~~Chiller Evaluation Protocol~~

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~~1 Measure Description~~

~~For the purposes~~

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Chapter *n*: Chiller Evaluation Protocol

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

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1 Measure Description

This protocol~~,~~ defines a chiller ~~retrofit is defined~~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. ~~Thermal~~It does not include 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.

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

The vapor compression cycle,[1] ~~,~~ 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~~listed in ~~Table 1,~~Table 1, ASHRAE standards and guidelines define the most common types of chillers ~~are defined~~ by the compressors they use (ASHRAE~~, 2008~~ 2012).

Table 1. ~~Three~~Four Common Chiller Types

Chiller Type	Description
Reciprocating, Screw, and ~~Screw~~Scroll	Reciprocating, screw, and ~~screw~~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~~, and~~ ~~Screw~~; 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:

[1] 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~~ A program may address chiller energy-efficiency activities ~~may be undertaken~~ alone, but ~~they are~~more often ~~implemented under~~, broader commercial, ~~multi-unit~~multiunit residential, or industrial custom programs~~. Since~~ will include these activities. As chiller savings often occur at the same time ~~as~~many jurisdictions experience 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~~Service providers and other stakeholders design 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 detailed 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~~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 ~~retrofit project~~measure.

- **Implementation incentives.** Program administrators often provide incentives to implement chiller ~~retrofit projects. Incentives are intended to~~measures. Again, ideally, the incentives can encourage end users to invest more capital ~~up front~~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 ~~retrofit projects~~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[2] that applies to all chiller ~~retrofit~~ measures. ~~Detailed~~Section 4, *Measurement and Verification Plan*, provides detailed direction on how to apply this equation ~~is presented under the Measurement and Verification Plan section of this protocol~~.

~~Savings should be determined using~~Use the following general equation to determine savings (US DOE FEMP~~,~~ 2008).

Equation 1

$$kWh\ Savings_{Total} = (kWh\ Savings_{Chiller}) + (kWh\ Savings_{Auxiliary})$$

Where,

$kWh\ Savings_{Total}$ = First-year energy consumption savings

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

And,

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

$kWh_{Reporting,\ Cooling\ Load}$ = 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 ~~can be applied~~ to consumption savings data.
- **Process loads.** ~~Since~~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. ~~Evaluators should~~First, produce project-specific load savings profiles and then apply ~~regional peak~~ site-specific coincidence factors~~, if~~

[2] 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.

applicable, or target specific periods or weather conditions to accurately determine savings during thecoincident peak demand periodssavings.

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

- **Early *Replacement*replacement.** Existing equipment has a remaining useful life (RUL).
- **Replace-on-*Burnout*burnout.** The effective useful life (EUL) of the existing equipment has expired.
- **Natural *Turnover.* Theturnover.** Replacement of 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.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 standard[3] for the applicable jurisdiction where the project is being undertaken. . The hypothetical baseline should also consider industry standard practicepractices and the existing equipment, which may set higher efficiency levels than the applicable energy--efficiency standards.

