

Chiller Evaluation Protocol

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1 Measure Description

For the purposes of this protocol, a chiller retrofit is defined 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. Thermal energy storage (TES) and absorption chillers fired by natural gas or steam are not included in this protocol, although a similar methodology may be applicable to these chilled water system components.¹

Chillers provide mechanical cooling for commercial, institutional, multi-unit 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, refrigeration equipment in grocery stores, manufacturing process cooling).

The vapor compression cycle², 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 described in Table 1, the most common types of chillers are defined by the compressors they use (ASHRAE, 2008).

Table 1. Three Common Chiller Types

Chiller Type	Description
Reciprocating and Screw	Reciprocating and screw chillers use positive-displacement compressors. These compressors increase refrigerant vapor pressure by reducing the volume of the compression chamber. <ul style="list-style-type: none">• Reciprocating chillers compress air using pistons, and• Screw chillers compress air using either single- or twin-screw rotors with helical grooves.
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:

¹ As discussed in *Considering Resource Constraints* in the “Introduction” 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 The vapor compression cycle consists of four main components: an evaporator, a compressor, a condenser, and an expansion valve.

- *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).

2 Application Conditions of Protocol

Chiller energy-efficiency activities may be undertaken alone, but they are often implemented under broader commercial, multi-unit residential, or industrial custom programs. Since chiller savings often occur at the same time as electricity system peaks are experienced in many jurisdictions, savings from these projects can have a significant impact on a custom program’s summer peak demand savings.

Energy-efficiency programs are designed 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 best practice detailed 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 best-practice, investment-grade energy audits.
- *Development incentives.* Program administrators sometimes provide incentives that encourage end users to undertake detailed feasibility studies for chiller retrofit projects. Incentives are intended to 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 retrofit project.
- *Implementation incentives.* Program administrators often provide incentives to implement chiller retrofit projects. Incentives are intended to encourage end users to invest more capital up front 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 retrofit projects 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 equation³ that applies to all chiller retrofit measures. Detailed direction on how to apply this equation is presented under the Measurement and Verification Plan section of this protocol.

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.

Savings should be determined using the following general equation (US DOE FEMP, 2008).

Equation 1

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

Where,

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

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

And,

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

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

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, 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 can be applied to consumption savings data.
- *Process loads.* Since 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. Evaluators should produce project-specific load savings profiles and then apply regional peak coincidence factors, if applicable, or target specific periods or weather conditions to accurately determine savings during the peak demand periods.

3.1 Determining Baseline Consumption

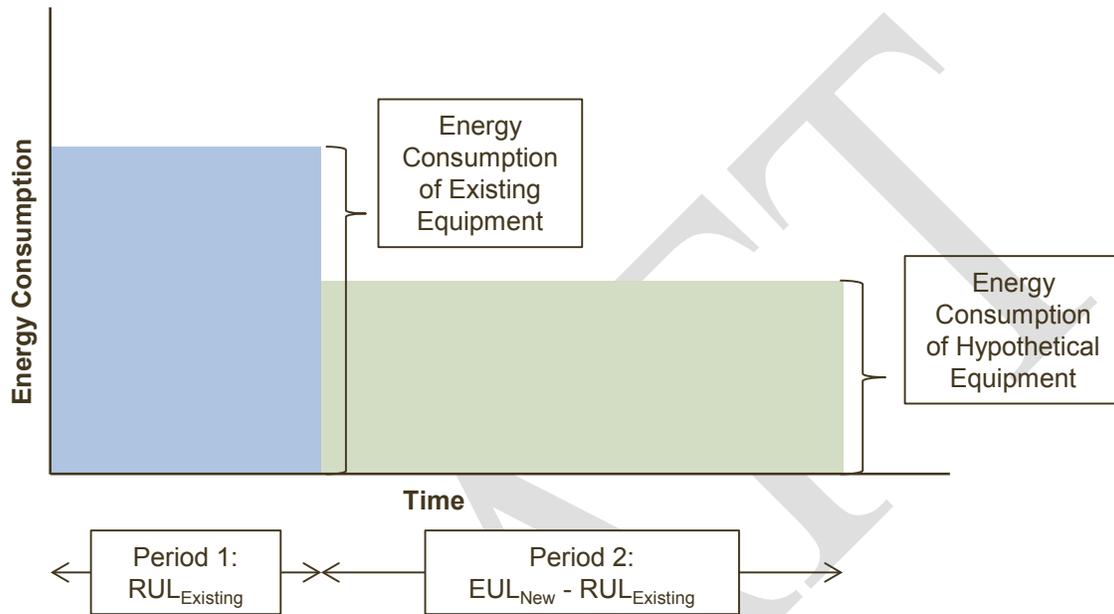
A common issue for many chiller programs is the use of existing equipment in determining the baseline for establishing project savings claims. The following discussion explains why this is not always the correct baseline.

