Informative Annex C examples include descriptions of the information contained in the record of baseline conditions.

4.2.4 Setting the Duration of the Postretrofit Measurements. Postretrofit measurements of the dependent and independent variables used in calculating savings shall be measured over a period of time that is sufficient to

a. encompass all operating modes of the retrofitted system(s);
b. span the full range of independent variables normally expected for the reporting period; and

c. provide the intended level of certainty in the reported savings.

The postretrofit measurement period may occur once at the beginning of a project, periodically throughout the reporting period, or continuously throughout the reporting period.

4.2.5 Selecting Measurement Equipment. All meters for measuring energy use, demand or independent variables introduce error. Meter error can be a significant factor affecting the uncertainty in computed savings. The number and location of the measurement devices also influences the level of uncertainty. Section 6 and Informative Annex A summarize key factors to consider in selecting measurement equipment. The type and end-to-end accuracy of measurement equipment used for baseline and postretrofit measurements shall be documented in the detailed M&V plan. The costs of the measurement equipment should be assessed in the M&V plan outlined in Section 4.4.

All measurement equipment used should be calibrated prior to use and recalibrated at the intervals recommended by the manufacturer (typically once every 12 months). Initial calibration shall be performed by a qualified calibration facility independent of the parties involved. Recalibration may be performed by one of the parties if it is witnessed by the other parties, and if the instrumentation to calibrate the measurement equipment has been calibrated to third order NIST standards. The calibration and recalibration process shall be described in the detailed M&V plan. Documentation of initial calibration and subsequent recalibration shall be provided in the M&V plan (for measurements performed prior to submission of the M&V plan) and savings reports.

Calibration of meters used by the utility or energy supplier is not required because they are used to determine the utility bills. It is not necessary to document calibration instrumentation at government weather stations.

4.2.6 Weather Data. Weather data include a wide variety of measurements and observations, but the most common parameters that affect energy use are outdoor air temperature and humidity (sometimes referred to as “outdoor air conditions”). Solar radiation (or cloud cover), wind speed, and direction can affect building energy use but are more commonly used to evaluate the performance of renewable energy measures. Precipitation can be an important variable for projects where water is used for irrigation.

Weather data are the most common independent variable affecting energy use and demand. Accurate and consistent measurement and observations of weather conditions are critical. Data obtained from government weather stations (e.g., NOAA Class A) are considered to be very reliable, but the limited number of government weather stations and the variations in microclimates may justify the use of on-site instrumentation.

Government weather stations, such as the Class A sites operated by NOAA (NOAA data are available from NOAA’s National Climatic Data Center, 191 Patton Ave, Asheville NC. See also www.ncdc.noaa.gov.), have rigorous measurements standards and extensive quality control procedures. Data from these weather stations are the most reliable source of weather data for sites in the immediate vicinity of the station. However, variations in microclimates can produce significant variations in weather over short distances (less than a mile) due to changes in terrain and altitude. Proximity to large bodies of water, urban centers, and even airports also affect microclimatic conditions. When using government weather stations, the station that most closely represents the microclimatic conditions at the project site should be used, even if there are other stations that are closer to the project site. Where a nearby weather station is unavailable, a more distant station may be used if its weather pattern is well correlated to the pattern at the particular facility, even if the total heating or cooling conditions are somewhat different. Where possible, short-term weather data from the site should be compared.
with the weather observations recorded at several weather stations to determine which station most closely corresponds to the site’s local weather conditions.

If on-site measurement of weather data are used, the measurement devices must also conform to the calibration requirements in Section 6. If possible, the same instruments should be used for baseline and postinstallation measurements to minimize bias in the postinstallation results. If different instruments are used, calibration data for both sets of instruments shall be compared. If the postinstallation instruments calibrations are biased relative to the baseline instruments, the postinstallation instruments shall be recalibrated to eliminate this bias.