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

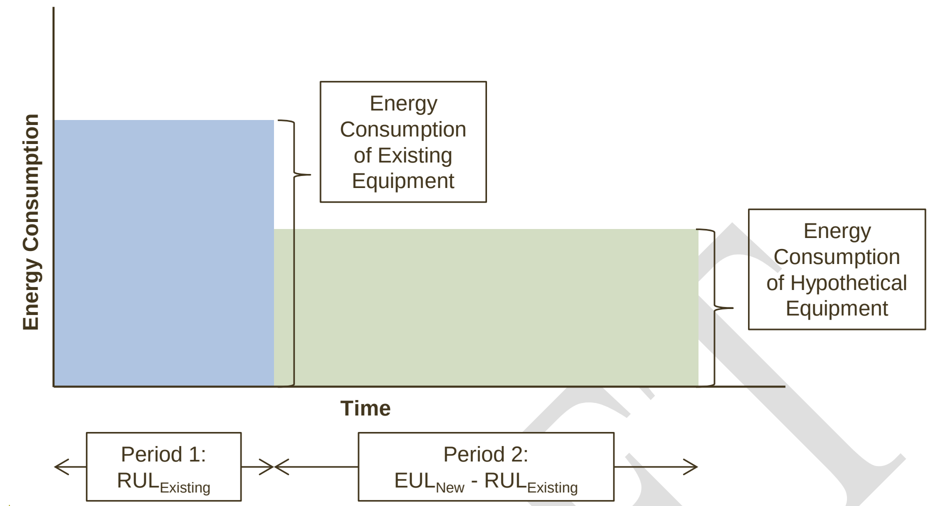
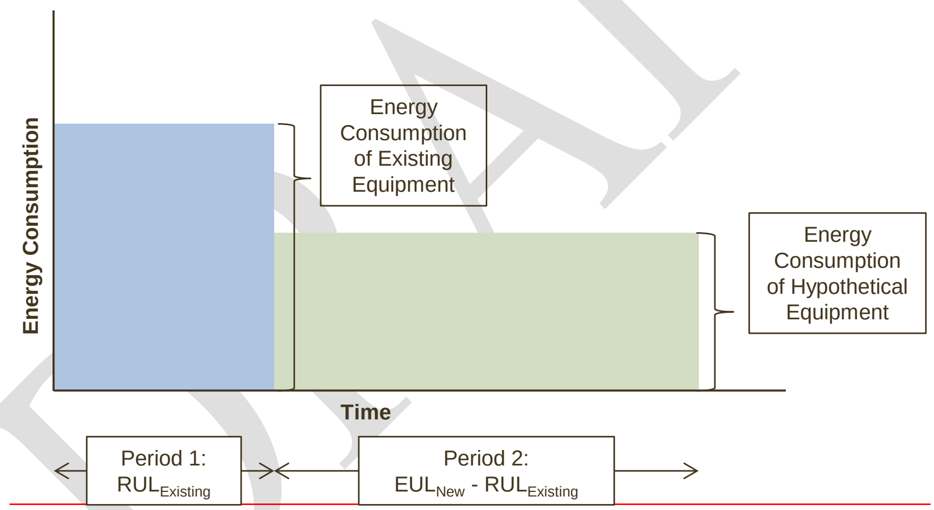


Figure 1. Dual~~-Baseline~~ baseline



As shown in ~~Figure 1~~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.

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The As available, use the program defined EUL offor chiller equipment should be defined by or consult regional technical reference manuals, as (TRM); when program or TRM information is not available, oruse other secondary sources.[4] Also,Similarly, use the method defined by the program to determine the RUL of baseline chiller equipment is simply. If this has not been previously established, consider defining RUL as the ,difference between the EUL minus theand current age of the chiller (or number of years since its last re-buildrebuild)[5]).

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

[5] Evaluators should use discretion regarding the scope of the re-buildrebuild 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~~. The information is presented~~ under the following headings:

- Measurement and ~~Verification~~verification (M&V) ~~Method~~method
- Data ~~Collection~~collection
- Interactive ~~Effects~~effects
- Detailed ~~Procedures~~procedures
- Regression ~~Model Direction~~model direction.

4.1 ~~M&V~~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) ~~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.[6]

In some cases, metered data may be available directly from the facility's building automation system (BAS~~)~~).[7]~~.~~ Also, if required, the facility can add 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~~the protocol recommends using submeters 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), consider two alternate approaches—IPMVP's Option C and Option D~~—may be considered~~.

- **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

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[6] ~~Note that even~~Even though ~~reporting period~~evaluators can measure efficiency data ~~can be measured~~for the reporting period, under a hypothetical baseline scenario it is generally best practice to use pre- and ~~post-installation~~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.

