Chapter 4: Small Commercial and Residential Unitary and Split System HVAC Heating and Cooling Equipment-Efficiency Upgrade 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 – September 2016

This version supersedes the version originally published in April 2013. The content in this version has been updated.

David Jacobson
Jacobson Energy Research
Providence, Rhode Island

Jarred Metoyer
DNV GL
Madison, Wisconsin

NREL Technical Monitor: Charles Kurnik

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Subcontract Report
NREL/SR-7A40-68560
October 2017

Contract No. DE-AC36-08GO28308

Chapter 4: Small Commercial and Residential Unitary and Split System HVAC Heating and Cooling Equipment-Efficiency Upgrade 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 – September 2016

This version supersedes the version originally published in April 2013. The content in this version has been updated.

David Jacobson
Jacobson Energy Research
Providence, Rhode Island

Jarred Metoyer
DNV GL
Madison, Wisconsin

NREL Technical Monitor: Charles Kurnik

Prepared under Subcontract No. LGJ-1-11965-01

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Subcontract Report
NREL/SR-7A40-68560
October 2017

Contract No. DE-AC36-08GO28308

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at SciTech Connect http:/www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
OSTI http://www.osti.gov
Phone: 865.576.8401
Fax: 865.576.5728
Email: reports@osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
NTIS http://www.ntis.gov
Phone: 800.553.6847 or 703.605.6000
Fax: 703.605.6900
Email: orders@ntis.gov

Cover Photos by Dennis Schroeder: (left to right) NREL 26173, NREL 18302, NREL 19758, NREL 29642, NREL 19795.

NREL prints on paper that contains recycled content.

Disclaimer

Preface

This document was developed for the U.S. Department of Energy Uniform Methods Project (UMP). The UMP provides model protocols for determining energy and demand savings that result from specific energy-efficiency measures implemented through state and utility programs. In most cases, the measure protocols are based on a particular option identified by the International Performance Verification and Measurement Protocol; however, this work provides a more detailed approach to implementing that option. Each chapter is written by technical experts in collaboration with their peers, reviewed by industry experts, and subject to public review and comment. The protocols are updated on an as-needed basis.

The UMP protocols can be used by utilities, program administrators, public utility commissions, evaluators, and other stakeholders for both program planning and evaluation.

To learn more about the UMP, visit the website, https://energy.gov/eere/about-us/ump-home, or download the UMP introduction document at http://www.nrel.gov/docs/fy17osti/68557.pdf.

Acknowledgments

The chapter authors wish to thank and acknowledge the following individuals for their thoughtful comments and suggestions on drafts of this protocol:

- Miriam Goldberg of DNV-GL
- Peter Jacobs of Building Metrics
- M. Sami Khawaja and John Walczyk of Cadmus
- Justin Spencer and Frank Stern of Navigant
- Kevin Warren of Warren Energy.

Suggested Citation

Jacobson, D. and Metoyer, J. (2017). *Chapter 4: Small Commercial and Residential Unitary and Split System HVAC Heating and Cooling Equipment-Efficiency Upgrade Evaluation Protocol*. The Uniform Methods Project: Methods for Determining Energy-Efficiency Savings for Specific Measures. Golden, CO; National Renewable Energy Laboratory. NREL/SR-7A40-68560. http://www.nrel.gov/docs/fy17osti/68560.pdf

Acronyms

AHRI	Air-Conditioning, Heating, and Refrigeration Institute
CEE	Consortium for Energy Efficiency
COPH	heating coefficient of performance
CV	coefficient of variation
ECM	electronically commutated motor
EER	energy efficiency ratio
EFLH	equivalent full-load hour
EM&V	evaluation, measurement, and verification
HSPF	heating seasonal performance factor
HVAC	heating, ventilating, and air conditioning
IEER	integrated energy efficiency ratio
IPLV	Integrated Part Load Value
IPMVP	International Performance Measurement and Verification Protocol
NEEP	Northeast Energy Efficiency Partnerships
NMBE	normalized mean bias error
RMSE	root mean squared error
SEER	seasonal energy efficiency ratio
TRM	technical reference manual
UMP	Uniform Methods Project

Protocol Updates

The original version of this protocol was published in April 2013.

This chapter has been updated to incorporate the following revisions:

- Expanded the protocol to include some heating equipment, including basic upgrades from standard to high efficiency equipment for ductless mini-split heat pumps and air source heat pumps.
- Updated the regression model to include heating, including the incorporation of a change point model for heating and cooling units.
- Updated the example protocols to reflect current programs.
- Revised data requirements to include more detailed model numbers with imbedded information.

Table of Contents

List of Tables

1 Measure Description

A packaged system—often called a "rooftop unit" because it is usually installed on the roof of a small commercial building—puts all cooling and ventilation system components (evaporator, compressor, condenser, and air handler) in one enclosure or package. The capacity of packaged systems typically ranges from 3 to 20 tons, although specifications go up to 63.3 tons.

Split systems primarily are used for residences and very small commercial spaces. These systems place condensers and compressors outdoors and place evaporators and supply fans indoors. On average, split systems have a capacity of less than 65,000 Btu/hr (5.4 tons).[1] Small systems are rated using the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) standard 210/240, while the large systems are rated using AHRI 340/360. For this protocol, split systems include ductless mini-split heat pumps and air source heat pumps. We recommend applying the protocol to applications where the unit serves a single conditioned zone. We recommend the enhanced or other more advanced methods for larger multi-zone units connected to a variable air volume system.

[1] A ton equals 12,000 Btu/hr, or the amount of power required to melt 1 ton of ice in 24 hours.

2 Application Conditions of Protocol

The specific measure described here involves improving the overall efficiency in air-conditioning systems as a whole (compressor, evaporator, condenser, and supply fan). The efficiency rating for cooling is expressed as the energy efficiency ratio (EER), seasonal energy efficiency ratio (SEER), and integrated energy efficiency ratio (IEER). The rated heating efficiency (applicable for heat pumps only) is expressed as either the heating seasonal performance factor (HSPF) or the heating coefficient of performance (COPH). The higher the EER, SEER, or IEER, the more efficient the unit is. The same applies for the rated HSPF and COPH.

