Chapter 9: Metering Cross-Cutting Protocol

The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures

Created as part of subcontract with period of performance September 2011 – September 2016

This document was republished in September 2017 after a thorough review; no substantive changes were made. This supersedes the version originally published in April 2013.

Dan Mort
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Sacramento, California

NREL Technical Monitor: Charles Kurnik

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September 2017

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Preface

This document was developed for the U.S. Department of Energy Uniform Methods Project (UMP). The UMP provides model protocols for determining energy and demand savings that result from specific energy-efficiency measures implemented through state and utility programs. In most cases, the measure protocols are based on a particular option identified by the International Performance Verification and Measurement Protocol; however, this work provides a more detailed approach to implementing that option. Each chapter is written by technical experts in collaboration with their peers, reviewed by industry experts, and subject to public review and comment. The protocols are updated on an as-needed basis.

The UMP protocols can be used by utilities, program administrators, public utility commissions, evaluators, and other stakeholders for both program planning and evaluation.

To learn more about the UMP, visit the website, https://energy.gov/eere/about-us/ump-home, or download the UMP introduction document at http://www.nrel.gov/docs/fy17osti/68557.pdf.

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Acronyms

CT	current transformers
DOE	U.S. Department of Energy
EEM	energy efficiency measures
EMS	energy management system
HVAC	heating, ventilating, and air conditioning
IPMVP	International Performance Measurement and Verification Protocol
IR	infrared
IWC	inches of water column
kW	kilowatt
kWh	kilowatt-hour
M&V	measurement and verification
MCC	motor control center
NIST	National Institute of Standards
PF	power factor
psi	pounds per square inch
psig	pounds-per-square-inch gauge
RH	relative humidity
RMS	root mean square
RTD	resistive temperature devices
UMP	Uniform Methods Project
V	voltage
Vac	alternating current voltage
Vdc	direct current voltage
VFD	variable frequency drive
VSD	variable speed drive

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1 Introduction

Metering is defined as the use of instrumentation to measure and record physical parameters. In the context of energy-efficiency evaluations, the purpose of metering is to accurately collect the data required to estimate the savings attributable to the implementation of energy efficiency measures (EEMs).

Estimated energy savings are calculated as the difference between the energy use during the baseline period and the energy use during the post-installation period of the EEM. This chapter describes the physical properties measured in the process of evaluating EEMs and the specific metering methods for several types of measurements. Skill-level requirements and other operating considerations are discussed, including where, when, and how often measurements should be made. The subsequent section identifies metering equipment types and their respective measurement accuracies. This is followed by sections containing suggestions regarding proper data handling procedures and the categorization and definition of several load types. The chapter concludes with a breakdown of recommended metering approaches by load category, which is summarized in Tables 2 through 7.[1]

[1] As discussed in the section "Considering Resource Constraints" of the Introduction chapter to this report, small utilities (as defined under U.S. Small Business Administration regulations) may face additional constraints in undertaking this protocol. Therefore, alternative methodologies should be considered for such utilities.

2 Metering Application and Considerations

Metering allows for the quantification of the energy use of a load. Metering can also record parameters—such as hours of operation, flows, and temperatures—used in the calculation of the estimated energy savings for specific end uses. (The recording of such parameters through metering methods is also referred to as “monitoring.”)

2.1 Identifying Scope

To optimize equipment and labor costs, it is important both to identify the scope of a metering procedure and to measure the key parameters required for estimating energy usage and savings. Although it may be possible to measure numerous parameters in a given facility, a metering procedure should focus on those parameters required for energy savings estimations. Therefore, to identify the necessary loads or parameters for the calculation, the savings estimation methodology for the EEM should be developed before the installation of metering instruments. If the data are a critical aspect of the estimated savings calculation, a redundant measurement or an additional proxy measurement for the parameter of interest may be considered. However, such considerations should be made within the context of ensuring a practical and cost-effective metering process.

The specific metering equipment for the job should be selected before visiting the site to install the meters. When installing more than one piece of equipment as part of an EEM, refer to Chapter 11: *Sample Design Protocol* to determine how many units need to be metered.

2.2 Ensuring Precision and Verification

The accuracy of a measurement is typically proportional to the cost of the instrument and the installation method. Additionally, such factors as measurement location, monitoring duration, and sampling interval also impact the accuracy of the results. For a given measurement or parameter, the necessary precision is an important consideration in the savings estimation. Higher-cost metering equipment may be required, depending on site and project characteristics. Further explanations regarding savings estimation analyses are detailed in other chapters.

Verification of the collected data is an essential aspect of ensuring an accurate metering process. Key best practices for data verification are these:

- Review the data to: (1) verify that they are complete and correct, and (2) identify readings that appear inappropriate or notably atypical for the specific system.
- If the readings appear to be incorrect, conduct cross-checks with other sensors or meters. Additionally, review the assumptions that were made when planning the metering to assess their validity and appropriateness.
- If the cross-checks do not validate the data, calibrate the equipment to match other metering instruments. Alternatively, determine whether the sensor or meter needs to be replaced.
- Validate the metering equipment results with facility-installed instruments, as needed, as another method of cross-checking. If the facility has data recording capability or an energy management system (EMS), readings from those systems can be used for

reference. Ultimately, however, these measurements must be objectively validated against independent metering equipment.

- Assign the data-collection responsibilities to a specific individual who will determine the design and structure of the metering process.
- Review the retrieved data for completeness and accuracy before incorporating it into the final analysis.

Before installing a meter, test it to ensure it is working properly and making the intended measurement. Use this checklist as a guide:

1. If meter operates on batteries, are the batteries in good condition, and do you have a backup set? Is the meter properly powered?
2. Is the meter clock synchronized to National Institute of Standards (NIST)[2] and local time zones?
3. Are all the settings on the meter correct?
4. Are sensors properly attached and in place?
5. If possible, did you turn the meter load on and off after installation and before removal to obtain a signal that the meter is capturing the correct equipment?

[2] www.nist.time.gov

3 Type of Measurement

Measurement types can be categorized by the associated physical properties they represent. Individuals conducting measurements should understand the purpose of the measurement. This section describes these properties and their respective measuring methodologies. The corresponding equipment descriptions are included in a subsequent section.

3.1 Electrical

Electric power and energy are typically the most important measurements for savings evaluations. As electric power is commonly a direct measurement of the energy use of a load, it may be the only measurement needed to determine savings between a base case and high efficiency measure.[3]

The common unit of power is kilowatts (kW). The common unit of energy is kilowatt-hour (kWh). Energy is power used during a unit of time. Other electrical measurements are voltage (V), current in amperes (A)[4], and power factor (PF). Although direct current voltage (Vdc) is used to power some types of equipment, utility transmission to customers occurs in the form of alternating current voltage (Vac). For this discussion, A and V are expressed in terms of alternating current, and the values measured or recorded are the root mean square (RMS) values. In general terms, RMS is the common presentation of alternating current electrical measurements. Apparent power (V·A) multiplied by the power factor equals the true power (W=V·A·PF). Power factor is given by the following:

- For perfect sinusoidal waveforms, the power factor is the cosine of the angle of the phase shift between the current and the voltage.
- If the voltage and current waveform are non-sinusoidal, the definition of power factor is (V·A)/W.

