

HVAC Controls (DDC/EMS/BAS) Evaluation Protocol

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Acronyms

BAS	Building automation system
CDD	Cooling degree day
DDC	Direct digital controls
EMS	Energy management system
HDD	Heating degree day
HVAC	Heating, ventilation, and air conditioning
IPMVP	International Performance Measurement and Verification Protocol
M&V	Measurement and verification
OAT	Outside air temperature
RMS	Root mean square
TMY	Typical Meteorological Year

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1 Measure Description

The HVAC Controls Evaluation Protocol is designed to address evaluation issues for direct digital controls/energy management systems/building automation systems (DDC/EMS/BAS) that are installed to control heating, ventilation, and air-conditioning (HVAC) equipment in commercial and institutional buildings. (This chapter refers to the DDC/EMS/BAS measure as HVAC controls.) This protocol may also be applicable to industrial facilities such as clean rooms and labs, which have either significant HVAC equipment or spaces requiring special environmental conditions¹.

This protocol addresses only HVAC-related equipment and the energy savings estimation methods associated with installing such control systems as an energy efficiency measure. The affected equipment includes:

- Air-side equipment (air handlers, direct expansion systems, furnaces, other heating- and cooling-related devices, terminal air distribution equipment, and fans)
- Central plant equipment (chillers, cooling towers, boilers, and pumps).

These controls may also operate or affect other end uses, such as lighting, domestic hot water, irrigation systems, and life safety systems such as fire alarms and other security systems.

Considerable nonenergy benefits, such as maintenance scheduling, system component troubleshooting, equipment failure alarms, and increased equipment lifetime, may also be associated with these systems. When connected to building utility meters, these systems can also be valuable demand-limiting control tools. However, this protocol does not evaluate any of these additional capabilities and benefits.

¹ As discussed in “Considering Resource Constraints” within the introduction section of this UMP report, small utilities (as defined under the Small Business Administration regulations) may face additional constraints in undertaking this protocol. Therefore, alternative methodologies should be considered for such utilities.

2 Application Conditions of Protocol

The type of HVAC control system to which this protocol applies is common in newly constructed commercial and institutional buildings that are larger than 100,000 ft² (PNNL, 2012). However, numerous older buildings have either minimal HVAC controls or older systems with less-efficient control sequences that can benefit from this measure. Many older BASs use pneumatic controls, which are often in disrepair. There is also a significant opportunity for more advanced control systems in smaller buildings. Energy efficiency programs encourage the installation of HVAC controls as retrofits in existing facilities and, in some cases, encourage installation in new construction. Generally, energy codes do not require that DDC/EMS/BAS-type controls be installed; however, energy codes tend to specify minimum HVAC control features, such as time-of-use on/off scheduling and economizer controls on air handlers. Some codes specify significantly more control requirements, such as reset schedules on supply air temperature in air handlers. In instances where code minimum requirements apply to new construction, or to new HVAC systems in major renovation projects, code-required controls should be considered baseline.

Two common program delivery mechanisms are in use around the country.

- **Prescriptive.** This approach usually entails an incentive that is based on an easy-to-calculate building metric (such as the building floor area affected by the HVAC controls) or on the number of qualifying control points. The incentives may vary, based on the type of building where the equipment is installed, because the achieved energy savings tend to be specific to a building's use (e.g., hospitals versus schools).
- **Custom.** This approach also provides an incentive for the HVAC controls that is based on the expected annual energy savings (kilowatt-hours) estimated using a custom calculation tool. The custom calculation approach is often used for facilities that apply incentives to multiple measures in a building. In this circumstance, estimation may be the result of a complete hourly building energy simulation model developed using a program such as eQUEST or EnergyPlus. However, other calculation approaches may be used, such as developing a bin model for the HVAC systems in a building. Custom programs may require measurement and verification (M&V) after the controls are installed to calculate savings and determine incentive amounts based on actual equipment performance.