- EER is the Btu/hr of peak cooling delivered per watt of electricity used to produce that amount of cooling. Generally, the EER is measured at standard conditions (95^{o}F outdoor dry bulb, 67^{o}F indoor wet bulb), as determined by the AHRI Standard 210/240 (AHRI 2008 with 2012 Addenda).
- SEER is a measure of a cooling system's efficiency during the entire cooling season for units with rated cooling capacities of less than 65,000 Btu/hr (less than 5.4 tons). The AHRI 210/240-2008 standard describes the tests and calculation method to determine SEER.[2] The SEER is also expressed in Btu/hr cooling per watt of electric input.
- IEER is a measure of a cooling system's efficiency during the entire cooling season for units with cooling capacities between 65,000 Btu/hr (5.4 tons) and 760,000 Btu/hr (63.3 ton), expressed in Btu/hr of cooling per watt of electric input. AHRI Standard 340/360 2015 defines IEER as "a single number figure of merit expressing cooling part load EER for commercial unitary air-conditioning equipment and heat pump equipment on the basis of weighted operation at various load capacities." It replaces the Integrated Part Load Value (IPLV) in ASHRAE standard 90.1-2007 (AHRI 2015).
- HSPF is a measure of a heat pump system's efficiency during the entire heating season for units with rated capacities of less than 65,000 Btu/hr. The AHRI 2010/240-2008 standard descries the tests and calculation method to determine the HSPF.[3]
- COPH is a ratio of the heating capacity in watts to the power input in watts at any given set of rating conditions, expressed in W/W. For COPH, supplementary resistance is excluded. The high and low temperature COPH are defined at the following conditions (AHRI Standard 340/360 2015):
    - High Temperature Coefficient of Performance, COPH, W/W, at 47°F
    - Low Temperature Coefficient of Performance, COPH, W/W, at 17°F.

For many commercial unitary rebate programs offered in 2013 through 2015, units greater than 5.4 tons qualified based on the EER only, and IEER is not captured. Although IEER provides a

[2] SEER was designed to represent the cooling seasonal efficiency in an average U.S. climate. The seasonal efficiency of a unit may vary across climates (Fairey et al. 2004).
[3] HSPF was designed to represent the heating seasonal efficiency in an average U.S. climate. The seasonal efficiency of a unit may vary across climates (Fairey et al. 2004).

more accurate measure of seasonal efficiency for larger units, its use is not yet commonplace throughout the incentive program community.

Table 1 presents a typical program offering for this measure. There are similar programs with additional references from Wisconsin and California.[4] The Consortium for Energy Efficiency (CEE) (2016) continues to provide consistent efficiency "tiers" across the country.

Table 1. Typical Incentive Offering for Air-Cooled Unitary AC, Split Systems, and Heat Pumps (New Condenser and New Coil)

Minimum Efficiency Levels/Incentive Levels						
HVAC Unit Size			Level 1		Level 2	
Tons	Btuh		Minimum SEER/EER for Incentive	Incentive $/Ton	Minimum SEER/EER for Incentive	Incentive $/Ton
Air Conditioning Systems						
Air Cooled Unitary and Split Air Conditioning Systems						
< 5.4	< 65,000	Split	14.0 SEER & 12.0 EER	$70	15.0 SEER & 12.5 EER	$125
< 5.4	< 65,000	Packaged	14.0 SEER & 11.6 EER	$70	15.0 SEER & 12.0 EER	$125
≥ 5.4 to < 11.25	≥ 65,000 to < 135,000		11.5 EER	$50	12.0 EER	$95
≥ 11.25 to < 20	≥ 135,000 to < 240,000		11.5 EER	$50	12.0 EER	$95
Large Commercial Air Cooled RTU and Split Systems						
≥ 20 to < 63	≥ 240,000 to < 760,000		10.5 EER	$30	10.8 EER	$60
≥ 63	≥ 760,000		N/A	N/A	10.2 EER	$60
Water and Evaporatively Cooled Air Conditioning Systems						
≥ 20	≥ 240,000		14.0 EER	$80	N/A	
Heat Pump Systems						
Air Cooled Heat Pump Systems						
< 5.4	< 65,000	Split	14.0 SEER & 12.0 EER & 8.5 HSPF	$70	15.0 SEER & 12.5 EER & 9.0 HSPF	$125
< 5.4	< 65,000	Packaged	14.0 SEER & 11.6 EER & 8.0 HSPF	$70	15.0 SEER & 12.0 EER & 8.5 HSPF	$125
≥ 5.4 to < 11.25	≥ 65,000 to < 135,000		11.5 EER & 3.4 COP	$50	N/A	
≥ 11.25 to < 20	≥ 135,000 to < 240,000		11.5 EER & 3.2 COP	$50		
≥ 20	≥ 240,000		10.5 EER & 3.2 COP	$30		

(EEAC 2015)

This measure's primary delivery channels are rebate programs, usually marketed through program administrator staff and heating, ventilating, and air conditioning (HVAC) contractor partners, or an upstream market program marketed through distributors. The programs provide:

- Rebates for units installed in commercial settings, typically paid on the basis of dollars-per-ton of cooling, which can vary by the efficiency level achieved.
- Rebates for residential units, which are often paid on a fixed rebate-per-unit basis to discourage oversizing, and to promote high-quality installation practices.

The rebates apply (1) at the time of normal replacement due to age or failure or (2) for new construction applications. Rebates are not usually offered for early replacements, except when unusually high use of air-conditioning occurs.

When a unit is installed in new construction or replaces an existing unit that has failed or is near the end of its life, the baseline efficiency standard it must meet is generally defined by local

[4] MassSave Cool Choice Program, offered in 2016-18 by all Massachusetts Program Administrators. http://ma-eeac.org/wordpress/wp-content/uploads/EEAC-CI-Innovation-Upstream-Memo-2015-12-30.pdf
Additional program examples:
https://www.premiumcooling.com/upload/2017_PECP_Equipment_Incentive_Schedule%20(FINAL).pdf;
https://focusonenergy.com/sites/default/files/HVAC_Plumbing_Catalog_v07_012017_web.pdf

energy codes, federal manufacturing standards, or ASHRAE Standard 90.1 for SEER-rated units (less than 5.4 tons) and IEER-rated units (5.4 tons or greater). This protocol assumes more efficient equipment of the same capacity runs close to the same number of hours as the baseline equipment. It does not cover:

- Early replacement retrofits
- Right-sizing initiatives
- Tune-ups
- Electronically commutated motor (ECM) retrofits on fans
- Savings resulting from installation of an economizer[5] or economizer controls, demand controlled ventilation, multi-unit controls, solar-power assistance, or energy recovery ventilation at the same time as installation of the new, high-efficiency equipment.

2.1 Programs with Enhanced Measures

Many program administrators offer other cooling measures in conjunction with higher EER/SEER/IEER cooling units. These measures include dual enthalpy economizers, demand controlled ventilation, and ECMs for ventilation fans as a retrofit or an upgrade option at the time of replacement.