It is recommended that on-site weather observations be periodically validated against the nearest government weather station data to check for drift and/or instrument failure. An initial comparison of observations obtained from recently calibrated on-site instruments with observations from the government weather station will establish the correlation between observations at the two sites. If subsequent comparisons differ significantly from the initial comparison, the on-site sensors should be recalibrated.

The uncertainty of observations from government weather stations with rigorous measurement standards and quality control procedures (e.g., NOAA Class A) can be assumed to be negligible, as long as the station is in the immediate vicinity of the facility. The uncertainty associated with other sources of weather data, including on-site measurements, must be considered.

4.2.7 Demand. Many utilities include charges based on demand, the rate at which energy or water is consumed, for electricity, gas, or district heat supply. Billing demand is usually related to the peak demand during the billing period but may involve time-of-use periods, ratchets, and other rate structures. It may be different from the simple metered peak demand, requiring that determinations of savings recognize the differences that apply to each utility account.

Billing demand can be a fixed quantity (contract demand) associated with a negotiated capacity installed by the utility. Alternatively, it can be measured each billing period as the highest usage rate during the period (peak demand). Some utility supply contracts involve a combination of both contract and peak demand quantities for determining billing demand.

Two common examples of how billing demand is different from peak demand are as follows:

a. Electrical billing demand is determined by increasing peak demand beyond that metered when power factor is below a prescribed level.

b. Electrical billing demand is determined as the higher of contract demand and 60% (for example) of the highest of the previous twelve months’ peak demands.

Demand savings determinations shall take into consideration all terms in the utility supply contract before computing the reduction in billing demand. Mathematical modeling of baseline demand should be applied to peak demand data as measured, before applying terms reflecting the utility’s algorithm for determining billing demand. Demand savings can be high risk, depending upon the rate structure in use by the provider. ASHRAE Research Project, RP-1093, “Diversity Factor Toolkit” (Abushakra et al. 2001) can be used to determine demand savings.

Electric demand, in kilowatts or kilovolt-amperes, is usually metered over a 15-minute interval, though one-, three-, five-, and thirty-minute intervals are also used. Metering intervals may be fixed, sliding window, or instantaneous. The fixed interval uses the stated period as the measurement period. The sliding window interval uses a subset of the window interval to “slide” the interval in time. For example, a 15-minute sliding window interval may use one, three, or five minute subintervals to accumulate the total demand for the 15-minute period. A new value for the 15-minute period is calculated every subinterval time. Instantaneous billing periods are usually one- or three-minute intervals. Natural gas demand is usually measured over a 24-hour period.

Demand meters installed to submeter electricity shall use the same or shorter metering interval as the supplying utility meter. The peak demand shall be measured at the same time as the utility meter’s peak demand is measured in order to measure demand coincident with the utility meter. A retrofit’s reduction in electrical load may not necessarily be fully reflected in reduced peak demand since the time of postretrofit peak may have shifted to a former secondary peak.

Where a utility bill shows that energy use was estimated, a valid demand meter reading is usually not available.

All data needed for determining billing demand may not be shown on the utility bill. The utility company may need to provide extra information such as factors and procedures used in billing and/or the time of monthly peak. Electric demand intervals should remain the same during the baseline and postretrofit period.

4.2.8 Calculations. Conditions, such as weather and usage that govern energy use or demand, are usually different between the baseline and postretrofit periods. Measured use and demand must be normalized to a common set of conditions in order to report savings properly. The selection of that common set of conditions for normalization is discussed in Section 4.2.8.1.

The changes in conditions can be either routine or nonroutine. Routine changes, such as weather, occupancy, or hours of operation, which vary from one period of time to another, are those that can be anticipated and that can be readily documented. Calculations involving routine changes are discussed in Section 4.2.8.2. Nonroutine changes, such as change in building use from office to warehouse, follow no expected pattern and often require special effort for documentation. Adjustments for nonroutine changes are discussed in Section 4.2.8.3.