3.1.1 Considerations

There are important safety and metering considerations associated with conducting power measurements. Only an electrician, an electrical engineer, or a technician with training and proper equipment should be allowed to work in live electrical panels. Also, the individuals conducting this work should know and follow codes and guidelines provided by the National Electric Code (NEC), the Occupational Safety and Health Administration (OSHA), and the National Institute for Occupational Safety and Health (NIOSH). Additionally, personal protective equipment (PPE) that complies with National Fire Protection Association (NFPA) 70E should be worn to protect against arc flash in open electrical cabinets.

Electrical measurements should be limited to 600 V or less. Due to spark gaps from the high voltage, only electrical linemen with special training and equipment should work on systems above 600 V. Some facilities have existing current and voltage sensors in place on systems greater than 600 V that can be safely utilized to make measurements.

[3] Note that power metering is also referred to as kW metering.
[4] Current metering is also referred to as Amp metering.

Current metering rather than power metering can be considered if:

- The load has a stable or well-defined power factor and the interval of recording is short relative to the system cycle
- The metering is only to determine operating hours.

When conducting current metering, additional analysis is needed to convert current data to power data.

Harmonics are produced by electronic loads. These non-sinusoidal waveforms can only be accurately measured by meters designed to make true RMS measurements.

3.1.2 Single Phase vs. Three-Phase Loads

The two common standard voltages utilities provide to most commercial customers are three-phase 120/208 V or 277/480 V. The term "277/480 V" signifies that the voltage from any one of the phases to ground is 277 V and the voltage from one phase to another phase is 480V.

- The two main types of three-phase electrical systems are wye and delta.
- Wye systems are three-phase and four-wire, where the fourth wire is neutral.
- Delta systems are three-phase and three-wire.

There are several less common variations with grounding differences relative to the active voltage legs.

Residential supply voltage is 120/240 V and is single phase. It uses a three-wire configuration consisting of two hot legs and one neutral.

While lighting is a single-phase load, most motors are three-phase loads. Three-phase motors are assumed to be balanced, which means the current draw is equal in each of the three phases. In practice, however, the three-phase currents are not always identical.

3.1.3 One Time Power Measurements

Power measurements require the opening of electrical panels to gain access to where the insulated conductors or wires make electrical contact with safety devices such as breakers or fuses. When conducting power measurements, the technician or engineer should reference the connection diagram provided by the meter manufacturer for the specific supply voltage.

Power measurements also require the simultaneous detection of both current and voltage. This is typically achieved by placing a clamp-on current probe around the conductor of a given phase. After placing one of the meter voltage leads in contact with an exposed junction of the same phase, connect the other lead to neutral or ground.

For handheld meters that can only make measurements on one phase at a time, measure each phase separately. For three-phase systems without a stable ground—or in situations where there are doubts about the configuration—make measurements with a portable three-phase power meter. The total power of the system is defined as the sum of the power for all three phases.

When conducting power measurements, document the V, A, W, and PF measurements for each phase. For loads where current metering is sufficient, metering one phase and conducting one-time measurements on all three phases is required. To determine power from current metering, the load must have a power factor that is stable or a well-defined profile with loading. Taking one-time measurements that include power factor at multiple load conditions (varying current) improve the power analysis.

3.2 Temperature

Temperature is an indirect parameter that is incorporated into the calculation of energy use or estimated savings for some types of EEMs. Temperature sensors can be designed to measure gases, liquids, or solids. Typical applications for temperature measurement include ambient air, supply or return air, air or other gas in an enclosed space (such as near a thermostat), combustion gas, supply and return of fluids (such as chilled water), water heaters or boilers, steam condensate, and refrigerant lines.

Unless otherwise specified, "air temperature measurement" always refers to a dry-bulb temperature measurement. Wet-bulb temperature is defined as the temperature of a wet surface when water is evaporated from that surface for a given condition. This temperature is always lower than dry-bulb temperature, unless the air is completely saturated with water vapor. In this case, the two values would be equal. Dry-bulb and wet-bulb temperature are used together to determine the humidity or moisture in the air. Humidity is used in energy-use estimations for various air-conditioning systems.

3.2.1 Considerations

There are no specific qualifications required for the personnel who conduct temperature measurements, but these individuals should understand the purpose of the measurement.

When making temperature measurements, consider such factors as these:

- Weather conditions
- Location, sunlight exposure
- Heat radiating from nearby hot surfaces
- Contact with the media being metered
- Insulation from ambient conditions
- Air movement stagnation or stratification.

3.2.2 Outdoor Air Temperature

Outdoor temperature measurements are notably vulnerable to the surrounding environment, so this effort requires these additional precautions:

- Protect the temperature sensor from moisture, such as blowing rain.
- Use a radiant shield to protect the sensor from direct sunlight and reflected surfaces.
- Place the sensor in a well-ventilated location so that neither air stagnation nor stratification contributes to the temperature measurement.

3.2.3 Duct Air Temperature

Temperature sensors in ducts should be placed where the air is well mixed. For example, the supply air temperature should not be immediately downstream from the evaporator coil; instead, it should be several duct diameters downstream. To determine the best sensor location, take spot measurements in a traverse. This can be a challenge in large ducts when deploying averaging sensors. (An averaging sensor is composed of an array of individual sensors that can be placed as a web or matrix of points in a duct cross-section to measure the average temperature in the space.)

3.2.4 Liquid Temperature

Water (or glycol) temperature in pipes can be measured by: (1) inserting temperature probes into the liquid, (2) placing probes in thermal wells, or (3) placing probes on the pipe surface. Both the physical configuration of the existing piping and the willingness of the customer or contractor to drill into pipes typically dictate the appropriate installation method. The costs are relatively comparable for each approach.

- **Insertion probes** make direct contact with the liquid and, thus, provide the most accurate measurement. However, insertion probes can be problematic, because they require either (1) an unused tap on the pipe with a port that has a self-sealing pressure gasket (Pete's Plug) where the probe can be inserted or (2) the installation of a costly hot tap on the pipe (a technique that allows insertion of a probe into a pressurized pipe without having to shut down the system).

- **Thermal wells** are an effective alternative to insertion probes. Some pipes have pre-existing thermal wells strategically placed to measure supply and return temperature; however, these wells are often already in use by system or process controls. If a thermal well is available, apply thermal grease to the probe to increase overall conductance.