Other programs, particularly residential, also focus on high-quality installation by requiring the work to meet Air Conditioning Contractors of America Quality Installation standards, which encompass proper duct sealing (ACCA 2015).

The evaluation methods addressed in this protocol do not include—on a standalone basis—savings resulting from these other measures. However, some overlap may occur with the evaluation, measurement, and verification (EM&V) of high-efficiency cooling system upgrades, particularly with demand controlled ventilation, ECMs, and dual enthalpy economizers.

2.1.1 Economizers

Economizers work by bringing in outside air for ventilation and cooling when outside conditions are sufficiently cool. In some jurisdictions, many of the new packaged or split systems have temperature or dry bulb-based economizers, as required by code or by standard practice. Evaluators can include units with temperature-based economizers in evaluation samples as a random occurrence as long as their occurrence in the sample is roughly the same proportion to their penetration in the population.

A dual-enthalpy economizer—a more sophisticated type, controlling both temperature and humidity—brings in outside air when the outside conditions are sufficiently cool and dry. These units tend to reduce the run hours of high-efficiency air conditioners as compared to units without economizers, thus reducing potential savings from more efficient units. Although dual-enthalpy economizers usually[6] are not required by code for these smaller sized units, some

[5] Most codes nationwide require basic economizers, such that baseline EFLH and measure EFLH should include free cooling, but measurement will likely reveal less than 100% functioning.
[6] Codes in California, Washington, and Oregon require advanced economizer controls in some applications.

utilities provide an incentive for them. More recently, some programs have provided incentives for adding more advanced digital economizer controls, which are similar to dual enthalpy economizers, but these controllers may provide additional compressor lockout and fan control. Units with advanced digital economizer controls also include automated fault detection diagnostics. If programs offer additional incentives for these more advanced economizers, savings for those measures should not be estimated using the protocol described here.

2.1.2 Demand Controlled Ventilation

Demand controlled ventilation (which uses a CO_2 sensor on return air to limit the intake of outside air to be cooled) can reduce the run hours for unitary and split systems. Units that receive rebates for demand controlled ventilation should not use this protocol, which assumes the equivalent full-load hour (EFLH) or load remains constant.

2.1.3 Right-Sizing

The savings estimated for this measure do not include the effects of right-sizing initiatives, which match outputs of cooling systems with cooling loads of facilities (thereby optimizing systems operations). The high-efficiency upgrade measure described here assumes both the base or code-compliant units and the high-efficiency units are the same size. Thus, the savings achieved through right-sizing initiatives must be determined using a more complex analysis method than is described here.

3 Savings Calculations

The calculation of gross annual energy savings for this measure, consistently defined by a number of technical reference manuals (TRMs) (MA Energy Efficiency Advisory Council Consultant Team 2015; United Illuminating Company and Connecticut Lighting and Power Company 2008; Vermont Energy Investment Corporation 2010), uses the following algorithms:

Cooling

Equation 1 (for units with a capacity of 5.4 tons or more)

$$\text{kWh Saved} = (\text{Size kBtu/hr}) * (1/EER_{baseline} - 1/EER_{installed}) * (EFLH_{cooling})$$

Equation 2 (for units with a capacity of fewer than 5.4 tons)

$$\text{kWh Saved} = (\text{Size kBtu/hr}) * (1/SEER_{baseline} - 1/SEER_{installed}) * (EFLH_{cooling})$$

Where:

Size kBtu/hr = cooling capacity of unit
$EER_{baseline}$ = energy efficiency ratio of the baseline unit, as defined by local code
$EER_{installed}$ = energy efficiency ratio of the specific high-efficiency unit
$SEER_{baseline}$ = seasonal energy efficiency ratio of the baseline unit, as defined by local code
$SEER_{installed}$ = seasonal energy efficiency ratio of the specific high-efficiency unit
$EFLH_{cooling}$ = equivalent full-load hours for cooling

While many efficiency providers currently use Equation 1 with EER for units of greater than 5.4 tons, the protocol recommends using the more accurate measure of seasonal efficiency, IEER, shown in Equation 3.

Equation 3 (for IEER)

$$\text{kWh Saved} = (\text{Size kBtu/hr}) * (1/IEER_{baseline} - 1/IEER_{installed}) * (EFLH_{cooling})$$

Where:

$IEER_{baseline}$ = integrated energy efficiency ratio of the baseline unit, defined to be minimally compliant with code, which is usually based on ASHRAE 90.1-2010
$IEER_{installed}$ = integrated energy efficiency ratio of the specific high-efficiency unit

Note that for many programs currently offered, only EER is required to qualify units 5.4 tons or greater. EER is not meant to represent annual efficiency and there is some error introduced by not using the IEER, but as of now there is no accepted general relationship between the two to use. It is recommended that all programs move toward using IEER or SEER for rebate qualification and energy savings estimates, and recording those values in the program tracking database. Peak demand savings are covered in Uniform Methods Project (UMP) Chapter 10;

however, in general we recommend using EER, which represents the system's full load efficiency, in any calculations of peak demand reduction.

For smaller units, SEER is almost always available, and it should be used for the calculation of annual energy savings. These formulas are consistent with ASHRAE Guideline 14–2014, although the guideline does not specify annual full load hours and focuses on the period of measurement.

Heating

Equation 4 (for units with a capacity of 5.4 tons or more)

$$\text{kWh Saved} = (\text{Size kBtu/hr}) / 3.413\ \text{kBtu/hr/kW} * (1/\text{COPH}_{baseline} - 1/\text{COPH}_{installed}) * (\text{EFLH}_{heating})$$

Equation 5 (for units with a capacity of fewer than 5.4 tons)

$$\text{kWh Saved} = (\text{Size kBtu/hr}) * (1/\text{HSPF}_{baseline} - 1/\text{HSPF}_{installed}) * (\text{EFLH}_{heating})$$

Where:

Size kBtu/hr = heating capacity of unit
$\text{COPH}_{baseline}$ = heating coefficient of performance of the baseline unit as defined by local code
$\text{COPH}_{installed}$ = heating coefficient of performance of the specific high-efficiency unit
$\text{HSPF}_{baseline}$ = heating seasonal performance factor of the baseline unit, as defined by local code
$\text{HSPF}_{installed}$ = heating seasonal performance factor of the specific high-efficiency unit
$\text{EFLH}_{heating}$ = equivalent full-load hours for heating

These formulas assume some simplifications: (1) baseline units and high-efficiency units are of equal size (that is, no downsizing or "rightsizing" due to increased efficiency); and (2) baseline and high-efficiency units have the same operating hours. Although this may not be the case for a given cooling or heating load, these simplifications have been determined reasonable in the context of other uncertainties.