4.2.8.1 Selecting a Common Set of Conditions. To be comparable, baseline and postretrofit period energy use and demand data must be projected to the same set of conditions. These conditions may be those of the postretrofit period, a typical or average set of conditions, or the baseline period. The selection of the set of conditions establishes the type of savings that will be reported, as follows:

a. Avoided costs, where baseline energy use is adjusted to postinstallation conditions. The adjusted baseline repre-
sents what would have happened in the absence of the retrofit, and the reported savings are the avoided energy use for that postretrofit period. Reported savings reflect changes in both the performance of the retrofit and the postinstallation conditions.

b. Normalize savings to typical conditions, usually the baseline conditions. Postinstallation energy use is adjusted to reflect the baseline conditions. Reported savings reflect changes in the performance of the retrofit, allowing comparison of performance from one year to the next.

4.2.8.2 Routine Adjustments. Routine adjustments are the adjustments that are expected to occur frequently during the reporting period. The methodology for these adjustments is defined by the detailed M&V plan.

If avoided costs are being reported, a baseline model is developed to correlate measured baseline energy use and/or demand with statistically significant independent variables (Section 4.2.1.1). This model is then used to calculate the adjusted baseline energy use at the actual postinstallation conditions, and the avoided costs are calculated as the difference between the adjusted baseline energy use and the actual postinstallation energy use.

If normalized savings are being reported, the postinstallation measurements are applied to a postinstallation model that normalizes postinstallation energy use or performance measurements to the agreed-upon normal conditions. This model is then used to calculate the adjusted postinstallation energy use at the normal conditions, and the normalized savings are calculated as the difference between the normalized baseline and postinstallation energy use.

Modeling techniques fall into two categories: empirical models, also known as “inverse methods,” and engineering models. Inverse methods, which include regression models, linear change-point models, and neural networks, create models based on the mathematical relationships between independent and dependent variables, without any knowledge of the physical processes that link them. Engineering models, which include hourly building simulation models (e.g., DOE2.1E), component models (e.g., TRNSYS), and bin models (e.g., ASEAM), are detailed mathematical representations of the physical processes that link independent and dependent variables. For any given set of data, some techniques may more faithfully predict a period’s actual energy use than others. The modeling method chosen should be consistent with the intended uncertainty of the savings determination, and the net determination bias should not exceed 10% of the estimated savings for regression models (see Section 4.2.10).

4.2.8.3 Nonroutine Adjustments. Changes to static factors that affect the energy use of the systems inside the measurement boundary require nonroutine adjustments. The changes are typically related changes in a facility’s use or operations, including, but not limited to, renovations, facility expansion, changes in usage, and the addition or removal of equipment. Nonroutine adjustments are modifications to the M&V methodology to account for these changes when reporting savings and may be permanent or temporary.

The energy use and demand impacts of the change shall be determined by specific measurements and/or engineering calculations that are consistent with the M&V plan. The impact of the changes shall be reflected as an adjustment to the baseline or postinstallation energy use model. The additional uncertainty introduced by the adjustment must be reported.

While the M&V plan may be able to address some common and straightforward changes that will require nonroutine adjustments, in most cases, the detailed methodology cannot be developed until the scope and nature of the changes are known. All parties involved must agree to the methodology for nonroutine adjustments.

Nonroutine adjustments shall be reported for the interval when they occurred. If it is determined that nonroutine adjustments are necessary after results have been reported, previously reported savings should be restated. Where contract compliance or payments are dependent on the results of these calculations, the detailed M&V plan or the contract itself should contain provisions to address the process for developing nonroutine adjustments, including retroactive adjustments.

4.2.9 Missing Data. Missing data may be estimated or interpolated from measured data using statistically valid engineering techniques, provided that the subsequent calculation of the level of uncertainty in the reported energy use and/or savings reflects the appropriate change in the uncertainty. The data used to interpolate or estimate the missing data shall represent the full range of operating conditions experienced during the missing data interval (if the dependent variable data are missing) or similar adjacent intervals (if data for the independent variables are missing). The data set used for interpolation or estimation of missing data should be an order of magnitude greater than the missing data interval (e.g., for monthly data, 12 months; for daily data, 7 to 14 days; for hourly data, 12 hours, etc.).