There are three main replacement scenarios (Fagan et al., 2011) that should be considered to establish an appropriate baseline:

- *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.* The equipment is being replaced 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, it is appropriate to establish a hypothetical baseline that uses a new chiller meeting the applicable energy efficiency standard⁴ for the jurisdiction where the project is being undertaken. The hypothetical baseline should also consider industry standard practice 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.

The EUL of chiller equipment should be defined by regional technical reference manuals, as available, or other secondary sources.⁵ Also, the RUL of baseline chiller equipment is simply the EUL minus the current age of the chiller (or number of years since its last re-build⁶).

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. The information is presented under the following headings:

- Measurement and Verification (M&V) Method
- Data Collection

⁴ ANSI/ASHRAE Standard 90.1 is an example of a widely recognized energy efficiency standard.

⁵ California's Database for Energy Efficient Resources (DEER) suggests an EUL of 20 years for chillers (CPUC, 2008).

⁶ Evaluators should use discretion regarding the scope of the re-build and how it may impact the RUL of the chiller.

- Interactive Effects
- Detailed Procedures
- Regression Model Direction

4.1 M&V 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, Option A (retrofit isolation – key parameter measurement) is the preferred method 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, control points may be added to the BAS, either as part of the implementation process or specifically for M&V purposes. Where the BAS cannot provide information, use temporary meters and data loggers to collect data, provided that the cost is not prohibitive.

To ensure that 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), two alternate approaches—IPMVP’s Option C and Option D—may be considered.

- *Option C.* – Consider a whole-facility approach 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 level⁹. This approach is relatively inexpensive since it involves an analysis of facility consumption data. The downside is that verification cannot be undertaken until a full season or year of reporting period data has been collected, and any changes to the facility’s static factors¹⁰ over the course of the measurement period need to be carefully monitored and documented. 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 in order to increase the accuracy of billing data analyses.

⁷ Note that even though reporting period efficiency data can be measured, under a hypothetical baseline scenario it is generally best practice to use pre- and post-installation 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 that the BAS is well maintained by qualified service personnel. 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 in order to confidently discriminate the savings from the baseline data when the reporting period is shorter than two years.

¹⁰ Many factors can affect a facility’s energy consumption, even though we 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.

- *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. Calibration should be undertaken in two ways: (1) the simulation should be calibrated to actual baseline or reporting period consumption data, and (2) the reporting period inputs should be confirmed via the BAS front-end system or the chiller control terminal, when possible.^{11 12}

4.2 Data Collection

When chiller measures are being assessed via Option A (the preferred approach), these M&V elements require particular consideration: the measurement boundary, the measurement period and frequency, the functionality of measurement equipment being used, and the 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, the location and number of measurement points required, the project's complexity and expected savings should be considered:

- A narrow boundary simplifies data measurement (e.g. chiller plant equipment directly affected by the retrofit), but any variables driving energy use outside the boundary (interactive effects¹³) will need to be accounted for;
- A wide boundary will minimize interactive effects and increase accuracy. However, since M&V costs may also increase, it is important to ensure that the expected increase in accuracy of project savings justify this cost increase.

