Chapter 14: Chiller Evaluation 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 – December 2014

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September 2014

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Acronyms

ANSI	American National Standards Institute
BAS	building automation system
EUL	effective useful life
HVAC	heating, ventilation, and air conditioning
IPMVP	International Performance Measurement and Verification Protocol
kWh	kilowatt-hour
M&V	measurement and verification
OAT	outdoor air temperature
RUL	remaining useful life
TMY	typical meteorological year
TRM	technical reference manual

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1 Measure Description

This protocol defines a chiller measure as a project that directly impacts equipment within the boundary of a chiller plant. A chiller plant encompasses a chiller—or multiple chillers—and associated auxiliary equipment. This protocol primarily covers electric-driven chillers and chiller plants. It does not include thermal energy storage and absorption chillers fired by natural gas or steam, although a similar methodology may be applicable to these chilled water system components.[1]

Chillers provide mechanical cooling for commercial, institutional, multiunit residential, and industrial facilities. Cooling may be required for facility heating, ventilation, and air conditioning (HVAC) systems or for process cooling loads (e.g., data centers, manufacturing process cooling).

The vapor compression cycle,[2] or refrigeration cycle, cools water in the chilled water loop by absorbing heat and rejecting it to either a condensing water loop (water cooled chillers) or to the ambient air (air-cooled chillers). As listed in Table 1, ASHRAE standards and guidelines define the most common types of chillers by the compressors they use (ASHRAE 2012).

Table 1. Four Common Chiller Types

Chiller Type	Description
Reciprocating, Screw, and Scroll	Reciprocating, screw, and scroll chillers use positive-displacement compressors. These compressors increase refrigerant vapor pressure by reducing the volume of the compression chamber. Reciprocating chillers compress air using pistons; screw chillers compress air using either single- or twin-screw rotors with helical grooves; and scroll chillers compress air through the relative orbital motion of two interfitting, spiral-shaped scroll members.
Centrifugal	Centrifugal chillers use dynamic compressors. These compressors increase refrigerant vapor pressure through a continuous transfer of kinetic energy from the rotating member to the vapor, followed by the conversion of this energy into a pressure rise. Centrifugal chillers transfer this kinetic energy using impellers similar to turbine blades.

Chiller plant auxiliary equipment includes chilled water and condensing water pumps; cooling tower fans and spray pumps (water-cooled chillers); condenser fans (air-cooled chillers), and water treatment systems.

Projects impacting chiller plant equipment generally fall into one of two categories:

- **Equipment replacement.** These projects involve replacing a chiller and possibly replacing some or all of the auxiliary equipment.
- **Modifications to existing equipment.** These projects typically involve adding control equipment (e.g., adding a variable frequency drive to an existing centrifugal chiller to improve its part-load efficiency).

[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] The vapor compression cycle consists of four main components: an evaporator, a compressor, a condenser, and an expansion valve.

2 Application Conditions of Protocol

A program may address chiller energy-efficiency activities alone, but more often, broader commercial, multiunit residential, or industrial custom programs will include these activities. As chiller savings often occur at the same time many jurisdictions experience electricity system peaks, savings from these projects can have a significant impact on a custom program's summer peak-demand savings.

Service providers and other stakeholders design energy-efficiency programs to overcome market barriers through activities that address the available market opportunities. Chiller programs may include some or all of the following activities:

- **Training.** Program administrators sometimes fund or develop training for service providers. For example, in some jurisdictions, service providers do not routinely undertake detailed common practice, feasibility studies for their customer base. If a program is to exploit to the fullest extent the achievable potential in its region, end users need to consider early replacement of equipment in their chiller plants. To facilitate this decision-making process, service providers may need training on how to conduct investment-grade energy audits, using recommended practices.
- **Development incentives.** Program administrators sometimes provide incentives that encourage end users to undertake detailed feasibility studies for chiller measures. Ideally, the incentives encourage end users to commission a detailed feasibility study, which could result in the development of a business case that would encourage end users to move forward with a chiller measure.
- **Implementation incentives.** Program administrators often provide incentives to implement chiller measures. Again, ideally, the incentives can encourage end users to invest more capital upfront to install higher-efficiency equipment or to invest capital sooner in early replacement projects.

This protocol provides direction on how to reliably verify savings from chiller measures using a consistent approach. It does not address savings achieved through training or through market transformation activities.