4 Measurement and Verification Plan

When choosing an option, consider the following factors:

- The equation variables used to calculate savings
- The uncertainty in the claimed estimates of each parameter
- The cost, complexity, and uncertainty in measuring each of those variables.

When calculating savings for unitary HVAC, the goal is to take unit measurements as cost-effectively as possible, so as to reduce overall uncertainty in the savings estimate. Thus, use these primary components:

- Unit size
- Efficiency of the base unit and the installed unit
- Annual operating hours for energy savings
- Coincidence factor for demand savings.

4.1 IPMVP Option

The recommended approach entails two steps: (1) Use one of the equations provided above with manufacturer rated values for capacity and efficiency (using industry-approved methods); and (2) incorporate program-specific measured values for the operating hours. This approach most closely resembles International Performance Measurement and Verification Protocol (IPMVP) Option A: Partial Retrofit Isolation/Metered Equipment.

Option A can be considered the best approach for the following reasons:

- The key issue for replace-on-failure/new construction programs is the usage of baseline equipment, defined as the *current* code or prevailing standard. However, this cannot be measured or assessed for participating customers because, by definition, lower-efficiency baseline equipment was never installed. The unit replaced is often old and below current requirements and is not the appropriate baseline. A nonparticipant group installing baseline equipment could be used, but only one known study has attempted this to date (KEMA 2010). For most situations, finding valid nonparticipants through random-digit dialing and performing extensive metering is simply too costly, given the savings level this measure contributes to typical portfolios.[7]
- Regarding the use of pre/post-billing analysis (IPMVP Option C) for participants, the same issue applies—pre-installation does not represent the baseline. Even without using pre/post-billing analysis, one might try using monthly billing data to determine cooling energy for a facility and then calculate facility-level full-load hours for use in the equations. However, this method is not recommended because cooling electricity usage cannot be easily disaggregated from total monthly electric usage with the accuracy

[7] This generally represents a small percentage of total commercial and industrial portfolio savings; primarily due to code, most new equipment is already relatively efficient.

required. As more residential and small commercial customers get kilowatt interval data (hourly or smaller time intervals), estimating cooling hours from whole-building data may become more feasible for very simple cases, but such methods are error-prone; feasibility will depend strongly on building size and type, HVAC system configuration, and the profiles of other loads.

- Option D (Calibrated Simulation) in which savings are determined using building simulation, is also not a recommended evaluation approach for the measure. Option D involves developing an energy model to estimate energy use for a proposed building. Often the measures in this protocol replace individual units and developing a whole building model and calibrating can be too costly for each sample point. Option D is primarily intended for new construction projects, or major retrofits with multiple measures, where a whole building approach includes HVAC and other measures that affect the HVAC loads. The protocol uses Option A and is applicable to new construction if only evaluating the unitary HVAC measures.

4.1.1 Capacity

Measuring cooling capacity is extremely expensive and would only result in replicating information already provided in a manner overseen by a technical standards group (AHRI). Thus, for a unit's peak cooling capacity (size), use the manufacturer's ratings, as these have generally been determined through an industry-standard approved process at fixed operating conditions. Although some variation may occur in the output of individual rebated units, it is assumed that on average, units perform closely to AHRI ratings.

4.1.2 Efficiency Rating

For determining the efficiency levels of base units and installed units, an industry accepted standard alternative to *in situ* measurement is available through manufacturers' ratings. (Also, performing *in situ* measuring is extremely costly.)

4.1.3 Equivalent Full-Load Hours

The EFLH variable must be measured or estimated for the population of program participants. Operating hours are specific to building types and to system sizing and design practices. Typical design practice tends to result in oversizing (using a larger-than-needed unit). In general, the greater the oversizing, the fewer the operating hours, and the less efficiently a unit operates.

Two primary methods exist for developing hours of use for the equations in *Savings Calculations*—creating a building simulation or conducting metering. The recommended approach favors using some actual measurement rather than relying exclusively on simulation-based estimates.

Detailed building simulation prototype models can be developed for a wide variety of building types, system configurations, and applicable weather data. Such analysis usually results in an extensive set of look-up tables for operating hours listed by building type and weather zone. Various TRMs use this approach, including New York and California (TecMarket Works 2010; Itron, Inc. 2005). In California, DEER look-up tables contain 9,000 unique combinations of unit types, building vintages, climate zones, and building types.

This approach is used to establish deemed savings and program planning estimates, but it does not include measurements to account for oversizing practices or the types of building populations served by the actual programs. Thus, the recommended approach entails metering demand (kW) for a sample of units to develop EFLH estimates (KEMA 2010).

Note that the energy consumption of the compressor(s), condenser fan(s), and evaporator (i.e. supply) fan(s) are used to calculate the EFLH, but only when the compressor and condenser actually supply cooling or heating.

Measurement of energy consumption can be used to validate building simulation models. However, in practice, the cost of metering the sample sizes required for developing data for all building types and weather zones would be cost-prohibitive and thus has not been attempted. In a California study, results from approximately 50 units in three climate zones were used to develop realization rates to calibrate the simulation approach to metered data, but not to determine EFLH for combinations of building types, climate zones, and system types (Itron, Inc. and KEMA 2008).

Measuring energy consumption involves on-site inspections, where unit-level power metering is performed for a wide range of temperature, occupancy, and humidity conditions. The resulting data can be analyzed to determine energy consumption as a function of outdoor wet-bulb or dry-bulb temperatures. These data can be extrapolated to the entire year by using typical meteorological year (TMY) data.

Dividing annual energy consumption (kWh) by the peak rated kW serves as a proxy for EFLH. The peak rated kW is defined as a unit's peak cooling capacity at AHRI conditions in kBtu/hr and divided by the EER or the peak heating capacity at AHRI conditions divided by (COPH*3.412). Metering used to determine the annual kWh consumption should be based on either (1) a true power (kW) meter and integration of power over time; or (2) an energy meter, which performs the integration internally. Such metering should include the compressor(s), condenser fan(s), and supply fan(s). If true power kW or energy metering proves too costly, amperage data may be acceptable if they are supplemented with spot power measurements under a variety of loading conditions.

When taking measurements, consider these factors: (1) Use a random sample of units spread across building types and (2) stratify the sample by climate zone (if the territory has a wide range of temperature and humidity conditions) and unit sizes. Note that unit-size stratification may not be required if unit sizes fall within a narrow range. Please see UMP *Chapter 11: Sample Design Cross-Cutting Protocol* for additional details.