4.2.2 Measurement Period and Frequency

These important timing metrics require consideration: (1) the measurement period; and (2) the measurement frequency. In general:

- The measurement period (the length of the baseline and reporting periods) should be chosen to capture a full cycle of each operating mode. For example, if a chiller is serving an HVAC load, data should be collected over the summer, shoulder, and winter seasons (if applicable).
- The measurement frequency (how regularly measurements are taken during the measurement period) should be chosen by assessing the type of load being measured:
 - *Spot Measurement.* For constant loads (e.g., constant speed chilled water pumps), power can be measured briefly, preferably over two or more intervals.

¹¹ In many cases, the simulation should represent the entire facility; however, in some cases, depending on the facility's wiring structure, a similar approach could be applied to building sub-meters, such as distribution panels that include the affected systems.

¹² See chapter on Commercial New Construction for more information on using Option D

¹³ Although significant interactive effects are uncommon for chiller retrofit projects, there are some scenarios that warrant consideration. See section 4.3 for further detail.

- *Short-Term Measurement.* For loads predictably influenced by independent variables (e.g., chiller compressors serving HVAC loads), short-term consumption measurements should be taken 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), consumption data should be measured continuously, or at appropriate discrete intervals, over the entire measurement period.

The directions regarding measurement period and frequency for each element of the previously introduced savings equation are provided below under Detailed Procedures.

4.2.3 Measurement Equipment

When the BAS cannot provide enough information and temporary meters are required, 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.

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

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

Accuracy of measured data should¹⁵ be quantified, if possible, and an error propagation analyses should be undertaken 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 retrofit projects, there are some scenarios that warrant consideration. For example, if waste heat from a chiller plant (heat taken from the

¹⁴ Further information of choosing meters can be found in Metering cross-cutting chapter

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.

condenser loop) is used to satisfy coincident heating loads in the facility, then a retrofit project 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 to consider, 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.