3 Savings Calculations

This section presents a high-level equation that applies to all HVAC controls measures for calculating gross energy savings.² Detailed direction on how to apply this equation is presented in the Measurement and Verification Plan section of this protocol.

Energy savings are determined using the following general equation (EVO 2012):

$$\text{Energy Savings} = (\text{Baseline Energy} - \text{Reporting Period Energy}) \pm \text{Routine Adjustments} \pm \text{Non-Routine Adjustments} \quad (1)$$

Where,

Energy Savings = First-year energy consumption savings.

Baseline Energy = Pre-implementation consumption.

Reporting Period Energy = Post-implementation consumption.

Routine Adjustments = Adjustments made to account for routinely changing independent variables (variables that drive energy consumption). Savings should be normalized to typical meteorological year (TMY) weather data as well as other significant independent variables (e.g., occupancy, production data), if applicable. If first-year energy savings are desired, savings should be normalized to the actual weather for the 12-month period following commissioning of the new controls.

Non-Routine Adjustments = Adjustments made to account for parameters that typically are not expected to change during the implementation period. If these parameters change *and* this change influences the reporting period energy use, they should be accounted for (e.g., changes to a facility's building envelope during implementation of an HVAC controls measure). This would have to be considered if savings were verified using Options C or D of the International Performance Measurement and Verification Protocol (IPMVP) (EVO 2012) or calibrated simulation per ASHRAE Guideline 14-2002 (ASHRAE 2002).³

² This protocol focuses on gross energy savings and does not include other parameter assessments, such as net-to-gross, peak coincidence factors, or cost effectiveness.

³ Whole-facility consumption analysis

HVAC controls demand savings is not a straightforward extension of verified consumption savings (unlike lighting retrofits, for example, where established load savings profiles can easily be applied to consumption savings data). For HVAC controls projects, the load savings profiles vary, depending on the distribution of the measure types implemented and are weather dependent. These complications are accounted for in the M&V methods described in Section 4.

4 Measurement and Verification Plan

This section contains four approaches for determining the energy savings resulting from the HVAC controls measure, and provides guidance on how and when to use each.

Two methods use pre- and post-installation data and the other two use post-installation data only.

- The first method (End Use Regression Model) is more accurate than the second, using pre- and post-installation metered data of the affected end uses. However, it has limitations caused by metering requirements and the necessity for fewer complication factors. The method is appropriate only for retrofit of HVAC controls.
- The second method (Consumption Data Analysis) is similar to the first, but it is much simpler and cheaper to conduct. However, because this method uses whole building consumption data (billing records, whole building interval or AMI data), it is also less accurate and typically requires that expected savings are greater than 10% of base year energy use to be separated from the noise. The method is appropriate only for retrofit of HVAC controls.
- The third method (Bin Model Calculations) is useful when pre-installation metering is not possible. This method can be used for most situations; however, it can be expensive to conduct for large, complicated systems unless a model is available from the ex-ante analysis or the evaluator has a model available that can be easily adapted. The method can be used for both retrofit of HVAC controls or for new construction.
- The fourth method (Calibrated Simulation) is appropriate for complex facilities, and it can be reasonably cost effective if the building simulation model is available from the ex-ante savings estimate documentation. The method can be used for both retrofit of HVAC controls or for new construction.

The End Use Regression Model is the most accurate method and is recommended for M&V of HVAC controls measures. However, it is rarely used because it has extensive pre- and post-retrofit metering requirements and potential complications from interactions of other measures concurrently installed. The pre-metering requirement can delay the installation and add significant cost to the M&V process. The other methods are all commonly used and M&V method selection is often based on the available calculation algorithm used to determine the ex-ante energy savings. Ultimately, the choice of method depends on the cost of performing the measurements, the magnitude of energy savings, and the scope and complexity of the measure.