- **Surface mount probes** mounted on a pipe—for pipes that are not plastic—are an alternative to thermal wells. Apply thermal grease between the probe and the pipe surface (on the underside of a horizontal pipe) to eliminate any air gaps. Then, use a minimum of one inch of insulation over the probe so that the probe registers the temperature of the pipe contents rather than the air.

- **Infrared (IR) thermometers** can be used to make instantaneous measurements of surface temperatures. Although the laser pointer on an IR thermometer produces only a small red dot, the surface area being measured is significantly larger. For example, if the distance-to-target ratio for the meter is 12:1, then at a distance of three feet, the surface area of measurement is three inches in diameter.

3.3 Humidity

The common unit of humidity is the percentage of relative humidity (%RH). Relative humidity is a measure of the relative amount of water vapor in the air for a given condition, versus the capacity of the air to hold water vapor at that same condition.

Humidity is measured when estimating the enthalpy or energy content of air in a heating, ventilating, and air-conditioning (HVAC) system. Humidity is also measured to determine comfort conditions using psychrometric charts. Outdoor humidity can be used to provide a measurement of ambient conditions. The placement requirements for humidity sensors are the same as those for ambient air temperature sensors. It is important to use measurements from steady-state conditions when using humidity sensors, because these sensors have a slow response time.

3.4 Flow of Liquids and Gases

The common unit of flow for liquids is gallons per minute (gpm), and the common unit of flow for gases is cubic feet per minute (cfm).

3.4.1 Water Flow

Measuring the flow rate of water or glycol in a chilled water loop is one parameter in determining the output of a chiller. Typically, a mechanical contractor is needed to install a water flow meter. A flow meter should be installed on a straight uniform section of pipe at least 15 diameters long, with the meter 10 diameters downstream from the last bend or transition, so as to minimize turbulence in the liquid stream.

A passive measurement of fluid flow can be made using an ultrasonic flow meter at a point where there is no pipe insulation. Ultrasonic flow meters, which are applied to the outside of the pipe, send pulsed sound signals through the fluid. These signals measure the flow of water-based liquids in pipes without interrupting the flow (as a flow sensor inside the pipe would). Note that ultrasonic flow meters are typically very costly and require experience to use, which should be considered when designing the metering process.

An alternative to water flow measurement entails measuring the pump motor electric demand to determine motor loading. The electric demand and another variable (such as pressure) are then cross-referenced with the manufacturer's pump curve data to calculate flow rate. While this option is a lower-cost solution, the resulting measurement is generally not as accurate using a water flow meter.

3.4.2 Duct Airflow

Airflow measurements are most commonly needed for ducts carrying conditioned air, and these measurements can be made by anyone trained in the technique. Note that gas or airflow rates should be normalized to standard temperature and pressure conditions (68°F and 14.7 psi).

The preferred methods for measuring airflow rate use these technologies. In residential applications, the first three of these options are viable; however, for commercial duct systems, the fourth option may be the only viable choice.

- A calibrated adjustable-speed fan at the return register
- A pitot tube array at the air filter
- A matrix of transverse air velocity measurement points in a long straight cross-section of the duct
- A flow capture hood at the return or supply registers (a less reliable technique).

The matrix of air velocity measurements is more costly, due to labor and preparation time. For this approach, select a straight uniform section of duct at least 15 diameters long, with velocity measurements that are made 10 diameters downstream from the last bend or transition, so as to minimize turbulence in the air stream.

Airflow in a compressed air system can be measured with a mass flow rate sensor, which compensates for density with respect to pressure. The sensor should be installed only when the system has been shut down by an individual having the appropriate mechanical experience.

3.4.3 Natural Gas

Natural gas can be measured by installing a utility-style meter on the gas-fired equipment. Generally, there are few opportunities to meter this equipment, however, because of the cost, difficulties in coordination of installation with the proper licensed trades, safety considerations (including clearing pipes of all residue gas before installation), and limited installation accessibility. In some cases, existing utility meters that supply gas to only the measure in question can produce a pulse for recording.

Natural gas-fired equipment that has a constant burner flow rate can be measured using the fine resolution dial on the utility meter and a stop watch ***if*** all other gas appliances are off during the test. Note that equipment gas lines should be turned off during the installation, and a qualified gas fitter should conduct the installation.

3.5 Pressure

The common unit of pressure is pounds per square inch (psi). Although pressure is not used to estimate energy use directly, it can be incorporated as a normalizing measurement or used to calculate the efficiency of fans or pumps. An example of this is measuring the pressure in a compressed air system before and after a variable frequency drive is installed.

3.5.1 High Pressure

High pressures occur in fixed volumes such as tanks, refrigerant loops, and pumping systems. Instances where high-pressure measurement is required include compressed air equipment, water pumping stations, and refrigerant lines. Place high-pressure sensors on a port with a valve so they can be installed without shutting down the system. A qualified mechanical contractor should conduct the installation of the port.

3.5.2 Low Pressure

Low-pressure air pressure measurements encompass static, dynamic, and barometric. Static and dynamic pressure measurements can be taken in air ducts to gauge airflow rates. These low-pressure measurements occur where the air is not enclosed in fixed volumes.

Static pressure measurement in a combustion ventilation pipe is used to determine whether adequate draft is available to exhaust combustion byproducts.

A technician can install a static pressure gauge in a duct system to measure static pressure change across the fan.

3.6 Light

Light level (or illuminance) is commonly measured in units of either foot-candles (fc) or lux. While illuminance is not used to estimate energy savings directly, it is often used to verify that the pre- and post-lighting equipment either supply an equivalent amount of light or meet certain end-use requirements. However, if, after the EEM is installed, there is a decrease in light levels to below code or recommended levels, illuminance measurements can be used to justify a reduction in final savings. Conversely, if light levels increase above code or recommended levels after an EEM is installed, the illuminance measurements justify applying additional savings. There are no specific qualifications required for personnel conducting illuminance measurements.

3.6.1 Considerations

When making illuminance measurements, consider both the working conditions and background daylight conditions. Take measurements at the level of the working surface, usually a desk or table. Also, account for ambient light or daylight by taking measurements when the EEM lighting is on and again when it is off. The difference in the two values is the illuminance attributable to the EEM lighting.

3.7 Status or Event

Some measurements are in the form of bi-level logic that identifies whether (1) a load is on or off or (2) a switch or door is open or closed. These are cost-effective approaches to metering a piece of equipment's time-of-use hours of operation. So long as these loggers are not placed in live electrical panels, there are typically no specific qualifications required for personnel placing status loggers; however, training is recommended.

Analyzing on/off status records of a load (such as lighting or motors) is a convenient method of measuring hours of operation. A valve or damper position may also be needed to determine operating mode of an HVAC system.