Although a sufficiently large random sample would likely capture the predominant building types of interest, we recommend checking distributions of building types in the sample relative to the population and then adjusting or redrawing the sample, as needed, if an adequate distribution does not result.

4.2 Verification Process

The key data to be verified are (1) the size of the unit rebated and (2) the nameplate efficiency of the installed unit. Verification can be performed through:

- A desk review of invoices and manufacturers' specification sheets (which should be required for rebate payment)
- An on-site audit of a sample of participants (usually the same participants selected for the end-use metering, discussed above)
- Request from program staff, distributors or contractors, and internet search to obtain manufacturer manuals and cut sheets with unit performance at varying conditions.

Cooling capacity and efficiency are measured by manufacturers under standard conditions; however, the EFLH is site-dependent and not measured. Thus, the major uncertainty arises in the EFLH, so metering should concentrate on that quantity.

If savings can be determined as a function of building types, then verification of building types on applications can be conducted through on-site visits or telephone surveys.

Baseline efficiency can be assumed to be that of a code-compliant unit in the service territory. Differences in efficiency between code-compliant units and standard practice would be reflected in the calculation of an appropriate net-to-gross ratio. [8]

4.3 Data Requirements

The minimum data required for evaluating a unitary HVAC rebate program are:

- Size (in Btu/hr or tons) of each unit installed
- Rated cooling efficiency (in EER, SEER, or IEER) of each unit installed
- Rated heating efficiency (in HSPF or COPH) of each installed unit, if applicable
- Assumed baseline efficiency for each category of units (from prevailing code or standard)
- Location of each unit, corresponding to specific weather station disaggregation used for analysis of metered data.

Metered data used in the evaluation consists of the EFLH developed for each weather zone, which is derived as the ratio of the annual kWh divided by the peak kW.

Using the appropriate equation in *Savings Calculations*, determine the savings for this measure with these data:

- The installed cooling capacity
- The EER, SEER, or IEER rating (from manufacturers' data) of the baseline unit and the installed unit
- The HSPF or COPH rating (from manufacturers' data) of the baseline and installed unit, if applicable

[8] Net-to-gross issues are addressed in UMP *Chapter 21: Estimating Net Savings – Common Practices*.

- The measured EFLH.

4.4 Data Collection Methods

Given the relative size of savings for this measure in a typical portfolio—one dominated by other higher-savings measures—the collection of data (which is comparatively costly) can best be conducted jointly with other program administrators in a state or region with similar weather conditions.

In the past 15 years, a number of studies have examined commercial unitary HVAC EFLH and load shapes of note (KEMA 2011; SAIC 1998; Itron, Inc. and KEMA 2008; KEMA 2010). Further, at least two studies have examined full-load hours of residential central air-conditioning systems (KEMA 2009; ADM 2009). The method this protocol recommends is based on work described in the Northeast Energy Efficiency Partnerships (NEEP) EM&V Forum study (KEMA 2011; Regional EM&V Methods and Savings Assumption Guidelines 2010), which, if conducted on a regional basis across multiple program administrators, balances rigor and cost.

As discussed, unit sizes and climate zones provide variables for developing a sampling framework. Large units tend to run for more hours and exhibit higher peak coincidence than small units (ranging from 3 tons to 15 tons). Large units also tend to use multiple compressors and are controlled differently than smaller, single-compressor units.

If a program predominantly rebates units smaller than 15 tons in size (or if the specific prescriptive program is limited to units smaller than 15 tons), only one size category is necessary. Similarly, if all units in the service territory or region studied have essentially the same temperature and humidity conditions (for example, one large city), sampling by climate zone is not needed.

Thus, if unit size and climate zone are not required sampling dimensions for representing the population, then sampling by predominant building type alone may be possible. Otherwise, sampling by combinations of climate zone, size, and building type may prove impractical.

4.4.1 Metering

Metering should capture integrated true root mean square kW power measurements at 15 minute intervals during at least half of the typical cooling season for the region, being sure to include either the spring or fall shoulder periods. If budget allows, metering should extend from the time units typically come on in spring until units are no longer needed in fall. Where budgets are constrained and timing allowed is not sufficient, the evaluator may meter for less time but should assure that the monitoring captures the preponderance of operating conditions to minimize the extent to which extrapolation must be performed outside the range of conditions captured. For high internal gain situations where cooling is needed year-round, metering should include some portion of the warmest weather and coldest weather months. If heating and cooling are to be derived for heat pumps, we recommend measurement of supply air temperature or control signal to indicate mode of operation. Full heat pump heating and cooling savings may require full year or near full year monitoring. This metering approach is consistent with the methods proposed in Normative Annex E of ASHRAE Guideline 14-2014.

Regardless of which metering intervals are used, data will be aggregated to one-hour averages for use in the model specified below, because publicly-available weather data are generally available in hourly formats.

This protocol is not designed to capture oversizing practices of the newly installed units, which requires more detailed cycling patterns (using 1-minute interval data) and goes beyond the determination of EFLH.

If budgets do not allow for measurement of kW using amperage and voltage measurements, using amperage measurements alone to determine EFLH and demand savings factors may be justified and is preferable over using values from studies conducted by other program administrators for similar climate zones and building types as described above. Direct kW measurements are preferable and the methods below assume kW measurements are taken. If amperage measurements are used, slight modifications to the formulas below for calculating EFLH are required.

The kW measurements should encompass the energy consumption of the compressor, condenser, evaporator, and supply fans. However, these measurements should only be used in the computation of the EFLH, when the compressor and condenser are actually running and supplying cooling (or heating, if applicable). The accuracy of kW measurements should be ± 2%, as recommended by Independent System Operator New England (ISO-New England, Inc. 2010).