[7] It is important to ensure ~~that the BAS is well maintained by~~ qualified service personnel~~.~~ maintain the BAS. Transducers that are out of calibration, or simply broken, could significantly impact M&V results.

the whole~~-~~-facility level.[8]~~.~~ This approach is relatively inexpensive ~~since~~because it involves an analysis of facility consumption data. The downside is ~~that~~evaluators cannot perform verification ~~cannot be undertaken~~ until after collecting a full season or year of reporting period data ~~has been collected, and~~and monitoring and documenting any changes to the facility's static factors[9] 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.

- **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~~Undertake calibration in two ways: (1) calibrate the simulation ~~should be calibrated~~ to actual baseline or reporting period consumption data~~,~~ and (2) confirm the reporting period inputs ~~should be confirmed~~ via the BAS front-end system or the chiller control terminal, when possible.[10,11]

4.2 Data Collection

When ~~chiller measures are being assessed via~~using Option A (the preferred approach~~), these~~) to assess chiller measures, the following M&V elements require particular consideration: ~~the measurement~~

- Measurement boundary~~, the measurement~~
- Measurement period and frequency~~, the functionality~~
- Functionality of the measurement equipment ~~being used, and the savings~~
- Savings uncertainty.

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[8] 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~~.~~ (EVO 2012).

[9] Many factors can affect a facility's energy consumption~~,~~ even though ~~we~~evaluators do not expect them to change. These factors are known as ~~'~~"static ~~factors'~~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.

[10] 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 ~~could be applied~~ to building ~~sub-meters~~submeters, such as distribution panels that include the affected systems.

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

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 ~~should be considered~~:

- A narrow boundary simplifies data measurement (e.g~~.~~., chiller plant equipment directly affected by the ~~retrofit), but~~chiller measure), but will require accounting for any variables driving energy use outside the boundary (interactive effects[12]~~) will need to be accounted for;~~)[13]
- 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 the accuracy of the project savings ~~justify this~~justifies the M&V cost increase.

4.2.2 Measurement Period and Frequency

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

- ~~The~~Choose 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, collect data ~~should be collected~~ over the summer, shoulder, and winter seasons (if applicable).
- ~~The~~Choose the measurement frequency (~~how regularly~~ the regularity of measurements ~~are taken~~ during the measurement period) ~~should be chosen~~ by assessing the type of load ~~being measured:~~:
  - **Spot ~~*Measurement*~~measurement.** For constant loads (e.g., constant~~-~~-speed chilled water pumps), measure power ~~can be measured~~ briefly, preferably over two or more intervals.
  - **Short-~~*Term Measurement*~~term measurement.** For loads predictably influenced by independent variables (e.g., chiller compressors serving HVAC loads), take 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*~~measurement.** For variable loads (e.g., chiller compressors serving process loads), measure consumption data ~~should be~~

~~[12] Although significant interactive effects are uncommon for chiller retrofit projects, there are some scenarios that warrant consideration. See section 4.3 for further detail.~~

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

~~measured~~ continuously, or at appropriate discrete intervals, over the entire measurement period.

~~The~~Section 4.4, *Detailed Procedures*, provides 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~~submeters are ~~required~~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.
- ~~Table 2 presents~~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).

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~~3°F
Power meters	True RMS ~~Power~~power (kW)	± 2%
Outdoor air temperature sensors	Outdoor air dry-bulb temperatures	±1.~~0°F~~0°F

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

4.2.4 Savings Uncertainty

~~Accuracy~~If possible, quantify the accuracy of measured data~~ should~~[15]~~ be quantified~~[16] and, if ~~possible, and~~practical, conduct 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~~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) ~~is used~~ to satisfy coincident heating loads~~ in the facility~~, then a ~~retrofit project~~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~~Table 3 presents the five-step procedure for determining the chiller savings term in Equation 1 (kWh $\text{Savings}_{\text{Total}}$ = kWh $\text{Savings}_{\text{Chiller}}$ + kWh $\text{Savings}_{\text{Auxiliary}}$). 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.