Table 3. Chiller M&V Procedures

Step	Details												
<p>1. Develop load curve model(s) by measuring reporting period operation.</p>	<p>To calculate chilled water load, use coincident measurements of chilled water flow (gpm), and chilled water supply and return temperatures (°F):</p> $\text{Cooling Load (tons)} = 500(\text{gpm})(\Delta T \text{ } ^\circ\text{F}) / (12,000 \text{ BTUh/ton})$ <p><u>For HVAC loads:</u> Take (or collect) short-term measurements at representative load levels for each season (summer, shoulder, winter) and <i>for each schedule type, if applicable</i>. Chilled water flow and chilled water temperatures may be collected by the BAS; cooling load (BTUh or tons) also may be calculated directly by the BAS.</p> <p><u>For Process loads:</u> Continuous measurements should be taken over the length of each type of process cycle.</p> <p>Independent variable data should also be collected:</p> <p><u>For HVAC loads:</u> Coincident OAT dry bulb (DB) and wet bulb (WB) data should be measured or collected.</p> <p><u>For Process loads:</u> Coincident process data should be measured or collected.</p> <p>Regression analysis should be undertaken to determine the relationship between independent variables and cooling load – this relationship should be expressed in terms of an equation (load curve model). <i>Multiple regression models may be required. For example, if the chiller plant is serving an HVAC load, and there is an occupied and an unoccupied schedule (e.g. an occupied cooling set point temperature, and an unoccupied cooling set point temperature), two regression models may be required.</i></p>												
<p>2. Develop a bin operating profile¹⁶ by typical meteorological year (TMY) OAT data or by normalized process data.</p>	<p>Develop bin data tables that present the following data (<i>one table for each schedule type, if applicable</i>):</p> <p>HVAC Load</p> <table border="1" data-bbox="488 1251 1477 1461"> <thead> <tr> <th data-bbox="488 1251 824 1293">Independent Variable</th> <th data-bbox="824 1251 1159 1293">Load</th> <th data-bbox="1159 1251 1477 1293">Annual Hours</th> </tr> </thead> <tbody> <tr> <td data-bbox="488 1293 824 1461">Create approximately 10 OAT bins over the TMY data range.</td> <td data-bbox="824 1293 1159 1461">Calculate the normalized load by applying the load curve model to the mid-point of each temperature bin.</td> <td data-bbox="1159 1293 1477 1461">Base this on TMY data and the chiller operating schedule.</td> </tr> </tbody> </table> <p>Process Load</p> <table border="1" data-bbox="488 1503 1477 1707"> <thead> <tr> <th data-bbox="488 1503 824 1545">Independent Variable</th> <th data-bbox="824 1503 1159 1545">Load</th> <th data-bbox="1159 1503 1477 1545">Annual Hours</th> </tr> </thead> <tbody> <tr> <td data-bbox="488 1545 824 1707">Create an appropriate number of process level bins for the given process parameter range.</td> <td data-bbox="824 1545 1159 1707">Calculate the normalized load by applying the load curve model to the mid-point of each bin.</td> <td data-bbox="1159 1545 1477 1707">Use continuous measured data to estimate the hours of operation within in each bin.</td> </tr> </tbody> </table>	Independent Variable	Load	Annual Hours	Create approximately 10 OAT bins over the TMY data range.	Calculate the normalized load by applying the load curve model to the mid-point of each temperature bin.	Base this on TMY data and the chiller operating schedule.	Independent Variable	Load	Annual Hours	Create an appropriate number of process level bins for the given process parameter range.	Calculate the normalized load by applying the load curve model to the mid-point of each bin.	Use continuous measured data to estimate the hours of operation within in each bin.
Independent Variable	Load	Annual Hours											
Create approximately 10 OAT bins over the TMY data range.	Calculate the normalized load by applying the load curve model to the mid-point of each temperature bin.	Base this on TMY data and the chiller operating schedule.											
Independent Variable	Load	Annual Hours											
Create an appropriate number of process level bins for the given process parameter range.	Calculate the normalized load by applying the load curve model to the mid-point of each bin.	Use continuous measured data to estimate the hours of operation within in each bin.											

¹⁶ Alternatively, if the independent variable is OAT, an hourly profile could be developed over the full operating schedule of the affected equipment.

Step	Details
3. Apply manufacturer part-load efficiency data to the bin data.	<p>Apply kW/ton part-load efficiency data from manufacturer specification sheets to each bin and then calculate kWh as follows:</p> $kWh_{bin} = tons_{bin} \times hrs_{bin} \times kW/ton_{bin}$ <p>Do this for the baseline (both existing and hypothetical if a dual-baseline is applicable) and the post-retrofit chiller <i>for each schedule type, if applicable</i>. *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 IPLV to all bins.</p>
4. Calculate kWh savings for each bin for each schedule type.	<p>For each schedule type:</p> $kWh\ Savings_{bin} = kWh_{bin, Baseline} - kWh_{bin, Reporting\ Period}$
5. Sum kWh savings across all load bins for each schedule type.	<p>For each schedule type:</p> $\sum_{Bin\ Data\ (Cooling\ Load)Range} kWh\ Savings_{Bin\ (Cooling\ Load)}$

4.4.2 Auxiliary Equipment

Table 4 lists additional steps for determining the auxiliary savings term in Equation 1 ($kWh\ Savings_{Total} = kWh\ Savings_{Chiller} + kWh\ Savings_{Auxiliary}$).