3.8 Normalizing Conditions

In many cases, to normalize the energy use of the EEM, it is necessary to collect additional data. Energy use for both a baseline and a post-implementation period should be normalized if any specific conditions differ between the two periods. For weather-dependent loads, typical meteorological year weather data are used to normalize the energy savings.

Normalizing data can either be measured and recorded from the equipment itself or collected from facility management, if necessary. Normalizing parameters typically include:

- Production volume
- Processed weight
- Sales
- Occupancy
- Set points
- Ambient temperature
- Weather
- Flow
- Pressure
- Speed
- Frequency
- Alternative operating modes

4 Levels of Measurement

Electric loads should be metered at the level appropriate for the type of EEM. The levels may be defined through aggregations of:

- Like loads (such as lighting)
- Measurements of electric load in an area (whole panels) that is a subset of the utility meter
- Measurements of a system (such as pumps, fans, and compressors of an HVAC system)
- The utility meter itself.

4.1 Single Loads

Measurements on single loads—such as motors—are performed on the conductors serving the unit exclusively. The electrical measurement can be made in (1) the motor control center (MCC) panel serving the load, (2) the disconnect box at the motor, or (3) the variable speed drive (VSD), if applicable.

In the case of a VSD, the measurement should not be made on the conductors between the VSD and the motor. Metering inside a VSD can be problematic in that the drive can cause interfering signals in metering equipment even if the metering is upstream of the drive. For this reason the preferred location to meter VSDs is at the MCC.

4.2 Aggregation of Like Loads

Lighting is generally updated as a retrofit throughout a wide area of a facility or throughout an entire facility, so metering a representative sample rather than conducting metering for a census of fixtures usually suffices.

When selecting a metering sample for an end use, the sample should be categorized by operating hours or by the variation in load. For example, lighting within a facility should be stratified by area types with different operating schedules or patterns. After the number of fixtures in each specific area type has been determined, the sample size can be quantified. (See Chapter 11: *Sample Design Protocol*.)

Measuring electric loads by area or by whole-panel metering is useful when developing an hourly use profile. Specifically:

- Meter whole electric panels that exclusively serve end uses of interest.
- For panels that also serve other end uses, account for those end uses by metering the panels and subtracting that load from the total, or by other means (such as engineering estimates).

When using building energy simulation models, area metering is useful for determining internal load profiles for inputs.

4.3 Measurements of a System

If the end use is a chiller, take measurements related to the operation of the chiller. The system may contain the chiller, chilled water and condensate pumps, cooling tower fans, and air handlers. These measurements may include power input and thermal output—as measured by supply—and return chilled water loop temperature and water flow rate. Note, however, that chilled water loop measurements may be hampered by pipe insulation. Conversely, condenser water pipes may not have insulation and, thus, they may provide greater accessibility for surface mounted temperature probes and externally mounted ultrasonic flow meters.

5 Duration of Measurement and Recording Interval

Measurement duration is classified into three categories: instantaneous, short-term, and long-term. Each duration category has a purpose and should be selected based on the specifics of the EEM and magnitude of the load.

5.1 Instantaneous

Instantaneous measurements (also known as "spot measurements" or "one-time measurements") are used to (1) quantify a parameter that is expected to remain constant or (2) calibrate instruments that will collect data over a period of time. These measurements are generally made using handheld instruments at the location of the parameter of interest; however, they can also be made using instruments installed as part of a system.

5.2 Short-Term

Short-term measurements are conducted to record the variation of a parameter over a period of time. To capture at least two cycles of the load or parameter of interest, instruments performing short-term metering are put into position for periods ranging from several hours to one month.

For example, although the lights in a business operation may turn on and off from day to night, the overall lighting in most business operations has a weekly cycle, because the weekend schedule generally differs from that of weekdays. Typically, a two-week period of data is collected, so that data from the second week can confirm the pattern of the first week. However, if the loads vary during the year, then long-term metering periods should be considered. Also, the appropriate monitoring period should be selected to include peak loads if demand savings estimates are part of the measurement and verification (M&V) effort. Cooling loads, for example, should be monitored during the hottest part of the year.

5.3 Long-Term

Long-term measurements are conducted to record variations of a parameter that occur over a period generally ranging from one month to one year. Instruments performing long-term metering are typically installed at sites that are:

- Weather-dependent (such as HVAC loads)
- Seasonal (such as agricultural processing)
- Operate on planned schedules (such as educational facilities).

5.4 Recording Interval

"Measurement time resolution" refers to the length of intervals used during data collection. Recording intervals are at one or more minutes (often in increments of 5, 10, or 15 minutes), although many loggers allow other time intervals.

Use intervals that are integer divisors of 60 to facilitate processing the data into hourly totals. Also, some equipment types average or sum the values for the interval, while other types only record an instantaneous reading at the end of each interval. Instantaneous readings at the end of each interval should only be used if the measured parameter is changing slowly with respect to the interval duration or if enough interval points are captured to provide statistical significance.

For most load types, 15-minute aggregate interval data provide sufficient time resolution to capture reaction of the load to the controlling conditions. (Note that utility electric meters are also designed to record peak kW on 15-minute intervals.) Where recorder memory capacity allows shorter intervals, it is possible to capture profiles of loads with short cycle times. For loggers that only provide instantaneous readings, the interval length should be short enough to capture at least five recordings per cycle of the load. For example, if an air-conditioning unit cycles once every 25 minutes, then the recording interval should be five minutes or less.

As technology advances and measurement equipment increasingly contains more memory storage, it is possible to collect data in very small time intervals. However, additional data are not likely to increase the accuracy of the savings estimation significantly, and there is typically an increase in the costs associated with analysis processing time.

For loggers that record both the date and time stamps of events, the time uncertainty is a combination of the reaction time of the sensor and the time stamp resolution.[5] Logger clock drift is generally small but should be checked at the time meters are retrieved in order to document any drift during the data recording period.

[5] Time stamp resolution is generally one second.

6 Equipment Types

This section, which discusses various metering devices, is categorized by the parameter the devices are used to measure. (Note that the terms “recorder” and “logger” are often used interchangeably to describe metering equipment.)

There are two main categories under which metering equipment are typically classified:

- Type of measurement (This equipment can be sub-categorized by dedicated single measurement or by multi-purpose and multi-channel.)
- Metering function, such as sensor-only, instantaneous readout meter, recording meter, or recorder only.

Instrument accuracy is typically not represented by a single value. In most cases, accuracy is provided as a plus or minus (±) percentage of the reading and is only appropriate for a prescribed range of values from the full-scale (fs) reading. Also, the accuracy may be different for various ranges.

Most meters use proprietary software to set proper data collection parameters, recording intervals, clock settings, etc. The manufacturer’s software must also be used to retrieve data from the meter and then export it to other usable formats (i.e., text or spreadsheets).