The specific methodology for estimating or interpolating missing data shall be described in detail in the savings reports, and the same methodology shall be used throughout the reporting period. The methodology may be modified to address new circumstances, as long as the modification is documented in the corresponding savings reports. A summary of the missing data, including parameters that were missing and the quantity of data missing, shall be reported in the savings reports.

Documentation required by the section shall be sufficient enough that the reported savings can be reproduced by a third party based on the data provided in the savings report.

4.2.10 Net Determination Bias. The necessary assumptions and the unavoidable errors in metering of energy use and demand introduce random error and bias into the computed savings. However modeling and computations used to calculate savings should not add any more error or bias than might be generated by the computational accuracy of modern computational equipment for the whole-building and retrofit isolation approaches. For the whole-building calibrated simulation approach, modeling error is constrained by the calibration requirements of this guideline.
Computational methods used in the whole-building and retrofit isolation approaches include three steps:

a. Development of the mathematical model of the baseline
b. Filtering that may be applied to postretrofit independent variable data
c. Application of the possibly filtered postretrofit independent variable data to the baseline model to determine the baseline energy use or demand adjusted to postretrofit conditions

Together these steps are defined herein as the “algorithm for savings determination.” Provided all steps are consistent with each other, only rounding errors will be added by the computational methods. For example the same logic must be used in filtering postretrofit data as is used in developing the model. Rounding errors should be insignificant so that no error is added by computational methods. In this guideline, such situation is defined as one with no net determination bias.

The algorithm for savings determination used in whole-building and retrofit isolation approaches shall be tested for net determination bias. The net determination bias test (see definitions) shall apply the baseline independent variable data to the algorithm for savings determination to recompute an algorithm-determined baseline energy usage or demand for each of the $n$ baseline data points ($i$). These recomputed quantities are then compared to the actual baseline energy use or demand ($i$) in the baseline period to derive the net determination bias, as shown below.

Net determination bias should be no more than 0.5% for regression models for whole-building and retrofit isolation approaches.

### 4.2.11 Savings Uncertainty Calculations

This guideline presents simplified methods of assessing the quantifiable uncertainty in savings computations. Other uncertainty analysis methods are deemed compliant with this guideline if they can be shown to be relevant to the situation and use methods presented in published statistical textbooks.

Three primary sources of quantifiable uncertainty in savings determination are discussed herein along with key methods for computing their impact as noted below:

a. Sampling uncertainty (Sections 4.2.11.1 and B4.1)
b. Measurement equipment error (Section 4.2.11.2, Annex A, and Section B4.2.)
c. Modeling uncertainty (Section 4.2.11.3 and Annex B)

Equations 4-6 and 4-7 in Section 4.2.11.4 consolidate these uncertainties for constant and varying baseline use, respectively. Annex B provides further background on these derivations of the uncertainty in computed savings.

Bootstrapping methods can also be used to estimate uncertainty. In the case of complex rates, a bootstrap approach may be the only way to estimate the uncertainty of cost savings.

Other types of uncertainty are not quantifiable. These include such systematic errors as human errors and errors of technique. Additional random or accidental errors include errors of judgment and unaccounted for changes in conditions. In addition, there are illegitimate errors, such as mistakes and incorrect placement of transducers. Such sources of uncertainty may not lend themselves to explicit quantitative uncertainty calculations, as discussed below. Nevertheless, their existence should be recognized, and their range of possible impacts presented in the M&V plan.

Many methods shown here for the three categories of quantifiable errors are simplifications of strict statistical theory for general application. These methods are shown so that practitioners can easily make reasonable estimates of the level of uncertainty in computed savings.