After collecting the kW data, perform a unit-level regression of the unit power against predictor variables such as real-time weather data and whether the specific hour fell within the second or third hot day in a row. The predictor variables selected should provide the most significant independent variables for use as inputs to estimate the weather-normalized annual kWh consumption, and to extrapolate consumption outside the metering period. The result will be an 8760 kW load profile for that specific unit using the predictor variables. The following model functional form has been successfully used for this analysis in Northeast climates (KEMA 2011). Modifications to this model may be justified by the climate conditions and evaluation scope:[9]

$$L_{dh} = \alpha + \beta_{Ch} THI_{dh} + \beta_{w(d)} w(d) + \beta_{g(h)} g(h) + \beta_{2h} H_{2d} + \beta_{3h} H_{3d} + \varepsilon_{dh} \quad (2)$$

Where, for a particular HVAC unit:

L_{dh}	= load on day *d* hour *h*, day = 1 to 365, hour = 1 to 24 in kW
THI_{dh}	= temperature-humidity index on day *d* hour *h*
w(d)	= 0/1 dummy indicating day type of day *d*, Monday through Sunday and Holidays for eight dummy variables
g(h)	= 0/1 dummy indicating hour group for hour *h*, hour group = 1 to 24
H_{2d}	= 0/1 dummy indicating that hours in day *d* are the second hot day in a row

[9] For example, in hotter climates, the variable for consecutive hot days may not be needed or, in more humid climates, the dry bulb temperature and humidity may need to be separated

H_{3d} = 0/1 dummy indicating that hours in day *d* are the third or more hot day in a row

α, β_{Ch}, β_{Hh}, $\beta_{w(d)}$, $\beta_{g(h)}$ = coefficients determined by the regression

β_{2h}, β_{3h} = hot day adjustments, a matrix of coefficients assigned to binary variables (0/1) for hours defined for 2^{nd} and 3^{rd} consecutive hot days; matrix variables are unique to each hour in each hot day

ε_{dh} = residual error

The THI in °F can be defined as:

$$THI = 0.5 \times OSA_{db} + 0.3 \times DPT + 15$$

Where:

OSA_{db} = outside dry bulb temperature in °F

DPT = outside air dew point temperature in °F

Note that this particular functional form is just an example of what has been successfully used for commercial cooling. There is no preferred method specified in ASHRAE Guideline 14-2014. For heat pumps, we recommend the four-parameter change-point regression model or variable-base degree-day model, specified below. These models also assume hourly data.

Four-parameter change-point model:

Heating: $E = C - B_1(B_3 - T)^+ - B_2(T - B_3)^+$

Cooling: $E = C - B_1(B_3 - T)^+ + B_2(T - B_3)^+$

Where:

E = energy use

C = energy use at the change point

B_1 = coefficient or slope that describes the linear dependency on temperature below the change point

B_2 = coefficient or slope that describes the linear dependency on temperature above the change point

B_3 = change-point temperature

T = temperature for the period of interest

$^+$ = positive values only for the parenthetical expression, the lower bound is zero for the difference between T and B_3. This is not the same as the absolute value of the parenthetical expression.

Variable-base degree-day model:

$E = C + B_1 \, (DD_{BT})$

Where:

E	= energy use
C	= constant energy use below or above the change point
B_1	= coefficient or slope that describes the linear dependency on degree-days
DD_{BT}	= heating or cooling degree-days (or degree hours), which are based on the balance point temperature

However, this protocol is not suggesting that using this specific regression model is a requirement. Other examples of modifications include using a variable for the presence of economizers or using log functions with independent variables.

The success of the model should be measured by diagnostics such as signs for coefficients and comparison of measured power to modeled power via coefficient of variation - root mean squared error (CV-RMSE), R-square for the model, and the normalized mean bias error (NMBE)[10].

The following equation provides an EFLH calculation for the overall load shape (hourly load factor) or for each unit metered:

$$EFLH = \sum_{h=1}^{8760} \left(\frac{Estimated\ Hourly\ Load\ (kW)}{Connected\ Load\ (kW)} \right)$$

The connected load is defined as the unit's maximum kW recorded or peak cooling capacity at AHRI conditions in kBtu/hr divided by the EER. When performing the recommended analysis, the EFLH is defined for each range of temperatures for which there exists performance data including capacity and connected load. If the measurements are limited, a high and low range of capacity and efficiency is still recommended, as modern equipment for many capacities is two-stage or variable speed.

The HVAC unit's rated cooling capacity can be obtained from the unit make and model numbers, which should be required to be entered in the tracking system.

Although the EFLH is calculated with reference to a peak kW derived from EER, it is acceptable to use these EFLH with SEER or IEER. Some inconsistency occurs in using full-load hours with efficiency ratings measured at part loading, but errors in calculation are thought to be small relative to the expense and complexity of developing hours-of-use estimates precisely consistent with SEER and IEER.

[10] CV-RMSE and NMBE are fully defined with examples in ASHRAE Guideline 14. CV-RMSE measures deviations for each hour and thus measures model fit to the "load shape." NMBE measures the percent error over the entire performance period, in this case one year for annualized savings.

The EFLH for the population can be determined by multiplying the EFLH for each metered unit by the appropriate weights developed in the sample design (see Uniform Methods Chapter 11), reflecting that unit's contribution to the total population's cooling capacity.

Explicit 8760 load shape data are not always needed. This information, however, can be helpful for on-peak energy or demand savings calculations when (1) the time period in which the peak demand is being calculated differs among participants in a particular metering study or (2) the definition changes after primary data are collected. If the study has produced data for all hours of the year, these data can easily be reanalyzed for different on-peak energy and peak demand definitions.

4.5 Secondary Calculation

More extensive measurements than those described above may be justified when (1) typical operating conditions are significantly different than conditions for which the equipment has been rated or (2) the savings for this measure make up a significant portion of total portfolio savings. For example, extensive measurements may be appropriate in very hot and dry climates (such as the Southwest), where the dry-bulb temperature is often higher than the 95^{o}F used for EER ratings and the humidity is very low, compared to conditions for SEER ratings. Navigant (2010) has shown that performance in hot, dry climates differs significantly from manufacturers' standard conditions. DNV GL (2016 and 2017) performed IEER analysis using the HVAC Loadshape study to show potential different weighting that would lead to higher efficiencies for units in the Northeast with significant runtime at cool conditions where unit capacity and efficiency can be very high (Analysis not published).

Another complicating issue is performance at low loading for large units with multiple compressors running in parallel, or for units with variable-speed compressors. In such cases, low-loading performance is higher than expected from typical SEER ratings. If a part load rating is available that matches operating conditions reasonably well, use SEER or IEER in place of EER for simplified equations, calculating energy savings in conjunction with metered estimates of full-load hours.

In cases such as these, where more extensive measurement is justified, consider the following steps:

1. Meter equipment to determine runtimes in high and low stages of operation.
2. Aggregate and normalize runtime data for weather effects to create a typical hourly runtime shape that corresponds with a typical set of weather conditions.
3. Collect detailed performance data for a representative selection of equipment of various IEER/IPLV, EER, or SEER.
4. Calculate hourly kWh/ton using detailed performance data and runtimes for each hour for each piece of equipment.
5. Sum the hourly kWh/ton over the full year to calculate annual kWh/ton and then average hourly kWh/ton over the peak period to calculate peak kW/ton.
6. Fit a mathematical function to determine kWh/ton = f(SEER or IEER, EER) and kW/ton = f(SEER or IEER, EER).