3 Savings Calculations

This section presents a high-level gross energy savings equation[3] that applies to all chiller measures. Section 4, *Measurement and Verification Plan,* provides detailed direction on how to apply this equation.

Use the following general equation to determine savings (US DOE FEMP 2008).

Equation 1

$$\text{kWh Savings}_{Total} = (\text{kWh Savings}_{Chiller}) + (\text{kWh Savings}_{Auxiliary})$$

Where,

$\text{kWh Savings}_{Total}$ = First-year energy consumption savings

$\text{kWh Savings}_{Chiller/Auxiliary}$ = $\sum_{Cooling\ Load\ Range}\left(kWh_{Baseline} - kWh_{Reporting}\right)_{Cooling\ Load}$

And,

$\text{kWh}_{Baseline,\ Cooling\ Load}$ = Energy required by the baseline equipment (either existing or hypothetical) at a given cooling load

$\text{kWh}_{Reporting,\ Cooling\ Load}$ = Energy required by the new equipment at a given cooling load

The approach for determining demand savings for chiller measures depends on the type of load being served by the chiller plant:

- **HVAC loads.** For chillers serving HVAC loads, apply regional load savings profiles based on regional weather (average daily load profiles for each season), calibrated building simulation models, engineering models targeting peak demand periods, and/or peak coincident factors to consumption savings data.
- **Process loads.** As load savings profiles vary, depending on the process, calculating the demand savings for chillers serving process loads is not as straightforward as it is for chillers serving HVAC loads. First, produce project-specific load savings profiles and then apply site-specific coincidence factors to determine coincident peak demand savings.

3.1 Determining Baseline Consumption

A common issue for many chiller programs is the use of existing equipment in determining the baseline for establishing project savings claims. The following discussion explains why this is not always the correct baseline.

[3] As presented in the Introduction, the protocols focus on gross energy savings and do not include other parameter assessments, such as net-to-gross, peak coincidence factors, or cost-effectiveness.

To establish an appropriate baseline, consider three main replacement scenarios (Fagan et al. 2011):

- **Early replacement.** Existing equipment has a remaining useful life (RUL).
- **Replace-on-burnout.** The effective useful life (EUL) of the existing equipment has expired.
- **Natural turnover.** Replacement of equipment for reasons other than energy savings.

For the first scenario (early replacement), apply a dual baseline (Ridge et al. 2011), as shown in Figure 1. For the latter two scenarios, establish a hypothetical baseline that uses a new chiller meeting the applicable energy-efficiency standard[4] for the applicable jurisdiction. The hypothetical baseline should also consider industry standard practices and the existing equipment, which may set higher efficiency levels than the applicable energy-efficiency standards.