System Commissioning. *Generally programs require commissioning of control systems prior to incentive payment. It is very important that the installed controls have been commissioned and are functioning as intended before M&V activities commence. It is also important that the M&V activities do not influence the customer or utility program behavior prior to M&V, since the objective is to provide an independent evaluation of measure performance. M&V should commence after sufficient time has passed to ensure full opportunity for commissioning but before the occurrence of supplemental control sequence changes not originally specified.*

4.1 Baseline Definition Considerations

For the measure evaluation to be consistent with program requirements, it is important to define clearly the baseline conditions. The two primary areas to consider when defining the baseline conditions are program requirements and multiple measure installation (discussed in Section 4.1.1 and Section 4.12, respectively). These considerations also impact the selection of the savings calculation method.

4.1.1 Program Requirements

The program under which the HVAC controls are incented often has specific rules about a measure's eligibility. For custom programs, the incentive payment is based on the estimated energy savings. Also, these programs often have specific requirements for the baseline definition as it relates to estimating the claimed savings. Some custom programs base the final incentive amount on the actual energy savings after a measure is installed, and those savings are often determined by required M&V process and a recalculation of savings.

Common eligibility criteria for new construction specify only that the HVAC control features exceed energy code minimum requirements. Therefore, the prevailing energy code must be examined carefully before a list of eligible controls can be developed for a project. For example, with retrofit applications, savings are often based on the pre-installation control of the affected systems. So it is important to determine whether the energy code was—or should have been—triggered by the retrofit, as this might impact the baseline estimate as if the project were new construction. Furthermore, the code to use for the baseline can be difficult to determine for projects with long timelines between design and construction. For example, some states apply the code in effect at the time of 100% construction drawings; others use the code in effect during plan submission at 60% drawings. This can make a significant difference in savings estimates for new construction or major renovations.

Also, some program rules specify that broken controls (or controls that are in place but are overridden in the pre-retrofit period) are not eligible and should not be considered in the savings estimate. These types of retrocommissioning issues include:

- An economizer that has dampers stuck in one position due to a failed damper motor
- A time clock for on/off scheduling that is not programmed (or has had all the “off” pegs removed) and allows the system to run all the time.

Although these types of retrocommissioning issues will likely be allowed under a retrocommission program, if they were completed under a custom HVAC program, the program rules may not allow them.

4.1.2 Multiple Measure Installation

For a major renovation, the HVAC controls measure is often only one of several in an overall package of measures. The package may include replacing constant-volume with variable-volume air handlers and replacing a chiller plant. In that instance, significant interactions between the measures need to be considered if the evaluation encompasses the HVAC controls measure only *or* if savings must be evaluated individually for each measure.

Although this protocol does not address the interactions of measures, it contains recommendations for the appropriate evaluation method to account for interactions. The first method, the End Use Regression Model, is discussed in detail with step-by-step descriptions. The other three methods are discussed in general terms only, because they are less conducive to being described in terms of a uniform method.

4.2 End Use Regression Model Method

Consistent with IPMVP Option B (Isolation Retrofit, All Parameter Measurement), this method uses measured pre- and post-installation metering of kilowatt consumption of all affected end uses (heating, cooling, fans, pumps, other auxiliary). The metered data are averaged into temperature bins that are based on the outside air temperature (OAT) (obtained from concurrent metering). The model is then adjusted for weather differences by applying TMY weather data to the measured data and extrapolating to all temperatures.

A significant advantage of this method is that the analyst does not need to know how to describe the control features, either in an engineering equation (as required for the Bin Model Calculation Method), or in a simulation model (as required for the Calibrated Simulation Method). Some control features are difficult to express with these methodologies.

The general overall equation describing this method is:

$$\text{Annual Savings} = \sum_{\text{End Uses}} \sum_{\text{Temp Bins}} (\text{Baseline kW} - \text{Installed kW}) \times \text{Bin Hours} \quad (2)$$

Where,

Annual Savings is in kWh,

Baseline kW is the metered kW averaged into temperature bins and extrapolated to the full range of TMY weather for the site,

Installed kW is the metered kW averaged into temperature bins and extrapolated to the full range of TMY weather for the site,

Bin Hours are the number of TMY hours in each temperature bin.