### Terminology

- $q$ = number of randomly selected items from a population of $Q$ items
- $Q$ = total number of pieces of equipment in a group to be sampled
- $F$ = approximate percentage of the baseline energy use that is saved. This percentage should be derived for the $m$ periods of the reporting period. Before savings are actually achieved, the predicted savings may be used in computing $F$ for purposes of designing the savings determination algorithm.
- $m$ = number of periods (months, weeks, days, hours) in the postretrofit savings reporting period
- $n$ = number of data points or periods in the baseline period
- $n'$ = number of independent observations in a total of $n$ observations during the baseline period, calculated as follows:

$$n' = n \times \frac{1 - \rho}{1 + \rho}$$

where $\rho$ is the autocorrelation coefficient of the series of $n$ observations at lag 1, derived from performing a regression of the series of $n$ observations against the same data series offset by one time step. The correlation coefficient is as follows:

$$\rho = 1 - \frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{\sum_{i=1}^{n} (y_i - y_i')^2}$$

For monthly data, this guideline permits an assumption that $\rho$ is 0, so $n'$ is equal to $n$.

- $p$ = number of parameters or terms in the baseline model, as developed by a mathematical analysis of the baseline data

### Equations

**Mathematical Analysis**

**Algorithm Approach**

**Other Considerations**

**References**

**General Considerations**

**Uncertainty Propagation**

**Summary**

**Appendix B**

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**References**
Equation \( r_{\text{rating}} \) = reading of an instrument at the point at which its manufacturer quotes its relative error (RE) (normally full scale).

Equation \( t \) = \( t \)-statistic found in statistics textbooks. Selected values are shown in the following table for various confidence levels and values of \( n - p \).

<table>
<thead>
<tr>
<th>( n - p )</th>
<th>68%</th>
<th>80%</th>
<th>90%</th>
<th>95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>1.00</td>
<td>1.48</td>
<td>2.02</td>
<td>2.57</td>
</tr>
<tr>
<td>10</td>
<td>1.00</td>
<td>1.37</td>
<td>1.81</td>
<td>2.23</td>
</tr>
<tr>
<td>15</td>
<td>1.00</td>
<td>1.34</td>
<td>1.75</td>
<td>2.13</td>
</tr>
<tr>
<td>20</td>
<td>1.00</td>
<td>1.33</td>
<td>1.73</td>
<td>2.09</td>
</tr>
<tr>
<td>25</td>
<td>1.00</td>
<td>1.32</td>
<td>1.71</td>
<td>2.06</td>
</tr>
<tr>
<td>Infinite</td>
<td>1.00</td>
<td>1.28</td>
<td>1.65</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Equation \( U \) = relative uncertainty in reported energy savings, expressed as a percentage of the savings.

Equation \( U_s \) = uncertainty created by sampling, expressed as a percentage of the mean.

Equation \( U_{iv} \) = savings uncertainty created by the error in measurement of postretrofit period independent variables, expressed as a percentage of the savings (See Section 4.2.11.2.)

Equation \( y \) = dependent variable of some function of the independent variable(s).

Equation \( \bar{y} \) = arithmetic mean of the sample of \( n \) observations.

Equation \( \hat{y} \) = regression model’s predicted value of \( y \).

**4.2.11.1 Sampling Uncertainty.** The relative uncertainty created by estimating the mean (\( \bar{y} \)) of a population of \( Q \) items from a random sample of \( q \) items with values \( y_i \) is

\[
U_s = \frac{100}{\sqrt{Q}} \times \sqrt{\left(1 - q/Q\right) \left(\frac{n}{q} \frac{(1)}{\sum_{i=1}^{n} (y_i - \bar{y})^2/(q - 1)}\right)}
\]

**4.2.11.2 Measurement Equipment Error.** The equipment used to measure physical quantities produces both measurement and data-capture errors due to the calibration, range, and repeatability of the equipment and installation effects. These factors influence the uncertainty of values reported for energy use and other variables.