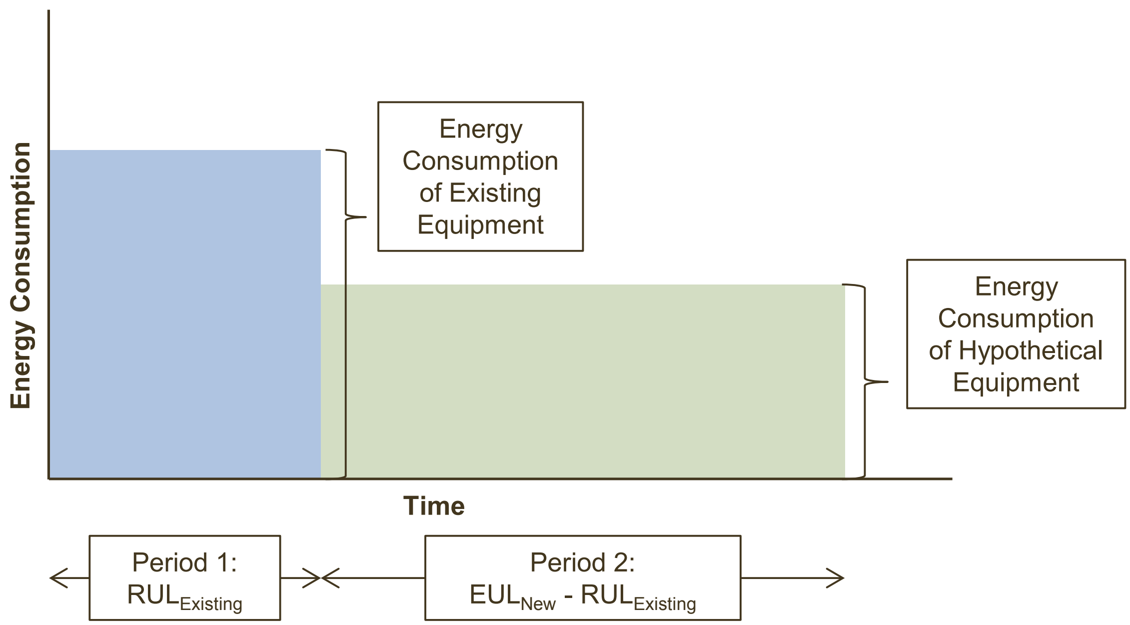

Figure 1. Dual baseline

As shown in Figure 1, there are two distinct baseline periods:

- **Period 1.** For the duration of the RUL of existing equipment, the existing equipment is the baseline.
- **Period 2.** For the remaining EUL of new equipment, use a hypothetical baseline.

[4] American National Standards Institute (ANSI)/ASHRAE Standard 90.1 is an example of a widely recognized energy-efficiency standard.

As available, use the program defined EUL for chiller equipment or consult regional technical reference manuals (TRM); when program or TRM information is not available, use other secondary sources.[5] Similarly, use the method defined by the program to determine the RUL of baseline chiller equipment. If this has not been previously established, consider defining RUL as the difference between the EUL and current age of the chiller (or number of years since its last rebuild)[6].

[5] California's Database for Energy Efficient Resources suggests an EUL of 20 years for chillers (CPUC 2008).
[6] Evaluators should use discretion regarding the scope of the rebuild and how it may impact the RUL of the chiller.

4 Measurement and Verification Plan

This section contains both recommended approaches to determining chiller energy savings and the directions on how to use the approaches under the following headings:

- Measurement and verification (M&V) method
- Data collection
- Interactive effects
- Detailed procedures
- Regression model direction.

4.1 Measurement and Verification Method

This protocol recommends an approach for verifying chiller energy savings that adheres to Option A of the International Performance Measurement and Verification Protocol (IPMVP). Because it is not possible to measure performance data for hypothetical baseline equipment, this protocol recommends Option A (retrofit isolation—key parameter measurement) rather than Option B (retrofit isolation—all parameter measurement).

Key parameters that require measurement include cooling load data and independent variable data, such as outdoor air temperature (OAT). Estimated parameters include manufacturer part-load efficiency data.[7]

In some cases, metered data may be available directly from the facility's building automation system (BAS).[8] Also, if required, the facility can add control points to the BAS, either as part of the implementation process or specifically for M&V purposes. Where the BAS cannot provide information, the protocol recommends using submeters and data loggers to collect data.

To ensure the M&V method balances the need for accurate energy savings estimates with the need to keep costs in check (relative to project costs and anticipated energy savings), consider two alternate approaches—IPMVP's Option C and Option D.

- **Option C.** Consider a whole-facility approach for early replacement projects if metering the required parameters is cost-prohibitive *and* if the estimated project-level savings are large compared to the random or unexplained energy variations that occur at the whole-facility level.[9] This approach is relatively inexpensive because it involves an analysis of facility consumption data. The downside is evaluators cannot perform verification until after collecting a full season or year of reporting period data and monitoring and

[7] Even though evaluators can measure efficiency data for the reporting period, under a hypothetical baseline scenario it is generally recommended to use pre- and postinstallation manufacturer efficiency data. This approach provides a more accurate estimate of the change in efficiency in comparison to an approach that uses a combination of measured reporting period efficiency data and manufacturer baseline efficiency data.
[8] It is important to ensure qualified service personnel maintain the BAS. Transducers that are out of calibration, or simply broken, could significantly impact M&V results.
[9] Typically, savings should exceed 10% of the baseline energy for the facility's electricity meter to confidently discriminate the savings from the baseline data when the reporting period is shorter than two years (EVO 2012).

documenting any changes to the facility's static factors[10] over the course of the measurement period. Also, an analysis of monthly consumption data may be inadequate for estimating peak demand savings; evaluators should investigate whether data from advanced metering infrastructure (e.g., interval meters) is available to increase the accuracy of billing data analyses.