The specific calculation steps are as follows.

Step 1. Define the system boundary

In defining the boundary around the equipment in the evaluation, include all the equipment directly impacted by the installed HVAC controls. An example of direct impact is the addition of demand ventilation controls to an air handler.

Also, include indirectly impacted equipment if this inclusion is expected to have a greater than 5% effect on the total savings. Examples of indirectly affected equipment are the chiller and boiler serving the air handler with the demand ventilation control if there are resulting changes in heating and cooling loads.

It may be appropriate to include the boiler but not the chiller when a building is located in a cold climate (where cooling energy is a very small percentage of total building consumption and heating energy is a much larger percentage). In a hot climate, the opposite would be true.

Step 2. Collect the data

Collect these data for the evaluation.

- **HVAC load determinants.** In most cases, the heating and cooling loads will be a function of OAT. Identify the TMY weather station that is closest to the project site. The weather data are needed to normalize both pre- and post-energy consumption and thus eliminate weather year differences.
- **Facility operations schedule.** Determine the period for each mode (defined, as needed, by hour of day, day of week, and season), because this method requires that metered data be collected during all schedule modes. If the HVAC systems have different operation modes, determine by the facility's operation schedule (e.g., setback of space temperature set point during night and weekend hours).
- **Equipment inventory.** Obtain nameplate information for each control system's affected equipment within the system boundary.

Step 3. Perform metering

Meter equipment to obtain the following information.

- **True root mean square (RMS) power.** For this protocol, it is preferable to have a trend log (noting the data in 15-minute intervals) of true poly-phase RMS power for all circuits powering the desired end uses. If the system load is primarily determined by OAT, the measurement period must be sufficient for capturing the system's operation during a range of outside temperatures. The metering periods must also span seasonal changes, if any, in the operating schedule. Some HVAC control systems have a power-trending function for some equipment. If using this function, take a one-time power measurement to verify the accuracy of the control system values. If these values are off, develop a calibration curve to adjust the values.
- **Alternative power measurement.** In lieu of true power trending, it is acceptable to trend the electrical current combined with a one-time true power measurement at three load levels within the typical operating range of the equipment.
- **OAT.** Trend the OAT concurrently with the power measurements. This information is likely available from the control system; however, check the values for accuracy. Alternatively, deploy a temperature logger to trend OAT.

When acquiring power measurements, take care that the effort conforms to the metering cross-cutting protocols in Chapter 9.

Step 4. Calculate the savings

Complete the following activities separately for the pre- and post-installation metering data. If more than one metering channel is recorded for each end use, sum all the metering data for each end use to create a single trend of values.

Also, to obtain a complete annual profile, 1°F temperature bins can be used instead of 2°F bins, and the savings can be applied to 8,760 hourly TMY temperatures.

- **Average kilowatts by trend log bin.** For each end use, average the kilowatt values by 2°F temperature bins for all trend log intervals during operating hours, as defined by facility operations schedules. If the facility has more than one operation mode, calculate the temperature-bin averages separately for each operation mode.
- **Operating hours by TMY bin.** Divide the 8,760 TMY OAT data into 2°F bins and compute the frequency of annual operating hours for each bin, as defined by facility operations schedules.
- **Average kilowatts by TMY bin.** The TMY average-bin kilowatts equal the trend log average-bin kilowatts for each matching bin. Extrapolate the average kilowatts for TMY bins that do not have trend log data. Plot the kilowatt value versus bin temperature data and then determine the regression equation that best fits through the data that extrapolates to the highest and lowest TMY temperature bin. No bin kilowatt value is allowed to exceed the full equipment kilowatt capacity.
- **Savings by bin.** For each end use and for each TMY bin, calculate the savings as the difference between the baseline estimate and the installed kilowatt values multiplied by the number of hours in the temperature bin.
- **Annual savings.** Sum the kilowatt-hour values across the TMY bins for each end use and then sum the end-use savings into an annual value.

