HVAC Controls (DDC/EMS/BAS) Evaluation Protocol

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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 system (DDC/EMS/BAS) installed in commercial and institutional buildings. (This document refers to the DDC/EMS/BAS measure as HVAC controls.) This protocol may also be applicable to industrial facilities that have either significant HVAC equipment or conditioned spaces requiring special environmental conditions, such as clean rooms and labs.

This protocol addresses only HVAC-related equipment and the energy savings estimation methods associated with installation of such control systems as an energy conservation measure. That includes the following:

- The two categories of air-side equipment (air handlers, direct expansion systems, furnace, other heating and cooling related devices, terminal air distribution equipment and fans), and
- 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 and irrigation systems, as well as life safety systems (such as fire alarm and security).

Also, there may be considerable non-energy benefits associated with these systems, such as maintenance scheduling, system component troubleshooting, equipment failure alarms, and increased equipment lifetime. Additionally, when connected to building utility meters, these systems can be a valuable demand-limiting control tool. However, this protocol will not address evaluating any of these additional capabilities and benefits.

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 more than 100,000 square feet in size. However, there are numerous older buildings that have either minimal HVAC controls or older systems with less-efficient control sequences that can gain from this measure. Many older building automation systems utilize pneumatic controls, and these controls 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 to 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.

There are two common program-delivery mechanisms 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 incentive may vary, based on the type of building where the equipment is installed, since the energy savings achieved 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 (kWh), which is estimated using a custom calculation tool. The custom calculation approach is often used for facilities that are applying incentives for 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 and EnergyPlus. However, other calculation approaches may be used, such as developing a bin model for the HVAC systems in a building. Note that custom programs may require M&V activities to be performed after the controls are installed so as 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[1]. 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):

Equation 1

Energy Savings = (Baseline Energy – Reporting Period Energy) ± Routine Adjustments ± Non-Routine Adjustments

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

[1] This protocol is focused on gross energy savings and does not include other parameter assessments, such as net-to-gross, peak coincidence factors, or cost-effectiveness.

significant independent variables (e.g., occupancy, production data), if applicable.

Non-Routine Adjustments = Adjustments made to account for parameters typically 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 only have to be considered if savings were verified using Option C of the International Performance Measurement and Verification Protocol (IPMVP).[2]

Determining 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.

4 Measurement and Verification Plan

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

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

- The first method (End Use Regression Model) is more accurate than the second, utilizing the pre- and post-installation metered data of the affected end uses. However, this method has limitations due to both the metering requirements and the necessity for fewer complication factors.
- The second method (Billing Analysis) is similar to the first, but it is much simpler and cheaper to conduct. However, because this method uses using billing records, it is also less accurate and typically requires that expected savings are greater than 10% of base year energy use in order to be separated from the noise.
- The third method (Bin Model Calculations) is useful when pre-installation metering is not possible. While this method can be used for most situations, it can be expensive to conduct for large, complicated systems. 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 claimed (*ex ante*) savings estimate documentation.

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[2] Whole-facility consumption analysis

4.1 Baseline Definition Considerations

For the measure evaluation to be consistent with program requirements, it is important to define clearly the baseline conditions. There are two primary areas of concern to consider when defining the baseline conditions: program requirements and multiple measure installation. These considerations also impact the selection of the appropriate savings calculation method.

4.1.1 Program Requirements

The conservation program under which the HVAC controls are incented often has specific rules concerning 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.

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. Examples of 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), thus allowing the system to run all the time. .

4.1.2 Multiple Measure Installation

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

Although this protocol does not address the interaction of measures, it contains recommendations regarding 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 only discussed in general terms, since 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 kW consumption of all of the 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 (obtained from concurrent metering). The model is then adjusted for weather differences by applying typical meteorological year (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 other methodologies.

The general overall equation describing this method is:

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

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 of 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 equipment that is indirectly impacted equipment if such inclusion is expected to result in more than a 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.

Note that 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 outside air temperature. Identify the TMY weather station that is closest to the project site. The weather data is 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, then determine by the facility's operations schedule (e.g., setback of space temperature setpoint 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 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 outside air temperature (OAT), then 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 outside air temperature 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 both the pre-installation metering data and the post-installation metering data. If more than one metering channel is recorded for each end use, then sum all of the metering data for each end use to create a single trend of values.

Also, to obtain a complete annual profile, one-degree temperature bins can be used instead of two-degree bins, and the savings can be applied to 8,760 hourly TMY temperatures.

- **Average kW by Trend Log Bin**. For each end use, average the kW values by two-degree 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 two-degree bins and compute frequency of annual operating hours for each bin, as defined by facility operations schedules.
- **Average kW by TMY Bin**. The TMY average-bin kW equals the trend log average-bin kW for each matching bin. Extrapolate the average kW for those TMY bins that do not have trend log data. Plot the kW value versus bin temperature data and then determine the regression equation that best fit through the data that extrapolates to the highest and lowest TMY temperature bin. Note that no bin kW value is allowed to exceed the full equipment kW 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 kW values multiplied by the number of hours in the temperature bin.
- **Annual Savings**. Sum the kWh values across the TMY bins for each end use and then sum the end-use savings into an annual value.

4.3 Whole Building Billing Analysis Method

Whole-building billing 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. While 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 that occur at the whole-facility level.[3] Thus, this analysis cannot be undertaken until after a full season or full year of reporting-period billing data is collected.

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 Method

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 end-use metering is not available or when there are other significant non-measure changes to the building during either the pre- or post-metering periods. The types of non-measure changes include such a significantly different occupancy level, the

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

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 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.)

To verify or define control sequences, use trends from the control system such as:

- Supply air temperature in the air handlers to verify reset schedules, and
- Economizer operation and fan speed or kW to obtain air flow as load varies with OAT.

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

While this method can be used for evaluating difficult situations (such as a heating hot water valve that is leaking and increasing the cooling load) and for fairly complex systems, using it could become expensive due to time required for model development time.

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.)

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 run again. The difference between the two runs will be the first-year savings. If long-term typical annual savings estimates are desired, then run the baseline and as-built models using TMY weather.

4.6 Other Modeling Considerations

Regression models may be very simple or complex, depending on the significance of the independent variables used. Below is some general modeling information.

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 model[4] for the majority of projects. The three types of analysis methods used to create a model are these:

- ***Linear Regression:*** For one routinely varying significant parameter (e.g., OAT).[5]
- ***Multivariable Linear Regression:*** For more than one routinely varying significant parameter (e.g., OAT and a process parameter).
- ***Advanced Regression:*** Such as polynomial or exponential.[6]

When these models are required, develop them in accordance with best practices. Also, use these models only when they are statistically valid. (See subsection 4.6.2, Testing Regression Model Validity.) Note that when there are no significant independent variables, then 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 here (EVO, 2012).

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.	< +/- 5% (While this value is typical, it depends on the project.)

4 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.

5 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 non-weather 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.

6 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, then the regression model is not considered statistically valid. Thus, it should not be used to normalize data. When possible, attempt to enhance the regression model by:

- Increasing or shifting the measurement period;
- Incorporating more data points
- Including independent variables that were previously unidentified; or
- Eliminating statistically insignificant independent variables.

4.7 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 the next table). 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 14-2000.

Model Calibration Criteria

Data Interval	Maximum Root Mean Square (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 VFD 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 net-to-gross chapter discusses an approach for determining net program impacts at a general level. To ensure that there is no double-counting of adjustments to impacts 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.

7 References

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