Follow local codes when metering with any type of equipment. This is not only for the safety of the technician but also for the safety of others where equipment is located.

6.1 Electrical

Electrical measurement equipment can be categorized as:

- Handheld (or portable) power meters
- Watt-hour transducers
- Meter recorders
- Current transformers (CT).

6.1.1 Handheld Power Meters

Select handheld power meters measure true RMS volts, amps, watts, and power factor. Ideally, these meters have a digital display of at least 3.5 digits and measure power to an accuracy of ±2.5% or better. The voltage, current, and power factor accuracy will all be greater than this because the combination of the individual measurement accuracies is used in determining the power accuracy.

A clamp-on current sensor can either be an integral part of the meter or a separate sensor connected to the meter with a wire cable. The jaws of the current sensor should be able to hold all of the conductors on the phase of the load being measured.

6.1.2 Watt-Hour Transducers

Watt-hour transducers only measure the power or energy use, so they need a separate logger to record the use over short-term or long-term metering. Watt-hour transducers typically produce a pulse output in which each pulse represents a predetermined number of kWh, depending on the system voltage and CT ratings. Following the recording, a multiplier is applied to scale the pulse output into units of kWh. (Review manufacturer specifications to determine the multiplier.)

The watt-hour transducer should have an accuracy of ±0.5% or better. Note that the CT accuracy must be added to the transducer accuracy to determine the power measurement accuracy. In the event that the two pieces of equipment are correlated, the accuracies are added together. If they are not correlated, then the combined accuracy is the square root of the sum of the squares of the individual accuracies.

Current sensors are typically selected separately and are sized based on the peak current the load will achieve during the metering. The signal output types for watt-hour transducers include 4-20mA, 0-10Vdc, LonWorks, Modbus, and BACnet. Some of these are more appropriate for EMS than for short-term monitoring.

6.1.3 Meter Recorders

Meter recorders both measure and record on the same instrument. The meter selected should measure true RMS power. Current sensors are generally selected separately and are sized based on the peak current that the load will achieve during the metering. To determine the accuracy of the power measurement, combine the CT accuracy with the transducer accuracy. (As mentioned in the previous section, the watt-hour transducer should have an accuracy of ±0.5% or better.)

In general, meters and sensors must be fully contained in the electrical panel; however, if the voltage exceeds 50 V, the meters and sensors will require wiring to be placed inside of conduit to the meter. Cables conducting low-voltage sensor signals (such as pulse outputs, 333mV CT leads, or communication signals) do not need to be inside of conduit. Follow the manufacturer's directions for connecting CTs and voltage leads, as these instructions differ, depending on number of phases and wires, voltage, and configurations (such as wye, delta, and high-leg delta).

6.1.4 Current Transformers/Transducers

Current transformers and current transducers—both of which are referred to as CTs—are sensors that measure current. When using CTs, confirm they have the correct output for the meter with which they will be paired.

- Current transformers, which output a current on the secondary wires, can produce dangerously high voltages if the wires are not shunted (that is, shorted, sometimes with a resistor). These CTs are typically rated by the transformer ratio, such as 100:5, where 100 refers to the maximum Amp rating of the primary conducts and 5 refers to the full scale Amp output of the secondary. Connect the leads of this type of CTs to the power meter before placing the CT on load conductors. Wire leads from these CTs must be routed through conduit or contained inside of electrical panels.
- Current transducers, which output a low voltage signal proportional to the current, are intrinsically safe to handle. Short-term power metering equipment typically uses CTs

with a full-scale output of 0.333 Vac. The wires from these CTs do not need to be run in conduit because they are intrinsically safe.

6.1.4.1 Split-Core CTs, Solid-Core CTs, and Current-Only Metering

Solid-core CTs, which have higher accuracy than split-core CTs, are in the shape of a ring, so the wire conductors of the load must be threaded through the center hole. This requires the load to be turned off while the wire is temporarily disconnected.

For temporary metering installations, split-core CTs are recommended to avoid turning off customer loads. Split-core CTs can be opened up and wrapped around a current conductor without shutting down the load. As some accuracy can be lost due to electromagnetic field (emf) leakage at the core junctions, the CT should have an accuracy of ±1.0% or better and a phase angle shift of 2° or less.

When only current metering is required, CTs with Vdc output (typically 2.5 Vdc) are used with a dc voltage logger.

6.2 Light/Motor/Event

There are several types of event (or status) loggers. Some have specific uses, such as light on/off loggers; others, such as state loggers, can be triggered by various inputs. All of these logger types record a date and time stamp when an event occurs.

6.2.1 Light

Light on/off loggers use a photo sensor with a sensitivity adjustment for the threshold setting. This setting triggers an event when the light level transitions above or below the threshold level.

6.2.2 Motor

Motor on/off loggers sense an electromagnetic field to trigger an event when the emf transitions above or below a threshold. The emf that triggers an event can be from a motor, a coil winding on a valve, or a conductor separated from other phase conductors.

6.2.3 State

State loggers record either the state of a switch or the open or closed position of a door or valve. A one-second time resolution on the event is typical for these types of loggers.

6.3 Temperature

Temperature is measured using a thermometer and there are several sensor types in use, such as:

- **Resistive temperature devices (RTD):** Available in various temperature ranges, RTDs are generally used in combination with a meter specifically designed for that type of sensor. Metal RTDs (such as platinum) generally have linear resistance with temperature. Thermistors, which are the most common RTD, have a ceramic semiconductor base and an electrical resistance that drops non-linearly with temperature.
- **Thermocouples:** Two dissimilar metals joined at the tip of a probe produce a very small voltage proportional to the temperature. A junction at a reference temperature is required. Types T, J, and K are common thermocouples suitable for different temperature ranges.

- **Integrated circuit (IC):** A semiconductor chip with a current that is linear with temperature characteristics.
- **Infrared (IR):** As infrared radiation is emitted by all objects, the peak emitted wavelength is correlated with a black body distribution curve to determine the temperature. An IR is a non-contact device.

Temperature sensors are connected to—or contained within—a meter that converts the sensor signal into a temperature reading. The ideal resolution of the temperature meter or logger is determined by the temperature range:

- Temperature measurements ranging from 32°F to 120°F should have a logger or meter with a resolution of 0.1°F and an accuracy of ±1°F or better.
- Temperature measurements ranging from 100°F to 220°F should have a resolution of 0.5°F and accuracy of ±2°F or better.
- Temperature measurements above 220°F should have a resolution of 1°F and an accuracy of ±4°F.

6.3.1 Loggers with Internal Probes

Many small battery-operated temperature loggers are available; however, as the sensor for such loggers is typically located within the case, these loggers are generally only suitable for air temperature measurements.