4.3 Consumption Data Analysis Method

Whole-building consumption data analysis is consistent with IPMVP Option C (Whole Building). This option is appropriate when conditions are similar to those of the End Use Regression Model method *but* pre-installation end-use metering is not possible or practical. Although this method is much less costly to perform, it is also less accurate. For this method, the HVAC controls measure savings must be large compared to the random or unexplained energy variations at the whole-facility level.⁴ Thus, this analysis cannot be undertaken until after a full season or full year of reporting-period billing data is collected.

⁴ Typically savings should exceed 10% of the baseline energy consumption for a particular meter (e.g., electricity meter) to confidently discriminate the savings from the baseline data when the reporting period is shorter than 2 years (EVO 2012).

A billing analysis requires that a full year of billing data be available for the pre- and post-installation years. The monthly energy use of the facility can be correlated to the weather data corresponding to each billing period. Commonly used forms of weather data for correlation include cooling degree days (CDDs), heating degree days (HDDs), and average temperature. Usually temperature will provide the best correlations, but CDD and HDD can also provide good correlations if the best correlation is searched from multiple sets of CDD and HDD values, produced from different base temperatures. This provides weather-specific correlations for the pre- and post-installation periods. The correlations are applied to TMY weather corresponding to each billing period to determine long-term average energy use for the pre- and post-installation periods. Savings are then calculated as the difference between pre- and post-installation annual energy use. If first-year savings are desired, the pre-installation period correlation can be used with the post-installation year weather to obtain energy use corresponding with post-installation year weather conditions.

If interval billing data or AMI data (hourly) is available, the correlations can be greatly improved by using the corresponding hourly weather in the correlations instead of monthly average values. The data can also then be divided into time categories, such as for occupied and unoccupied hours and/or weekday and weekend day types. The correlations can be done for each category. Nonlinear correlations or change point linear correlations may be appropriate to define the models across the entire year.

Note that this method cannot be used for new construction or a major renovation because the baseline whole-building consumption would not be representative of a building constructed to the prevailing energy code. (That is, for a major renovation, the entire building would have to be in compliance with the prevailing energy code.)

4.4 Bin Model Calculations Method⁵

Consistent with IPMVP Option A (Isolation Retrofit, Key Parameter Measurement), this method uses metered key variables of the affected equipment to inform the development of an engineering model that describes system operation. The model is then used to calculate energy consumption for the installed HVAC control system. The baseline consumption is determined by making changes to the model that reflect the baseline system operation.

This method can be used when pre-installation metering data are not available or when there are other significant non-measure changes to the building during either the pre- or post-installation metering period. The types of nonmeasure changes include a significantly different occupancy level, the installation of other conservation measures, or a determination that the baseline is different from the actual pre-equipment operation.

The system boundary is defined through activities similar to those described for Step 1 of the End Use Regression Model method. Also, the data collection effort would encompass both a

⁵ This also called the Inverse Bin method.

complete inventory of the equipment within the boundary and the operating sequences of that equipment. (The as-built plans and control system can be very useful for collecting these data.)

Trend data from the control system or from evaluator installed metering equipment should be used to inform the bin model and to calibrate the bin model. Examples of the use of trend data include:

- Supply air temperature trends in air handlers to verify temperature reset schedules, such as reset defined by OAT (this requires that OAT be trended also). This can be used in the bin model to define how the supply air temperature varies.
- Fan speed or kilowatt trends to determine the airflow at differing conditions in the model. This might also be a function of OAT. Fan kilowatts can also be used to determine if the model is responding well by comparing the metered fan energy to the bin model calculated fan energy (calibration of the model).

The baseline model will be developed by using the calibrated post-installation model and changing the appropriate control function to baseline conditions. An example is an HVAC controls system change from an air handler with constant supply air temperature control to one that resets supply air temperature based on OAT. The post-installation model should be calibrated with the air handler supply air temperature that varies with OAT as indicated by the trend data. The baseline version of the model will then result from changing the supply air temperature to the constant baseline value.