- **Option D.** Consider a calibrated simulation approach if metering the required parameters is cost-prohibitive *and* the estimated project-level savings are small compared to the random or unexplained energy variations that occur at the whole-facility level. Undertake calibration in two ways: (1) calibrate the simulation to actual baseline or reporting period consumption data and (2) confirm the reporting period inputs via the BAS front-end system or the chiller control terminal, when possible. [11,12]

4.2 Data Collection

When using Option A (the preferred approach) to assess chiller measures, the following M&V elements require particular consideration:

- Measurement boundary
- Measurement period and frequency
- Functionality of the measurement equipment
- Savings uncertainty.

4.2.1 Measurement Boundary

For all projects, especially those that require metering external to the BAS, it is important to define the measurement boundary. When determining boundaries, consider the location and number of measurement points required as well as the project's complexity and expected savings:

- A narrow boundary simplifies data measurement (e.g., chiller plant equipment directly affected by the chiller measure), but will require accounting for any variables driving energy use outside the boundary (interactive effects)[13]
- A wide boundary will minimize interactive effects and increase accuracy. However, since M&V costs may also increase, it is important to ensure the expected increase in the accuracy of the project savings justifies the M&V cost increase.

[10] Many factors can affect a facility's energy consumption even though evaluators do not expect them to change. These factors are known as "static factors" and include the complete collection of facility parameters that are generally expected to remain constant between the baseline and reporting periods. Examples include: building-envelope insulation, space use within a facility, and facility square footage.

[11] In many cases, the simulation should represent the entire facility; however, in some cases, depending on the facility's wiring structure, evaluators can apply a similar approach to building submeters, such as distribution panels that include the affected systems.

[12] See the Uniform Methods Project's *Commercial New Construction Protocol* for more information on using Option D.

[13] Although significant interactive effects are uncommon for chiller measures, there are some scenarios that warrant consideration. See Section 4.3 for further detail.

4.2.2 Measurement Period and Frequency

Consider these important timing metrics: (1) the measurement period and (2) the measurement frequency. In general:

- Choose the measurement period (the length of the baseline and reporting periods) to capture a full cycle of each operating mode. For example, if a chiller is serving an HVAC load, collect data over the summer, shoulder, and winter seasons (if applicable).
- Choose the measurement frequency (the regularity of measurements during the measurement period) by assessing the type of load:
    - **Spot measurement.** For constant loads (e.g., constant-speed chilled water pumps), measure power briefly, preferably over two or more intervals.
    - **Short-term measurement.** For loads predictably influenced by independent variables (e.g., chiller compressors serving HVAC loads), take short-term consumption measurements over the fullest range of possible independent variable conditions, given M&V project cost and time limitations.
    - **Continuous measurement.** For variable loads (e.g., chiller compressors serving process loads), measure consumption data continuously, or at appropriate discrete intervals, over the entire measurement period.

Section 4.4, *Detailed Procedures*, provides directions regarding measurement period and frequency for each element of the previously introduced savings equation.

4.2.3 Measurement Equipment

When the BAS cannot provide enough information and submeters are necessary to obtain data, use these guidelines to select the appropriate meter:[14]

- Size the meter for the range of values expected most of the time.
- Select the meter repeatability and accuracy that fits the budget and intended use of the data.
- Install the meter as recommended by the manufacturer.
- Calibrate the meter before it goes into the field and maintain meter calibration, as recommended by the manufacturer. If possible, select a meter with a recommended calibration interval that is longer than the anticipated measurement period.
- If budget allows, consider installing submeters permanently.

If using BAS data, exercise due diligence by determining when the BAS was last calibrated and by checking the accuracy of the BAS measurement points.

Table 2 lists recommended levels of accuracy for the types of metering equipment used for chiller M&V (US DOE FEMP 2008).

[14] Further information on choosing meters can be found in the Uniform Methods Project's *Metering Cross-Cutting Protocols.*

Table 2. Recommended Meter Accuracies

Meter Type	Purpose	Accuracy of Meter
Flow meter	Chilled water flow (GPM)	± 2%
Immersion temperature sensors	Chilled water temperatures	± 0.3°F
Power meters	True RMS power (kW)	± 2%
Outdoor air temperature sensors	Outdoor air dry bulb temperatures	±1.0°F

4.2.4 Savings Uncertainty

If possible, quantify the accuracy of measured data[15] and, if practical, conduct an error propagation analyses to determine overall impacts on the savings estimate.