[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.~~

[16] 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

Step	Details
~~1.~~ Develop load curve model(s) by measuring reporting period operation~~.~~	To calculate chilled water load, use coincident measurements of chilled water flow (gpm), and chilled water supply and return temperatures (~~°F~~ F): Cooling ~~Load~~load (tons) = 500(gpm)(ΔT ~~°F~~ F)/(12,000 BTUh/ton) For HVAC loads: Take (or collect) short-term measurements at representative load levels for each season (summer, shoulder, winter) and *for each schedule type, if applicable.* ~~Chilled~~Evaluator may also collect chilled water flow and chilled water temperatures ~~may be collected~~ by the BAS~~;~~ and calculated cooling load (BTUh or tons) ~~also may be calculated~~ directly by the BAS. For ~~Process~~process loads: ~~Continuous~~Take continuous measurements ~~should be taken~~ over the length of each type of process cycle. ~~Independent~~ Additionally, collect the independent variable data ~~should also be collected~~: For HVAC loads: ~~Coincident~~Measure or collect coincident site-specific OAT dry~~-~~-bulb ~~(DB)~~ and wet~~-~~-bulb ~~(WB)~~ data ~~should be measured or collected~~. For ~~Process~~process loads: ~~Coincident~~Measure or collect coincident process data ~~should be measured or collected.~~.[a] ~~Regression~~ Conduct a 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). *~~Multiple~~Evaluators may be required to run multiple regression models ~~may be required.~~. For example, if the chiller plant is serving an HVAC load~~,~~ and ~~there is~~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 ~~may be required~~.*

<table>
<tr><th>Step</th><th>Details</th></tr>
<tr><td>~~2.~~ For HVAC Loads:
Develop a bin operating profile~~[17]~~ by typical meteorological year (TMY)[b] OAT data or, if possible, develop an hourly profile over the full operating schedule of the affected equipment

For Process Loads:
Develop a bin operating profile by normalized process data~~.~~</td><td>~~Develop~~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 ~~mid-point~~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 ~~mid-point~~midpoint of each bin~~.~~</td><td>Use continuous measured data to estimate the hours of operation within ~~in~~ 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>
<tr><td>~~3.~~ Apply manufacturer part-load efficiency data to the bin data~~.~~</td><td>Apply ~~kW~~kilowatt/ton part-load efficiency data from manufacturer specification sheets to each bin and then calculate ~~kWh~~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 ~~post-retrofit~~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.</td></tr>
</table>

~~[17] Alternatively, if the independent variable is OAT, an hourly profile could be developed over the full operating schedule of the affected equipment.~~

Step	Details
~~4.~~ Calculate ~~kWh~~kilowatt-hour savings for each bin for each schedule type~~.~~	For each schedule type: $kWh\ Savings_{bin} = kWh_{bin,\ Baseline} - kWh_{bin,\ Reporting\ Period}$
~~5.~~ Sum ~~kWh~~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~~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
~~1.~~ Measure ~~baseline~~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 ~~retrofit~~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 ~~retrofit~~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 ~~retrofit~~chiller measure. 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~~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~~, kW~~; kilowatts will be the same for all bins). Calculate ~~kWh~~kilowatt-hour savings by bin and sum as described in ~~Table 3~~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

~~To calculate~~Calculating normalized savings~~,~~ for the majority of projects—whether following the IPMVP's Option A~~, Option C,~~ or Option ~~D, the~~C—will require the development of a baseline and reporting period regression model[~~18~~] ~~will need to be developed for the majority of projects. There are~~.[19] Use one of the following three types of analysis methods ~~that can be used~~ to create ~~a~~the model:

- **Linear** ***~~Regression~~*****regression:** For one routinely varying significant parameter (e.g., OAT~~)~~).[20]~~.~~
- **Multivariable** ***~~Linear Regression~~*****linear regression:** For more than one routinely varying significant parameter (e.g., OAT, process parameter).
- **Advanced** ***~~Regression:~~*** ~~Such as~~**regression:** For a multivariable, nonlinear fit requiring a polynomial or exponential model.[21]~~.~~

~~When required, these~~

Develop all models ~~should be developed~~ in accordance with best practices~~,~~ and ~~they should~~ only ~~be used~~use them when ~~they are~~ statistically valid (see ~~subsection~~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), ~~no model is~~evaluators are not required~~,~~ to use a model because the calculated savings ~~will be~~are 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 provides an example of the data required for model development.