Because no pre-installation trend data are likely to be available, the baseline conditions need to be verified during the evaluation. This can be done through discussions with staff who are familiar with the baseline system. This may include building maintenance staff or an HVAC maintenance contractor. Baseline control and operation may also be determined by reviewing the original (or most recent pre-installation) mechanical drawings, control sequences, commissioning reports, or balancing reports.

Viewing this method as a uniform method of analysis can be difficult because achieving results that are consistent between analysts is a challenge. This method requires that a site-specific model be developed for the measure; however, engineers are likely to develop the bin model differently, and they may use different trend data to inform the model.

This method is commonly used and can be implemented at a reasonable cost for evaluating difficult or complex situations (such as a heating hot water valve that is leaking and increasing the cooling load), especially when the model has already been developed for the ex-ante savings calculations or when the evaluator has an existing bin model that can be easily adapted. However, if a model is not available, model development cost should be a consideration when choosing an evaluation method.

4.5 Calibrated Simulation Method

Consistent with IPMVP Option D (Calibrated Simulation), this is a good method to use for large, complex facilities because it can handle many different control sequences. It is also a useful

approach for modeling multiple measures and accounting for the interactive effects between them.

This method may be cost effective when a model developed for the claimed savings analysis is available to the evaluator. However, it is important to confirm that the model is representative of the actual installed systems. (Unless the model was used for M&V after the installation, it may be different from what was originally anticipated during the claimed savings analysis.)

An essential component of an effective savings estimate is analytical credibility and the ability for a third party to validate it. For this reason, evaluators often exclude proprietary building simulation models, models that prevent the reviewer from seeing the inputs, and models for which the simulation methodology is not published or documented publicly. The U.S. Department of Energy website has an extensive list of whole-building analysis energy simulation tools.⁶

Ideally, the model represents the post-installation conditions and is calibrated to monthly bills with actual weather coincident with the bills. The HVAC control features should then be changed to be consistent with the baseline control features before the model is rerun. The difference between the two runs will be the first-year savings. If long-term typical annual savings estimates are desired, use TMY weather to run the baseline and as-built models.

Issues around obtaining baseline information are the same as those discussed in Section 4.4. It is also important to use trend data from the control system or from evaluator-installed metering equipment to inform and assist in calibrating the model. Space temperature trends can be obtained to confirm the space temperature set points that should be specified in the model. Air handler supply fan kilowatt trends can be used to calibrate the fan energy use that the model predicts. This can greatly enhance the model calibration process by providing some end-use calibration to the model and increase confidence in the overall model calibration. Other data from observation of the control system should also be incorporated into the calibrated model. This will include items such as chilled water temperature set point, air handler operating schedules, and minimum outside air damper settings. Some end uses, such as lighting and plug loads, are more difficult to specify and in some cases may be defined by default characteristics (ASHRAE 2000).

4.6 Other Modeling Considerations

Regression models may be very simple or complex, depending on the significance of the independent variables used. Some general modeling information is included in Section 4.6.1 through Section 4.6.3.

⁶ http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm

4.6.1 Regression Modeling Direction

To calculate normalized savings—whether following the IPMVP’s Option A, Option C, or Option D—develop the baseline and reporting period regression model⁷ for most projects (ASHRAE 2004; BPA 2011). The three types of analysis methods used to create a model follow:

- **Linear regression.** For one routinely varying significant parameter (e.g., OAT).⁸
- **Multivariable linear regression.** For more than one routinely varying significant parameter (e.g., OAT and a process parameter).
- **Advanced regression.** Polynomial or exponential, for example.⁹

When these models are required, develop them in accordance with best practices. Also, use these models only when they are statistically valid (see Section 4.6.2). When there are no significant independent variables, no model is required, because the calculated savings will be inherently normalized.

4.6.2 Testing Regression Model Validity

To assess the accuracy of the model, review the parameters listed in Table 1 (EVO 2012).