Table 4. Auxiliary Equipment M&V Procedures

Step	Details
1. Measure baseline and reporting period auxiliary demand data	<ul style="list-style-type: none"> • If the energy consumption of auxiliary equipment is constant, take spot measurements on the auxiliary equipment affected by the retrofit. • If consumption of auxiliary equipment is variable <i>and</i> the chiller plant is serving an HVAC load, take short-term measurements at representative load levels for auxiliary equipment affected by the retrofit. • If consumption of auxiliary equipment is variable <i>and</i> 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 retrofit. • If more than one piece of auxiliary equipment is affected, the measurements across affected equipment should be coincident.
2. Develop bin data and sum the kWh savings	<p>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, kW will be the same for all bins).</p> <p>Calculate kWh savings by bin and sum as described in Table 3.</p>

4.5 Regression Modeling Direction

To calculate normalized savings, whether following the IPMVP’s Option A, Option C, or Option D, the baseline and reporting period regression model¹⁷ will need to be developed for the majority of projects. There are three types of analysis methods that can be used to create a model:

- *Linear Regression*: For one routinely varying significant parameter (e.g., OAT)¹⁸.
- *Multivariable Linear Regression*: For more than one routinely varying significant parameter (e.g., OAT, process parameter).
- *Advanced Regression*: Such as polynomial or exponential¹⁹.

When required, these models should be developed in accordance with best practices, and they should only be used when they are statistically valid (see subsection 4.5.2, Testing Model Validity). If there are no significant independent variables (as would be the case for a constant-process cooling load), no model is required, because the calculated savings will be inherently normalized.

4.5.1 Best Practice 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 illustrates this.

Table 5. Example of Data Required for Model Development

	Shoulder Season	Summer Season
Occupied Hrs	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 Hrs	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).

The data collected should be analyzed to identify outliers. This involves employing approaches such as the cumulative sum (CUSUM)²⁰ of differences technique or visually inspecting a plot of the cooling

¹⁷ 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.

¹⁸ 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.

¹⁹ Advanced regression methods might be required if a chiller plant is providing cooling for manufacturing or industrial processes.

²⁰ The CUSUM technique involves running the independent variable data through the model and comparing its cooling load outputs to the actual cooling load data. The differences are summed over the range of independent variable inputs. If there are

load data versus the independent variable data. Outliers should typically only be removed if a tangible explanation is provided to support the erratic data points.

4.5.2 Testing Model Validity

To assess the accuracy of the model, review 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 variations in the dependent variable from its mean value are explained by the regression model.	> 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.	Will depend on the project, but generally: < +/- 5%

If any of these parameters fall outside their acceptable range, the regression model is not considered statistically valid, and should not be used to normalize data. When possible, attempts should be made to enhance the regression model by increasing or shifting the measurement period; by incorporating more data points; by including independent variables that were previously unidentified; or by eliminating statistically insignificant independent variables.

5 Sample Design

Chapter 11: *Sample Design* describes general sampling procedures that should be consulted if the chiller project population is sufficiently large, or if the evaluation budget is constrained. Ideally, stratified sampling should be undertaken by partitioning chiller projects by facility type, process vs. HVAC load, and/or the magnitude of ex-ante project savings. This stratification 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 lifetime and net program chiller measure impacts, the following evaluation issues should be considered in addition to first-year gross impact findings:

- Net-to-Gross Estimation
- Early Replacement
- 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. Best practices include close coordination between gross and net impact results and teams

no significant outliers, the plotted sum of differences should be a horizontal line intersecting zero on the y-axis (i.e., the differences should be insignificant).

collecting site specific impact data to ensure that there is no double counting of adjustments to impacts at a population level.

6.2 Early Replacement

As a supplement to this general section, the evaluator may want to consider assessing whether early replacement projects were program-induced. If the early replacement was not program-induced, it would be 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 (ex-post gross savings / ex-ante gross savings) exist over the EUL of the new equipment.

- The *Period 1* realization rate is applicable over the first part of the dual baseline; where the gross ex-post savings are calculated using the existing equipment as the baseline.
- The *Period 2* realization rate is applicable over second part of the dual baseline; where the gross ex-post savings are calculated using a hypothetical baseline.

Therefore, if lifecycle gross impact findings need to be reported, both Period 1 and Period 2 realization rates should be taken into account.

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