4.3 Interactive Effects

For projects evaluated using Option A, consider and estimate any significant interactive effects. Although significant interactive effects are uncommon for chiller measures, there are some scenarios that warrant consideration. For example, if a facility uses waste heat from a chiller plant (heat taken from the condenser loop) to satisfy coincident heating loads, then a chiller measure that increases the efficiency of the chiller plant will decrease the amount of waste heat available. In such cases, estimate interactive effects by using equations that apply the appropriate engineering principles.

Interactive effects for projects being verified using Option C or Option D are typically included in the facility-level savings estimates.

4.4 Detailed Procedures

This section lists the detailed steps required for using the recommended M&V approach (Option A) for chiller measures (specifically, for projects that impact both chillers and the chiller's auxiliary equipment).

4.4.1 Chillers

Table 3 presents the five-step procedure for determining the chiller savings term in Equation 1 ($\text{kWh Savings}_{\text{Total}} = \text{kWh Savings}_{\text{Chiller}} + \text{kWh Savings}_{\text{Auxiliary}}$). These steps cover the range of actions depending on:

- Whether the chiller plant is serving an HVAC load or a process load or
- Whether the plant has a single schedule or multiple operating schedules.

[15] Metering accuracy is only one element of savings uncertainty. Inaccuracies also result from modeling, sampling, interactive effects, estimated parameters, data loss, and measurements being taken outside of a meter's intended range.

Table 3. Chiller M&V Procedures

<table>
<tr><th>Step</th><th>Details</th></tr>
<tr><td>Develop load curve model(s) by measuring reporting period operation</td><td>To calculate chilled water load, use coincident measurements of chilled water flow (gpm), and chilled water supply and return temperatures (°F):

Cooling load (tons) = 500(gpm)(ΔT °F)/(12,000 BTUh/ton)

<u>For HVAC loads</u>: Take (or collect) short-term measurements at representative load levels for each season (summer, shoulder, winter) and for each schedule type, if applicable. Evaluator may also collect chilled water flow and chilled water temperatures by the BAS and calculated cooling load (BTUh or tons) directly by the BAS.
<u>For process loads</u>: Take continuous measurements over the length of each type of process cycle.

Additionally, collect the independent variable data:

<u>For HVAC loads</u>: Measure or collect coincident site-specific OAT dry-bulb and wet-bulb data.
<u>For process loads</u>: Measure or collect coincident process data.[a]

Conduct a regression analysis to determine the relationship between independent variables and cooling load—this relationship should be expressed in terms of an equation (load curve model). Evaluators may be required to run multiple regression models. For example, if the chiller plant is serving an HVAC load and has an occupied and an unoccupied schedule (e.g., an occupied cooling set point temperature, and an unoccupied cooling set point temperature), evaluators may require two regression models.</td></tr>
<tr><td><u>For HVAC Loads</u>: Develop a bin operating profile by typical meteorological year (TMY)[b] OAT data or, if possible, develop an hourly profile over the full operating schedule of the affected equipment

<u>For Process Loads</u>: Develop a bin operating profile by normalized process data</td><td>If a bin analysis is being used, develop bin data tables that present the following data (one table for each schedule type, if applicable):

HVAC Load
<table>
<tr><th>Independent Variable</th><th>Load</th><th>Annual Hours</th></tr>
<tr><td>Create approximately 10 OAT bins over the TMY data range</td><td>Calculate the normalized load by applying the load curve model to the midpoint of each temperature bin</td><td>Base this on TMY data and the chiller operating schedule</td></tr>
</table>

Process Load
<table>
<tr><th>Independent Variable</th><th>Load</th><th>Annual Hours</th></tr>
<tr><td>Create an appropriate number of process level bins for the given process parameter range</td><td>Calculate the normalized load by applying the load curve model to the midpoint of each bin</td><td>Use continuous measured data to estimate the hours of operation within each bin</td></tr>
</table>

If an hourly analysis is being used for HVAC loads, the normalized load for each hour should be calculated by applying the load curve model developed in Step 1. In this scenario, the subsequent analysis outlined in Steps 3 through 5 should be conducted on an hourly basis, rather than on a bin-by-bin basis.</td></tr>
</table>