Table 1. Model Statistical Validity Guide

Parameter Evaluated	Description	Suggested Acceptable Values
Coefficient of determination (R^2)	A measure of the extent to which the regression model explains the variations in the dependent variable from its mean value.	> 0.75
T-statistic	An indication of whether the regression model coefficients are statistically significant.	> 2
Mean bias error	An indication of whether the regression model overstates or understates the actual cooling load.	< $\pm 5\%$ (This value is typical, but depends on the project.)

⁷ This could either be a single-regression model that uses a dummy variable to differentiate the baseline/reporting period data, or two independent models—one for the baseline periods and one for the reporting period.

⁸ One of the most common linear regression models is the three-parameter change-point model. For example, a model that represents cooling electricity consumption would have one regression coefficient that describes nonweather-dependent electricity use; a second regression coefficient that describes the rate of increase of electricity use with increasing temperature; and a third parameter that describes the change-point temperature (also known as the balance-point temperature), where weather-dependent electricity use begins.

⁹ Advanced regression methods might be required if a chiller plant is providing cooling for manufacturing or industrial processes.

If any of these parameters fall outside of the acceptable range, when possible, attempt to enhance the regression model by:

- Increasing or shifting the measurement period.
- Incorporating more data points. This may include additional metering or obtaining trends from the EMS.
- Including independent variables that were previously unidentified. This may include additional metering or obtaining additional trends from the EMS. It may also be as simple as dividing the available trend data into different categories such as separating Saturdays out because they operate the same hours as weekdays, but at only half the weekday staffing levels.
- Eliminating statistically insignificant independent variables.

After enhancement attempts, if the model is still outside the suggested range, this indicates that parameter coefficients are quite poorly determined and that normalized consumption will have a relatively high statistical prediction error. Ordinarily such a model should not be used for normalization, unless the analysis includes appropriate statistical treatment of this prediction error. Discussion of how to proceed in such circumstances is outside the scope of these guidelines.

4.6.3 Model Calibration

In estimating energy usage for systems and equipment, engineering models rely on thermodynamic, heat transfer, and other physical principles. When it is practical to do so, measure the energy use of the modeled system during the post-installation period. Then compare the estimated energy use (as derived from the model) to the measured use.

To calibrate the model to the measured use, adjust the model inputs or specification, as needed. The objective for this calibration process is to achieve a match between the modeled use and measured use that is within the limits defined by the IPMVP Option D protocol (summarized in Table 2). By applying the model to hourly data and comparing monthly and hourly values of metered data, bin models and statistical models can also be specified to achieve these limits, as determined by ASHRAE Guideline 14-2002 (ASHRAE 2002).

Table 2. Model Calibration Criteria

Data Interval	RMS Error	Maximum Mean Bias Error
Monthly	± 15%	± 5%
Hourly	± 30%	± 10%

5 Sample Design

Consult Chapter 11 (“Sample Design”) for a description of general sampling procedures. Use this information when either the HVAC controls measure includes a sufficiently large population of air handlers or the evaluation budget is constrained.

Ideally, use stratified sampling to partition the air handlers by size, type, and operating schedule. This ensures that sample findings can be extrapolated confidently to the remaining project population. The confidence- and precision-level targets that influence sample size are typically governed by regulatory or program administrator specifications.

6 Other Evaluation Issues

When claiming net program HVAC controls measure impacts, consider the following evaluation issues in addition to considering the first-year gross impact findings:

- Net-to-gross estimation
- Realization rates.

6.1 Net-to-Gross Estimation

The cross-cutting chapter, *Estimating Net Savings: Common Practices*, discusses various approaches for determining net program impacts. To ensure adjustments to impacts are not double-counted at a population level, follow the best practices that include close coordination between: (1) staff estimating gross and net impact results, and (2) the teams collecting site-specific impact data.

6.2 Realization Rates

For program-induced projects, divide the claimed (*ex-ante*) gross savings by the evaluated (*ex-post*) gross savings to calculate the realization rates.

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