6.3.2 Loggers with External Probes

Temperature loggers having external probes are required for surface mountings, liquid immersion, or small openings into air streams. For any application in which the sensor may become damp or wet, use an encapsulated probe. Probes in stainless steel sheaths will typically not be compromised by harsh environments.

6.3.3 Differentials

Measurements used to estimate differential temperature—such as supply and return air—should use a matched pairs of sensors.

6.4 Humidity

Humidity can be measured using either a humidity sensor connected to an analog signal logger or a humidity meter. Many humidity meters also meter dry-bulb temperature and can display other humidity-related values. The humidity measurement should have a resolution of 0.1% RH and an accuracy of ±2.5% RH or better over a range from 10% to 90% RH.

As humidity sensors become saturated easily and remain so for a period longer than the air is saturated, avoid condensation conditions.

6.5 Pressure

Pressure measurement instruments are categorized for use with high-pressure liquids/gases or low-pressure gases. Recording these measurements typically requires the use of a pressure sensor wired to an analog input recorder. Pressure sensors typically have 4-20 mA or 0-5 Vdc output.

6.5.1 High-Pressure Sensors

These sensors are used for refrigerant systems, compressed air, water storage, or water pumping. The common unit of measure is pounds-per-square-inch gauge (psig), which is the pressure above ambient atmospheric pressure. These pressure measurements should have a resolution of 1 psig and an accuracy of ±1% or better.

6.5.2 Low-Pressure Sensors

These sensors are used for barometric readings, air ducts, and combustion exhaust pipes, and one type—a differential pressure sensor—is routinely used to measure duct static pressure. The common unit of measure is inches of water column (IWC). The low-pressure measurements should have a resolution of 0.1 IWC and an accuracy of ±1% or better.

6.5.3 Instantaneous

Use digital pressure gauges for conducting instantaneous readings.

6.6 Flow

The majority of flow measurements will be for water (liquid), air (gas), or natural gas. Flow measurement accuracy is particularly dependent on the proper use of the flow instruments.

6.6.1 Water

Water flow instruments should have an accuracy of ±2% or better of full-scale flow rate.

- Paddle wheels and turbines are commonly used water flow sensors, but they must be inserted into the flow.
- Ultrasonic flow meters use pulsed sound signals applied to the outside of the pipe. These signals measure water-based liquids in pipes without interrupting the flow to install the meter.

6.6.2 Air

Measurements may be taken of conditioned air or exhaust, and the measurement should have an accuracy of ±5% or better. Hot-wire anemometers, pitot tubes, calibrated duct fans, balometers, and capture hoods are instruments used for air velocity or volume flow rates.

6.6.3 Natural Gas

Natural gas meters, which use a positive displacement approach to measure flow, should be installed inline. These meters should have an accuracy of ±1% or better and be temperature-compensated.

6.7 Other Sensors

Other commonly used sensors and meters are these:

- Occupancy sensors
- CO_2 sensors
- Combustion gas analyzers

- Solar radiation sensors (such as pyranometers)
- Wind speed sensors
- British thermal unit (Btu) meters.

When selecting the desired level of accuracy for each of the sensor types, consider both cost-effectiveness and the importance of the measurement to the final savings estimations.

6.7.1 Digital Cameras

Digital cameras are very useful in documenting metering equipment before and after its installation and during the evaluation of the EEM.

6.8 Pulse and Analog Signal Loggers

Certain data loggers (single channel and, more commonly, multi-channel) record generic sensor signal inputs. Depending on the logger, digital channels or pulse loggers can be used to count (1) pulses, (2) switch openings and closings, and (3) the percentage of time a switch is open or closed during an interval.

Inputs are categorized as digital or analog. Analog signal input channels include 4-20 mA, various ranges of dc voltage, and resistance in ohms. The logger should have an accuracy of ±0.5% or better.

Sensor accuracy is a separate measure that is dependent on the type of sensor and should be considered in the final measurement.

6.8.1 Battery Operated

Data loggers may be battery operated, powered by a separate power supply, or powered by a line voltage input. When using battery-operated loggers, ensure that the useful life of the battery is sufficient to allow the unit to remain operational until the next site visit.

The time accuracy of data loggers should be one minute per month or better. Logger and sensor calibration should be conducted as often as the manufacturer suggests; however, review all measurements for validity.

7 Data Storage, Retrieval, and Handling

There is a wide range of commercially available data loggers. When selecting a data device for a project site, consider the data storage specifications and retrieval requirements. Also, it is important to handle the data appropriately after retrieval, which includes making backup copies in the event that original files become corrupted.

7.1 Data Storage

Although the memory storage capacity of data loggers varies widely, loggers ideally will have sufficient capacity to store at least one month of data. Memory time capacity depends on the recording interval, the number of channels active, and the number of parameters stored. However, event logger memory can quickly reach capacity if the trigger condition is met frequently. (This occurs, for example, when there is a short delay time for occupancy sensors on lighting controls.) Review the manufacturer's instructions for details as to how long a logger can record data before the memory reaches capacity.

7.2 Retrieval

Evaluation of EEMs generally entails short-term metering. At the end of the metering period, the logger is retrieved and data are collected by direct connection between the logger and a laptop computer. While the metering equipment is still on site, field evaluation staff should review the data to confirm that (1) all necessary information was collected and (2) the data are within valid ranges.

The data retrieval method depends on the logger, and manufacturers typically have customized software to communicate with the logger. Also, some manufacturers have specialized interface cables to connect the logger to a computer. With some loggers, communication and data retrieval can occur by alternative methods such as modems with landlines or cell phones, Ethernet and Internet, and other digital contact via local networks.

7.3 Handling

After retrieving the data, make backup copies immediately. For the data files, use a filename convention that includes the site, EEM, logger number, and date.

Because data logger software generally stores the raw data in a proprietary format, export a copy of the data into a common format, such as comma-separated value (CSV), ASCII, or Excel. Store the exported data on a secure system that is regularly maintained and monitored.

8 Metering Methods by Load Type

This section provides summary tables of metering methods for various load types and the preferred metering approach for each type. To determine the appropriate metering approach, categorize the characteristics of the load type into one of the following load types defined in Table 1. Use these definitions to find the load type that most closely matches the EEM to be evaluated.

Some measures (such as building envelopes) do not directly use energy, but they impact energy use. In those cases, the end use that would be metered is the energy-using equipment impacted by the measure. In general, these categories are listed in increasing order of metering complexity. The example end uses provided in tables 2 through 7 are not intended to be an exhaustive list of measures; rather they are a guide for the most common energy efficiency measures. The examples are predominantly electric loads, because they account for the most commonly evaluated measures.