Step	Details
Apply manufacturer part-load efficiency data to the bin data	Apply kilowatt/ton part-load efficiency data from manufacturer specification sheets to each bin and then calculate kilowatt-hour as follows: $kWh_{bin} = tons_{bin} \times hrs_{bin} \times kW/ton_{bin}$ Do this for the baseline (both existing and hypothetical if a dual baseline is applicable) and the new chiller *for each schedule type, if applicable.* The part-load efficiency data presented by manufacturers is typically calculated based on Air-Conditioning and Refrigeration Institute standard conditions. If available, use manufacturer efficiency data that adjusts for designer-specified evaporator and condenser entering and leaving water temperatures. *If part-load efficiency data does not align with bin mid-points, interpolate. *If part-load efficiency data does not exist for the baseline chiller, apply the integrated part load value (IPLV) to all bins.
Calculate kilowatt-hour savings for each bin for each schedule type	For each schedule type: $kWh\ Savings_{bin} = kWh_{bin,\ Baseline} - kWh_{bin,\ Reporting\ Period}$
Sum kilowatt-hour savings across all load bins for each schedule type	For each schedule type: $\sum_{Bin\ Data\ (Coolinlg\ Load) Range} kWh\ Savings_{Bin\ (Cooling\ Load)}$

[a] Production output is an example of an independent variable that commonly impacts manufacturing process energy use.
[b] Use the most recent typical meteorological year dataset. As of January 2014, the most comprehensive national typical meteorological year dataset is TMY3. Evaluators should confer with the local jurisdiction to see if they should use a different, regional, dataset instead.

4.4.2 Auxiliary Equipment

Table 4 lists additional steps for determining the auxiliary savings term in Equation 1 (kWh SavingsTotal = kWh SavingsChiller + kWh SavingsAuxiliary).

Table 4. Auxiliary Equipment M&V Procedures

Step	Details
Measure baseline[a] and reporting period auxiliary demand data	If the energy consumption of auxiliary equipment is constant, take spot measurements on the auxiliary equipment affected by the chiller measure. If consumption of auxiliary equipment is variable *and* the chiller plant is serving an HVAC load, take short-term measurements at representative load levels for auxiliary equipment affected by the chiller measure. If consumption of auxiliary equipment is variable *and* the chiller plant is serving a process load, take continuous measurements over the length of each type of process cycle for all auxiliary equipment affected by the chiller measure. If more than one piece of auxiliary equipment is affected, the measurements across affected equipment should be coincident.
Develop bin data and sum the kilowatt-hour savings	Bin baseline and reporting period data using bin profiles established for the chiller (if consumption of auxiliary equipment is constant—as it might likely be for the baseline scenario; kilowatts will be the same for all bins). Calculate kilowatt-hour savings by bin and sum as described in Table 3.

[a] If auxiliary equipment is replaced as part of a replace-on-burnout or natural turnover project, the building code could require upgrades to the auxiliary equipment. If this is the case, establish a hypothetical baseline for the affected auxiliary equipment.

4.5 Regression Modeling Direction

Calculating normalized savings for the majority of projects—whether following the IPMVP's Option A or Option C—will require the development of a baseline and reporting period regression model.[16] Use one of the following three types of analysis methods to create the model:

- **Linear regression:** For one routinely varying significant parameter (e.g., OAT).[17]
- **Multivariable linear regression:** For more than one routinely varying significant parameter (e.g., OAT, process parameter).
- **Advanced regression:** For a multivariable, nonlinear fit requiring a polynomial or exponential model.[18]

Develop all models in accordance with common practices and only use them when statistically valid (see Section 4.5.2, *Testing Model Validity*). If there are no significant independent variables (as would be the case for a constant-process cooling load), evaluators are not required to use a model because the calculated savings are inherently normalized.

[16] This could either be a single regression model that uses a dummy variable to differentiate the baseline/reporting period data or two independent models for the baseline and reporting period, respectively.
[17] One of the most common linear regression models is the three-parameter change point model. For example, a model that represents cooling electricity consumption will 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.
[18] Evaluators may need to use advanced regression methods if a chiller plant is providing cooling for manufacturing or industrial processes.