7. Apply the mathematical functions for kWh/ton and kW/ton to the population's energy-efficient and baseline cases to determine savings for each piece of equipment.

An alternative for jurisdictions with detailed TRMs (such as New York) is the option used by Itron and KEMA in California, which involved measurement for a sample of units and development of a relationship between metered EFLH and that predicted by simulation models (Itron, Inc. and KEMA 2008). Expressed as a realization rate, such a relationship can be used for all unmetered sites to adjust simulation-based EFLH values. This alternative approach, however, is very expensive and, for equivalent funding, using the recommended approach can result in obtaining measurement data from five to 10 times more pieces of equipment. (Other measurement options are discussed in various ASHRAE publications [ASHRAE 2000; ASHRAE 2010; ASHRAE 2014].)

If all detailed measurements fall beyond an evaluation's available budget, program administrators can use available EFLH data from studies conducted for similar climate zones and building types. This approach, however, involves no actual measurements to reflect typical system sizing and design practices, building types, or weather in a region or service territory.[11]

[11] As discussed in the *Considering Resource Constraints* section of the "Introduction" chapter to this UMP report, small utilities (as defined under the U.S. Small Business Administration [SBA] regulations) may face additional constraints in undertaking this protocol. Therefore, alternative methodologies should be considered for such utilities.

5 Sample Design

Evaluators will determine the required targets for confidence and precision levels, subject to specific regulatory or program administrator requirements and aligned with UMP *Chapter 11: Sample Design Cross-Cutting Protocol*. In most jurisdictions, the generally accepted confidence levels should be designed to estimate EFLH with a sampling precision of 10% at the 90% confidence interval. If attempting to organize the population into specific subgroups (such as building types or unit sizes), it may be appropriate to target 20% precision with a 90% confidence interval for individual subgroups, and 10% precision for the large total population.

In addition to sampling errors, errors in measurement and modeling can also occur. In general, these errors are lower than the sampling error; thus, sample sizes commonly are designed to meet sampling precision levels alone.

Sample sizes for achieving this precision level should be determined by estimating the coefficient of variation (CV), calculated as the standard deviation divided by the mean. Air conditioning and heat pump savings CVs generally range from 0.5 to 1.0,[12] and the more homogeneous the population, the lower the likely CV. After the study is completed, the CV should be recalculated to determine the actual sampling error of the metered sample.

As discussed, units should be sampled based on climate zones and unit sizes, if sufficient variation occurs in these quantities. Alternatively, the most prevalent building types can be sampled if the program administrator's database tracks building types accurately. One overall EFLH average can be developed if most units lie within a single climate zone and have a narrow range in capacity.

Many customers taking advantage of unitary HVAC rebate programs have multiple air-conditioning units rebated simultaneously. Consequently, the sampling plan must consider whether a sample can be designed for specific units, groups of units by size, or all units at a given site. It is also important to consider the resources needed to schedule and send metering technicians or engineers to a given site. Once those fixed costs have been incurred, metering multiple units at a site becomes an attractive option.

Decisions on how best to approach site (facility) sampling versus unit sampling depend on the degree of detail in the information available for each unit rebated. In many cases, rebate applications and tracking systems only record the total number of units in each size category, rather than the specific information on the location of each unit. For these instances, develop a specific rule that calls for random sampling of a fixed percentage of units at a given site.

Based on these considerations, sampling should be conducted per-customer site or application, with a specified minimum number of units sampled at a given site. A reasonable target is two or more units in each size category at each site with multiple units.

[12] At a CV of 0.5, the sample size to achieve a 10% precision with a 90% confidence interval is 67. At CV of 1.0, the sample size is 270. Program savings may vary less than EFLH when considering large geographic areas for multi-utility state, regional, or national studies.

6 Program Evaluation Elements

To assure the validity of data collected, establish procedures at the beginning of the study to address the following data issues:

- Procedures for filling in limited amounts of missing data
- Meter failure (the minimum amount of data from a site required for analysis)
- High and low data limits (based on meter sensitivity, malfunction, etc.)
- Units to be metered not operational during the site visit (For example, determine whether this should be brought to the owner's attention or whether the unit be metered as is.)
- Units to be metered malfunction during the mid-metering period and have (or have not) been repaired at the customer's instigation.

In addition to the raw data, the quality of an acceptable regression curve fit based on ASHRAE Guideline 14 (based on CV-RMSE, NMBE, R^2,) may further limit the sample. It is recommended to add to the sample an additional 10% of the number of sites or units to account for data attrition.[13]

At the beginning of each study, determine whether metering efforts should capture short-term measure persistence. That is, decide how the metering study should capture the impacts of non-operational rebated equipment (due to malfunction, cooling no longer needed, equipment never installed, etc.). For non-operational equipment, these could either be treated as equipment with zero operating hours, or a separate assessment could be done of the in-service rate.[14]

One key issue is how to extrapolate data beyond the measurement period for cooling-only units that may be left on after the primary cooling season ends. To address this and other unique operating characteristics, conduct site interviews with facility managers or homeowners (for residential units), as customers often know when units have been and are typically turned off for the season. These interview data can be used to omit non-typical data from the regression analysis indicating non-routine usage (e.g. cooling in the off-season), provided the customer can be certain the unit has not operated.

In analyzing year-round data from a mid-Atlantic utility, KEMA found that once the THI fell below 50^{o}F, most units shut off for the season. That information enabled KEMA to apply this rule to other sites in the NEEP EM&V Forum study, resulting in a more realistic estimate of fall and winter cooling hours than was obtained by applying only regression results (Regional EM&V Methods and Savings Assumption Guidelines 2010). If heating and cooling are to be derived, we recommend measurement of supply air temperature to indicate mode of operation.

[13] In KEMA's study for the NEEP EM&V Forum, approximately 9% of metered units were removed due to data validity problems (KEMA 2011).
[14] UMP *Chapter 6: Residential Lighting Evaluation Protocol* further discusses in-service rates.