This guideline assigns zero measurement error for the following items:

a. Energy use, demand, and independent variables included in a regression model for the baseline period. These errors are inherently assessed by the coefficient of variation determined for the baseline model (Section 4.2.11.3), assuming there is no bias in the reported data.

b. Postretrofit period energy use data that are reported on utility bills.

c. Postretrofit period weather data published by a government-operated weather reporting service in the United States and Canada.

Measurement error shall be assessed for nonbilling energy use meters, adjustments for inventories of stored energy quantities, and measurements of postretrofit independent variables. Errors shall be estimated in terms of both accuracy and confidence levels. Manufacturer’s literature or a series of field measurement system verification tests will provide estimates of accuracy, termed “relative error” (\( \text{RE}_{\text{instrument}} \)), at some rating point (\( r_{\text{rating}} \)), usually full scale. Where accuracy or confidence intervals are unknown, the values shown in Section A5 may be used, assuming a 68% confidence interval. The source of measurement error estimates shall be indicated.

The combination of several components in measuring any value will combine the individual errors of each. The \( \text{RE}_{\text{instrument}} \) of \( C \) dependent variables can be combined into a final value for overall instrument-error using Equation 4-2, where RE represents the mean reading on any instrument.

\[
\text{RE}_{\text{instrument}} = \sqrt{\sum_{c}^{c} \left(\text{RE}_{\text{instrument}} \times r_{\text{rating},i} \right)^2}
\]

Error in measuring postretrofit independent variables shall not be combined with any error in metered energy use. The impact of this independent variable error (\( U_{iv} \)) shall be simply assessed by computing the savings twice: once with the independent variables at their maximum values and once with them at their minimum values for the stated confidence interval. The difference between these two computed savings defines the total span of the extra uncertainty created by the error in measuring independent variables. The maximum and minimum independent variable values used shall be stated.

**4.2.11.3 Modeling Uncertainty.** This guideline uses the following three indices to represent how well a mathematical model describes the variability in measured data. These indices shall be computed for the single mathematical model used to describe the baseline data from all operating conditions (i.e., both summer and winter shall be consolidated in one model for evaluating these indices):

a. Coefficient of Variation of the Standard Deviation (\( \text{CV}[\text{STD}] \))

\[
\text{CV}(\text{STD}) = \sqrt{\frac{\sum (y_i - \bar{y})^2}{\bar{y}^2}}
\]

b. Coefficient of Variation of the Root-Mean-Square Error (\( \text{CV}[\text{RMSE}] \))
CV(RMSE) = \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{(n - p)}} \tag{4-4}

c. Normalized Mean Bias Error (NMBE)

\text{NMBE} = \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)}{(n - p) \times \bar{y}} \tag{4-5}

For calibrated simulations, the CV(RMSE) and NMBE of modeled energy use shall be determined by comparing simulation predicted data \( (y_i) \) to the utility data used for calibration \( (\hat{y}_i) \), with \( p = 1 \).

4.2.11.4 Computing Savings Uncertainty. Overall savings uncertainty is estimated by considering sample size \( (q, Q) \), measurement error \( (\text{RE}_{\text{instrument}} \text{ and } U_{\text{iv}}) \), modeling uncertainty \( (CV) \), the length of the savings determination period \( (m) \), and the fraction of baseline energy saved \( (F) \). Overall savings uncertainty shall be estimated as follows:

a. Adjust the measurement and modeling uncertainties to a common confidence interval, using the ratio of the relevant \( t \)-statistics in the table shown in Section 4.2.11.

b. Use Equation 4-6 or 4-7, as appropriate. The Section 4.2.11 table \( t \)-statistic used shall match the confidence levels used in assessing the measurement and modeling uncertainties.

c. Report the confidence level with the uncertainty.

d. Uncertainty associated with any baseline adjustments (Section 4.2.8.3) shall be included by treating it as part of the error in postretrofit energy use measurements, using Equation 4-2.