Table 1. Load Type Definitions

Load Type	Definition
Constant Load Time-Dependent	The load or energy demand does not change. The energy use depends only on when the load is operated, and there is a schedule of operation.
Constant Load Cycling	The load or energy demand does not change. The energy use depends only on when the load is operated, and conditions dictate when the load cycles on or off.
Variable Load Weather-Dependent	The load or energy demand varies with the weather and does not run constantly.
Variable Load Continuous	The load or energy demand varies, and the equipment runs continuously during a scheduled period.
Variable Load Cycling	The load or energy demand varies. The load may (1) be repetitive, (2) turn on and off, or (3) cycle based on conditions.
Loads Measured Indirectly	The load or energy demand of the end use cannot be measured directly, so it is calculated from one or multiple metered measurements.

Alternatively, follow the flowchart in Figure 1.

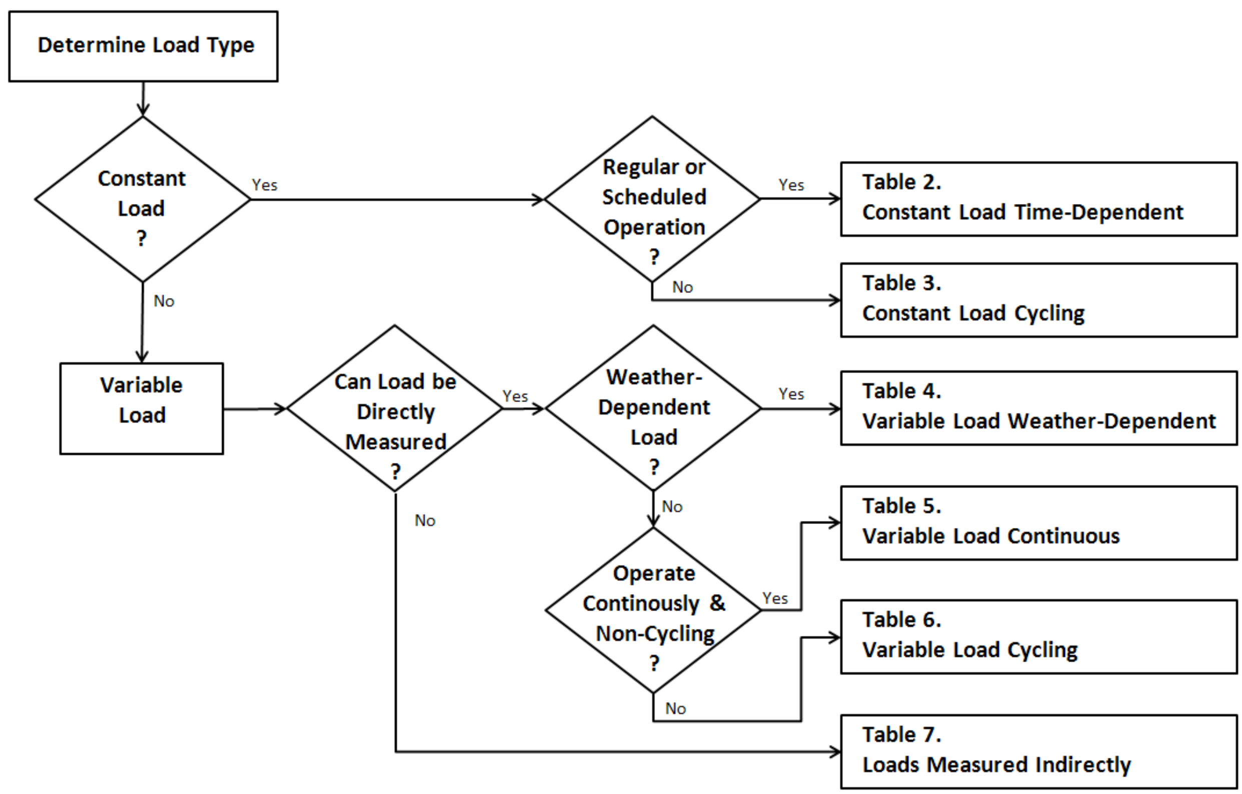

Figure 1. Load type determination flowchart

8.1 Levels of Rigor

Rigor is associated with the level of precision, with a higher level of rigor corresponding to a higher level of precision—and, often, with higher costs or more labor hours. Because the level of rigor varies widely among metering methods, consider this relationship between precision and cost when selecting the preferred metering approach.

Typically, there are multiple metering methods possible for the majority of load types, so the metering methods shown in tables 2 through 7 are ranked by level of rigor. Of the three levels of rigor, Level 1 is the lowest level and Level 3 is the highest level of rigor.

Identify the preferred level of rigor when developing the measurement approach. The tables list alternative levels of rigor that may be selected for the measurement approach if circumstances justify the level selection. The durations listed in tables are minimum monitoring times, but M&V plans may request longer periods or multiple periods with different conditions. Conditions may include various seasons for weather-dependent loads or periods with different operating hours (such as in schools or colleges). Selecting when monitoring occurs can be as important (or more important) than the duration of the monitoring.

Current (or Amp) metering rather than power metering can be conducted when:

- A load has a stable or well-defined power factor and the interval of recording is short relative to the system cycle

- Metering is done only to determine operating hours.

With Amp metering, additional analysis effort is needed to convert current data to power rather than directly metering power.

8.2 Proxy Measures

Indirect measurement of energy is the most practical approach for many end uses, and there are suitable substitute proxy measurements for most end uses. Proxy measurements generally produce less accurate results than direct measurements. Most proxy measurements require a multiplier or scalar factor, which is either measured or determined. As an example, a natural gas-fired boiler with a constant burner flow rate can be measured by metering the "on" status of the combustion air fan, which is energized when the burners are operating. Alternatively, the burner gas flow rate can be measured by using the utility gas meter and a stopwatch, if all other gas appliances are switched off.

Table 2. Constant Load Time-Dependent

Example End-Use	Rigor Level
Lighting (non-dimming) Pool pumps Constant-speed chilled water pumps Condenser water pumps Constant volume fan motors Data center equipment	**Level 1—Preferred Approach** Equipment: On/off loggers Additional measurement: Instantaneous Volts, Amps, kW, and power factor (if wattage is not deemed) Duration: Two weeks Interval: n/a
	Level 2 Equipment: Amp metering Additional measurement: Instantaneous Volts, Amps, kW, and power factor. Duration: Two weeks Interval: 5 minutes
	Level 3 Equipment: Power (kW) metering Duration: Two weeks Interval: 15 minutes

Table 3. Constant Load Cycling*

Example End-Use	Rigor Level
Lighting with occupancy sensors or bi-level controls Refrigerators and freezers Water heaters, electric Plug-in loads Household and office electronics Electronically commutated motor fans Electric ovens or grills	**Level 1** Equipment: On/off loggers Additional measurement: Instantaneous Volts, Amps, kW, and power factor (if wattage not deemed). Duration: Two weeks Interval: n/a
	Level 2—Preferred Approach Equipment: Amp metering Additional measurement: Instantaneous Volts, Amps, kW, and power factor. Duration: Two weeks Interval: Two minutes
	Level 3—Preferred Approach Equipment: Power (kW) metering Duration: Two weeks Interval: 15 minutes

* Either meter for operating hours or have well-defined power factor profiles.