Table 5. Example of Data Required for Model Development

Shoulder Season	Summer Season

~~[18] 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.~~

[19] 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.

[20] 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~~ 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.

[21] ~~Advanced~~Evaluators may need to use advanced regression methods ~~might be required~~ if a chiller plant is providing cooling for manufacturing or industrial processes.

Occupied ~~Hrs~~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 ~~Hrs~~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).

~~The~~Analyze the data collected ~~should be analyzed~~ to identify outliers. ~~This involves employing approaches such as the cumulative sum (CUSUM)[22] of differences technique or visually inspecting a plot of the cooling load data versus the independent variable data. Outliers should typically only be removed if~~ Only remove outliers when there is a tangible explanation ~~is provided~~ 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, ~~review~~begin by reviewing the parameters listed in ~~Table 6~~Table 6 (EVO, 2012).

Table 6. Model Statistical Validity Guide

Parameter Evaluated	Description	Suggested Acceptable Values
Coefficient of ~~Determination~~determination (R^2)	A measure of the extent to which the regression model explains variations in the dependent variable from its mean value ~~are explained by the regression model~~.	> 0.75
T-statistic (absolute value)	An indication of whether the regression model coefficients are statistically significant.	> ~~2~~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%

~~If any~~[a] Determine the t-statistic threshold based on the evaluator's chosen confidence level; a 95% confidence level requires a t-statistic of ~~these parameters fall outside their~~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~~, the regression model is~~ 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 ~~considered statistically valid, and should not be used~~use such a model for normalization, unless the analysis

~~[22] 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 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).~~

includes appropriate statistical treatment of this prediction error. Discussion of how to normalize data. proceed in such circumstances is outside the scope of this protocol.

When possible, attempts should be madeattempt to enhance the regression model by increasing:

- Increasing or shifting the measurement period; by incorporating
- Incorporating more data points; by including
- Including independent variables that were previously unidentified; or by eliminating
- 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* describes*Cross-Cutting Protocol* for general sampling procedures that should be consulted if the chiller project population is sufficiently large, or if the evaluation budget is constrained. -Ideally, use stratified sampling should be undertaken by partitioningto partition chiller projects by facility type, process vs. HVAC load, and/or the magnitude of claimed (*ex- ante*) project savings. This stratificationStratification ensures thatevaluators can confidently extrapolate sample findings can be extrapolated confidently to the remaining project population. TheRegulatory or program administrator specifications typically govern the confidence and precision level targets that, which will 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, consider the following evaluation issues ~~should be considered~~ in addition to first-year gross impact findings:

- Net-to-~~Gross Estimation~~gross estimation
- Early ~~Replacement~~replacement
- ~~Realization Rates~~
- Dual baseline realization rates.

6.1 Net-to-Gross Estimation

The Uniform Methods Project's cross-cutting ~~net-to-gross chapter~~Estimating Net Savings: Methods & Practice 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 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 Uniform Methods Project's Estimating Net Savings: Methods & Practice, the evaluator ~~may want to~~should consider assessing whether early replacement projects were program-induced. If the early replacement was not program-induced, it ~~would be~~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-ante*] gross savings) exist over the EUL of the new equipment~~.~~:

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

Therefore, if ~~lifecycle~~reporting life cycle gross impact findings, evaluators need to ~~be reported,~~account for both Period 1 and Period 2 realization rates ~~should be taken into account.~~

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7 References

ASHRAE. (2002). Guideline 14-2002: Measurement of Energy and Demand Savings. American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (.