4.5.1 Recommended Method for Model Development

Use cooling-load data and independent-variable data that are representative of a full cycle of operation to the maximum extent possible. For example, if a chiller plant located in New England is serving an HVAC load with a temperature adjustment during unoccupied hours, then collect load data across the full range of outdoor air temperatures for each of the operating schedules (occupied and unoccupied) for each season. Table 5 provides an example of the data required for model development.

Table 5. Example of Data Required for Model Development

	Shoulder Season	Summer Season
Occupied Hours	Short-term load measurements during occupied hours. Measurements should be representative of full range of shoulder season OAT (approximately 10 OAT bins).	Short-term load measurements during occupied hours. Measurements should be representative of full range of summer season OAT (approximately 10 OAT bins).
Unoccupied Hours	Short-term load measurements during unoccupied hours. Measurements should be representative of full range of shoulder season OAT (approximately 10 OAT bins).	Short-term load measurements during unoccupied hours. Measurements should be representative of full range of summer season OAT (approximately 10 OAT bins).

Analyze the data collected to identify outliers. Only remove outliers when there is a tangible explanation to support the erratic data points. Discussion of how to identify outliers is outside the scope of this protocol.

4.5.2 Testing Model Validity

To assess the accuracy of the model, begin by reviewing the parameters listed in Table 6 (EVO 2012).

Table 6. 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 variations in the dependent variable from its mean value.	> 0.75
T-statistic (absolute value)	An indication of whether the regression model coefficients are statistically significant.	> 2[a]
Mean bias error	An indication of whether the regression model overstates or understates the actual cooling load.	Will depend on the project, but generally: <± 5%

[a] Determine the t-statistic threshold based on the evaluator's chosen confidence level; a 95% confidence level requires a t-statistic of 1.96. Evaluators should determine an acceptable confidence level depending on project risk (i.e., savings risk), budget, and other considerations.

A model outside the suggested range indicates parameter coefficients that are relatively poorly determined, with the result that normalized consumption will have relatively high statistical prediction error. Ordinarily, evaluators should not use such a model 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 this protocol.

When possible, attempt to enhance the regression model by:

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

Also, when assessing model validity, consider the coefficient of variation (CV) of the root mean squared error (RMSE), fractional savings uncertainty, and residual plots. Refer to ASHRAE Guideline 14-2002 and Bonneville Power Administration's *Regression for M&V: Reference Guide* for direction on how assess these additional parameters.

5 Sample Design

Consult the Uniform Methods Project's *Chapter 11: Sample Design Cross-Cutting Protocol* for general sampling procedures if the chiller project population is sufficiently large or if the evaluation budget is constrained. Ideally, use stratified sampling to partition chiller projects by facility type, process vs. HVAC load, and/or the magnitude of claimed (*ex ante*) project savings. Stratification ensures evaluators can confidently extrapolate sample findings to the remaining project population. Regulatory or program administrator specifications typically govern the confidence and precision targets, which will influence sample size.

6 Other Evaluation Issues

When claiming lifetime and net program chiller measure impacts, consider the following evaluation issues in addition to first-year gross impact findings:

- Net-to-gross estimation
- Early replacement
- Dual baseline realization rates.

6.1 Net-to-Gross Estimation

The Uniform Methods Project's cross-cutting *Estimating Net Savings: Common Practices* discusses an approach for determining net program impacts at a general level. It is recommended that the collection between gross and net impact results and teams collecting site-specific impact data to ensure there is no double counting of adjustments to impacts at a population level.

6.2 Early Replacement

As a supplement to the Uniform Methods Project's *Estimating Net Savings: Common Practices*, the evaluator should consider assessing whether early replacement projects were program-induced. If the early replacement was not program-induced, it is appropriate to use a hypothetical baseline rather than a dual baseline.

6.3 Dual-Baseline Realization Rates

For program-induced early replacement projects, two different realization rates (evaluated [*ex post*] gross savings/claimed [*ex ant*e] gross savings) exist over the EUL of the new equipment:

- **Period 1 Realization Rate.** The realization rate is applicable over the first part of the dual baseline; evaluators should calculate the gross *ex pos*t savings using the existing equipment as the baseline.
- **Period 2 Realization Rate.** The realization rate is applicable over second part of the dual baseline; evaluators should calculate the gross *ex post* savings using a hypothetical baseline.

Therefore, if reporting life cycle gross impact findings, evaluators need to account for both Period 1 and Period 2 realization rates.

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