Table 4. Variable Load Weather-Dependent

Example End-Use	Rigor Level
Air conditioner* Heat pump* Packaged HVAC Chiller Cooling tower* Refrigeration Furnace, electric	**Level 1** For those indicated by (*) and applied only for single compressor/motor w/no VSD Equipment: On/off loggers, outdoor temperature logger Additional measurement: Instantaneous Volts, Amps, kW, and power factor (if wattage not deemed) Duration: one month Interval: n/a
	Level 2—Preferred Approach For loads without VSDs Equipment: Amp metering, outdoor temperature logger Additional measurement: Instantaneous Volts, Amps, kW, and power factor Duration: One month Interval: Two minutes
	Level 3—Preferred Approach Equipment: Power (kW) metering, outdoor temperature logger Duration: One month Interval: 15 minutes

Table 5. Variable Load Continuous

Example End-Use	Rigor Level
Water pump with VSD Warehouse lighting with daylight dimming Lighting with dimming controls Air compressor with VSD Fan with VSD Motor with VSD Industrial Process Equipment Boiler*	**Level 1 – N/A**
	Level 2 Equipment: Amp metering, (*gas meter with pulse output and pulse logger) Additional measurement: Instantaneous Volts, Amps, kW, and power factor at five different speeds or conditions. Duration: Four weeks Interval: Two minutes
	Level 3—Preferred Approach Equipment: Power (kW) metering, (*gas meter with pulse output and pulse logger) Duration: Four weeks Interval: 15 minutes

Table 6. Variable Load Cycling

Example End-Use	Rigor Level
Air compressor Injection molding machines* Oil well pumpjack* Industrial Process Equipment	Level 1 – N/A
	Level 2 Equipment: Amp metering Additional measurement: Instantaneous Volts, Amps, kW, and power factor. Duration: Four weeks (*Two weeks) Interval: 2 minutes
	Level 3—Preferred Approach Equipment: Power (kW) metering Duration: Four weeks (*Two weeks) Interval: 15 minutes

Table 7. Loads Measured Indirectly

Example End-Use	Example of Preferred Approach When Direct Measurement Not Practical
Furnace, gas Boiler, gas Water Heater, gas	Duration: One month Interval: 15 minutes **For Constant Rate Burners** Equipment: On/off motor loggers mounted on gas valve 24 Vac coil or combustion air fan motor Additional measurement: Measure burner flow rate using utility meter with all other loads off and stopwatch **For Variable Rate Burners** Equipment: Amp metering of combustion air fan or analog signal logger for modulating valve Additional measurement: Measure burner flow rate using utility meter with all other loads off and stopwatch for three typical flow-rate conditions and correlate to fan Amps or valve signal
High voltage loads >600 Vac (such as 4,160 Vac motors or chillers)	Equipment: Amp metering on 5 Amp secondary of CT used for panel mount display of load Amps Determine CT ratio: kW=V*A* (Assume V and) Duration: One month Interval: 15 minutes

9 Resources

Alereza, T.; Martinez, M.; Mort, D. (1989). "Monitoring of Electrical End-Use Loads in Commercial Buildings." *ASHRAE Transactions*. (95:2). http://repository.tamu.edu/bitstream/handle/1969.1/6558/ESL-HH-88-09-52.pdf?sequence=3.

American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE). (1995). *ASHRAE Handbook: HVAC Applications.* Chapter 37: "Building Energy Monitoring."

ASHRAE. (1996). *Methodology Development to Measure In-Situ Chiller, Fan, and Pump Performance*. ASHRAE Research Report, Research Project 827. http://industrycodes.com/products/4a6765/rp-827-methodology-development-measure-situ.

ASHRAE. (June 2002). *Guideline 14-2002*: *Measurement of Energy and Demand Savings*. http://gaia.lbl.gov/people/ryin/public/Ashrae_guideline14-2002_Measurement%20of%20Energy%20and%20Demand%20Saving%20.pdf.

ASHRAE. (2010). *Performance Measurement Protocols for Commercial Buildings*.

Bonneville Power Administration. (September 2010). *End-Use Metering Absent Baseline Measurement: An M&V Protocol Application Guide, Version 1.0*. www.bpa.gov/energy/n/pdf/BPA_End_Use_Metering_Absent_Baseline_Measurement_A_Measurement_and_Verification_Protocol_Application_Guide.pdf.

California Public Utilities Commission (CPUC). (June 2004). *The California Evaluation Framework*. www.calmac.org/publications/California_Evaluation_Framework_June_2004.pdf.

Dent, C.; Mort, D., "Electrical Metering Fundamentals", (June 1-3, 1992). "Metering Your End-Use Needs". Bend, Oregon.
Federal Energy Management Program (FEMP). (September 2000). *Measurement & Verification Guidelines for Federal Energy Projects Version 2.2*. DOE/GO-102000-0960. www.nrel.gov/docs/fy00osti/26265.pdf.

FEMP. (April 2008). *Measurement & Verification Guidelines for Federal Energy Projects Version 3*. www1.eere.energy.gov/femp/pdfs/mv_guidelines.pdf.

FEMP. (August 2011). *Best Metering Practices Release 2.0*. www1.eere.energy.gov/femp/pdfs/mbpg.pdf.

Institute of Electrical and Electronics Engineers (IEEE). (1989). *Master Test Guide for Electrical Measurements in Power Circuits*. ANSI/IEEE Std. 120-1989.

International Performance Measurement and Verification Protocol (IPMVP). (2010). IPMVP *Volume 1: Concepts and Options for Determining Energy and Water Savings*. EVO 10000 – 1:2010. Washington, D.C.: Efficiency Valuation Organization. www.evo-world.org/index.php?option=com_form&form_id=38.
National Electric Code (NEC). (2011). National Fire Protection Association (NFPA) 70.

National Institute for Occupational Safety and Health (NIOSH). (July 1999). *Preventing Worker Deaths from Uncontrolled Release of Electrical, Mechanical, and Other Types of Hazardous Energy*. Publication No. 99–110. www.cdc.gov/niosh/docs/99-110/pdfs/99-110.pdf.

Occupational Safety and Health Administration (OSHA). *Standard 1910* (emphasis on Subpart S – Electrical). www.osha.gov/pls/oshaweb/owasrch.search_form?p_doc_type=STANDARDS&p_toc_level=1&p_keyvalue=1910.