ASHRAE). 2008. *2008*. (2012). *2012 ASHRAE Handbook: HVAC Systems and Equipment.* American Society of Heating, Refrigeration and Air-Conditioning Engineers.

California Public Utilities Commission (CPUC). April 2006. *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals.*

California Public Utilities Commission (CPUC). 2008.. (2008). *Database for Energy Efficiency Resources (DEER).* California Public Utilities Commission.

Connecticut Light & Power, United Illuminating Company. 2005. *UI and CL&P Program Savings Documentation for 2006 Program Year.*

Efficiency Valuation Organization (EVO).. (January 2012.). *International Performance Measurement and Verification Protocol – Concepts and Options for Determining Energy and Water Savings Volume 1.* Efficiency Valuation Organization.

Fagan, F., Bradley, K., Lutz, A. (2011.). *Strategies for Improving the Accuracy of Industrial Program Savings Estimates and Increasing Overall Program Influence*. Prepared for the International Energy Program Evaluation Conference.

Ridge, R., Jacobs, P., Tress, H., Hall, N., Evans, B. (2011). *One Solution to Capturing the Benefits of Early Replacement: When Approximately Correct is Good Enough*. Prepared for the International Energy Program Evaluation Conference.

US DOE FEMP. (April 2008). *M&V Guidelines: Measurement and Verification for Federal Energy Projects—Version 3.0.* U.S. Department of Energy Federal Energy Management Program.

8 Bibliography

BPA. (2011). *Regression for M&V: Reference Guide.* Bonneville Power Administration.

CPUC. (April 2006). *California Energy Efficiency Evaluation Protocols: Technical, Methodological, and Reporting Requirements for Evaluation Professionals.* California Public Utilities Commission.

Connecticut Light & Power, United Illuminating Company. (2005). *UI and CL&P Program Savings Documentation for 2006 Program Year.*

Itron, Inc. (February 2010~~.~~). *2006-2008 Evaluation Report for PG&E Fabrication, Process and Manufacturing Contract Group*. Prepared for California Public Utilities Commission.

Jacobson, D., Studer, E. (2007~~.~~). *Lessons Learned from a Decade of Evaluating Customized Commercial and Industrial Efficiency Measures*. Prepared for the International Energy Program Evaluation Conference.

~~Northeast Energy Efficiency Partnerships (~~NEEP~~).~~ . (May 2010~~.~~). *Regional EM&V Methods and Savings Assumptions Guidelines.* Northeast Energy Efficiency Partnerships.

~~Ontario Power Authority (~~OPA~~).~~ . (March 2011~~.~~). *saveONenergy Retrofit Program Project Measurement and Verification Procedures.* Ontario Power Authority.

~~Ridge, R., Jacobs, P., Tress, H., Hall, N., Evans, B. 2011. *One Solution to Capturing the Benefits of Early Replacement: When Approximately Correct is Good Enough*. Prepared for the International Energy Program Evaluation Conference.~~

RLW Analytics, Inc. (October 2008~~.~~). *2004-2005 Los Angeles County ~~–~~ Internal Services Department / Southern California Edison ~~/~~ /Southern California Gas Company Energy Efficiency Partnership Impact Evaluation Study*. Prepared for California Public Utilities Commission.

Robert Mowris & Associates. (June 2005~~.~~). *Measurement & Verification Load Impact Study for NCPA SB5X Commercial and Industrial HVAC Incentive Programs*. Prepared for Northern California Power Agency.

Summit Blue Consulting, LLC. (September 2008~~.~~). *APS Measurement, Evaluation & Research (MER) Report~~—~~—Solutions for Business*. Prepared for Arizona Power Service.

~~U.S. Department of Energy Federal Energy Management Program (US DOE FEMP). April 2008. *M&V Guidelines: Measurement and Verification for Federal Energy Projects – Version 3.0.*~~