In cases where the baseline energy use or demand is essentially the same for all periods, or unaffected by any known independent variables (e.g., a lighting circuit’s energy use read monthly):

\[ U = \frac{t}{F} \sqrt{\frac{\text{CV}(\text{STD})^2}{m} + U_{iv}^2 + \text{RE}_{\text{instrument}}^2} \tag{4-6} \]

In cases where baseline energy use or demand varies from period to period in response to known independent variables,

\[ U = \frac{t}{F} \sqrt{\frac{\text{CV}(\text{RMSE})^2}{m} \times \left[ \frac{n}{n} \times \left( 1.6 + \frac{3.2}{m^2} \right) \right] + U_{iv}^2 + \text{RE}_{\text{instrument}}^2} \tag{4-7} \]

Equation 4-7 simplifies to Equation 4-8 for the common situation where no sampling is done \( (q = Q) \), utility bills are the source of all energy use data \( (\text{RE}_{\text{instrument}} = 0 \text{ and } n = n') \) and United States or Canadian government-published weather data are used as the only independent variable \( (U_{iv} = 0) \). Figure B-1 and Table B-2 in Annex B portray this relationship at 68% confidence and a 12-month baseline period.

\[ U = t \times \frac{1.26 \times \text{CV}(\text{RMSE})}{F} \times \sqrt{\frac{n + 2}{n}} \times \frac{n \times m}{n \times m} \tag{4-8} \]

It should be noted that savings uncertainty estimates using these formulas for the calibrated simulation approach apply only to the total savings determined for a meter, not to the savings of individual retrofits. Also, \( t \) should be determined for calibrated simulations using \( p = 1 \).

4.2.11.5 Managing Uncertainty. When planning a retrofit project, a target savings uncertainty level should be established. Equations 5-6 or 5-7 can then be used to evaluate feasible combinations of model \( \text{CV}(\text{RMSE}) \), instrument error, sample size, postretrofit period length, and expected savings fraction. The costs of feasible combinations of savings determination characteristics can be evaluated to find the lowest cost means of achieving the target uncertainty.

It should be noted that uncertainty \( (U) \) declines as the savings reporting period \( (m) \) lengthens. However compliance with this guideline’s maximum level of uncertainty is determined from annual savings only.

Examples of the use of these equations are shown in Annexes B and C.

4.3 Compliance Requirements. To claim compliance with this guideline, the savings measurement shall meet the basic and specific requirements shown in Sections 4.3.1 and 4.3.2, respectively. Examples of compliant savings measurement processes are listed in Informative Annex C. The general methodology of all compliant methods is summarized below:

a. Prepare an M&V plan showing the compliance path chosen, the metering, and analysis procedures.

b. Measure the energy use and demand and the selected independent variables (see Sections 4.2.1 and 4.7) driving energy use in the baseline period. Document baseline conditions (see Section 4.2.3).

c. Measure the same energy use and demand and independent variables in the postretrofit period.

d. Project the baseline and/or postretrofit period energy use and demand measurements to a common set of conditions (see Section 4.2.8.1).

e. Subtract the projected postretrofit period use and billing demand from the projected baseline period use and billing demand to determine the savings. For performance path compliance, the level of uncertainty must be less than one half of the total savings reported in the postretrofit reporting period.

4.3.1 Basic Requirements

a. Prepare an M&V plan, as defined in Section 4.4.1, before retrofit implementation.

b. Measure and report postretrofit energy use and demand, independent variables, and conditions used in the algorithm for savings determination.

c. Apply the algorithm for savings determination for all periods where independent variables are no more than 110% of the maximum and no less than 90% of the minimum values of the independent variables used in deriving the baseline model.

d. For periods not complying with Section 4.3.1(c), any savings report shall note that the independent variable(s) for that period are beyond the range of applicability of the model derived from baseline data.