7 Looking Forward

Since this protocol was first published in April 2013, there have been few, if any, metering studies on commercial unitary systems, and several studies for ductless mini-split and cold climate heat pumps for residential applications. Future evaluations are encouraged to include metering to provide valuable insight, since several TRM estimates may be based on aging estimates representing out-of-date equipment and milder climates. This protocol focuses on measuring total consumption and load shape, as these are typically the most uncertain parameters in HVAC measure savings. As of the date of publication of this protocol update (September 2017), there are lower cost options to meter HVAC loads at circuit breaker panels for both residential and nonresidential applications. Additional measurement options which are currently being studied for application to HVAC measures include:

- Efforts to further develop non-intrusive load monitoring options
- Efforts to use data from web-enabled “smart” thermostats
- Whole building hourly consumption analysis with advanced analytics.

In some situations, the efficiency change may require further scrutiny. These include using SEER and IEER in extreme climates, or early retirement where the existing unit efficiency is the relevant baseline for the remaining useful life of the removed equipment. This protocol does not include calculations for these situations. This protocol also does not address potential fan power savings during non-cooling and heating operation for space ventilation. Future protocols should:

- Develop coefficients to modify standard part load efficiency metrics to local climate and loads. Fairey et al. (2004) and new research is applicable to commercial buildings and IEER.
- Determine methods to estimate fan power savings for single zone variable air volume, two-speed and variable speed systems, and systems that reduce flow during ventilation-only operation (e.g., Advanced Digital Economizer Controls system).
- Consider protocol calculations for other measures that could be included in an HVAC measure in addition to the efficiency improvement, such as right sizing, adding economizers, and other load reduction or load shifting measures.

EM&V efforts can be used in larger studies to determine which measures perform best, or they can be deployed in targeted efforts. A larger effort would measure sufficient samples by technology, application, and climate, while a targeted effort would only sample the portions of a utility or state territory where participation is high or growing the fastest. There remains a challenge for TRMs with several full load hour combinations such as the simulation-based estimates in California and New York. This protocol recommends two options of either a large study designed for comparison across technology, application, and climate, or focusing on a specific combination and using the results of this protocol to produce end-use calibration targets. In this case, the most frequent combinations are calibrated and all other estimates are simulations of other combinations which should be proportionally correct, although not directly calibrated.

Although it may not be cost-effective to conduct a metering study solely for an HVAC rebate program, evaluators can leverage other in-home and commercial end-use metering efforts—such as those primarily designed to inform end-use disaggregation, which may initially be focused on residential applications. This approach may not yield a sufficient sample size for a primary metering study with one effort. However, if the data are collected in accordance with the guidance in Section 4.4, collective efforts among evaluators could yield robust samples that are sufficient to update regional estimates.

8 References

ADM. (November 2009). "Residential Central AC Regional Evaluation." Prepared for NSTAR Electric and Gas Corporation, National Grid, Connecticut Light & Power, and United Illuminating. Air Conditioning Contractors of America (ACCA). (2015). *Standard 5 (ANSI/ACCA 5 QI-2015) HVAC Quality Installation Specification.*

Air-Conditioning, Heating and Refrigeration Institute (AHRI). (2008 with 2012 Addendum). *ANSI/AHRI 210/240-2008 with Addendum 2, Performance Rating of Unitary Air-Conditioning & Air-Source Heat Pump Equipment.* http://www.ahrinet.org/App_Content/ahri/files/standards%20pdfs/ANSI%20standards%20pdfs/ANSI.AHRI%20Standard%20210.240%20with%20Addenda%201%20and%202.pdf

AHRI. (2015). *Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment.* http://www.digeca.go.cr/sites/default/files/documentos/ahri_standard_340-360_2015.pdf

American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE). (2000). *Compilation of Diversity Factors and Schedules for Energy and Cooling Load Calculations,* ASHRAE Research Report 1093.

ASHRAE. (2014). *Guideline 14-2014 Measurement of Energy, Demand, and Water Savings*.

ASHRAE. (2010). *Performance Measurement Protocols for Commercial Buildings.*

California Public Utilities Commission. (2015-present). Database of Energy Efficient Resources (DEER) Updates. HVAC Measure updates in 2015, 2016, 2017, and 2018-19 Updates. http://deeresources.com/

Consortium for Energy Efficiency (CEE). (2016). *Commercial Unitary AC and HP Specifications, Unitary Air Conditioning Specification*. Effective January 12, 2016. https://library.cee1.org/system/files/library/7559/CEE_ComACHP_UnitarySpec2016.pdf

DNV GL. (2016 and 2017). 2013-14 and 2015 Upstream HVAC Impact Evaluation (HVAC1). Prepared for the California Public Utilities Commission. www.calmac.org

Fairey, P.; Parker, D.; Wilcox, B.; Lombardi, M. (2004). "Climate Impacts on Heating Seasonal Performance Factor (HSPF) and Seasonal Energy Efficiency Ratio (SEER) for Air Source Heat Pumps." ASHRAE Transactions, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., Atlanta, GA, June 2004.

ISO-New England, Inc. (June 2010). *ISO New England Manual for Measurement and Verification of Demand Reduction Value from Demand Resources Manual (M-MVDR)*.

Itron, Inc. (December 2005). *2004-05 Database of Energy Efficient Resources (DEER) Update.* Prepared for Southern California Edison.

Itron, Inc. and KEMA. (December 31, 2008). *2004/2005 Statewide Express Efficiency and Upstream HVAC Program Impact Evaluation.* Prepared for the California Public Utility Commission, Pacific Gas & Electric Company, San Diego Gas & Electric Company, Southern California Edison, and Southern California Gas Company. www.calmac.org/publications/FINAL_ExpressEfficiency0405.pdf.

KEMA. (2009). *Pacific Gas & Electric SmartAC™ 2008 Residential Ex Post Load Impact Evaluation and Ex Ante Load Impact Estimates, Final Report.* Prepared for Pacific Gas and Electric. March.

KEMA. (February 10, 2010). *Evaluation Measurement and Verification of the California Public Utilities Commission HVAC High Impact Measures and Specialized Commercial Contract Group Programs 2006-2008 Program Year.* www.calmac.org/publications/Vol_1_HVAC_Spec_Comm_Report_02-10-10.pdf.

KEMA. (August 2, 2011). *C&I Unitary HVAC Load Shape Project*. Prepared for the Regional Evaluation, Measurement and Verification Forum facilitated by the Northeast Energy Efficiency Partnerships (NEEP).

MA Energy Efficiency Advisory Council (EEAC) Consultant Team. (December 30, 2015). *C&I Innovation – A Review of Upstream Offerings*. http://ma-eeac.org/wordpress/wp-content/uploads/EEAC-CI-Innovation-Upstream-Memo-2015-12-30.pdf

Navigant. (June 2010). "The Sun Devil in the Details: Lessons Learned from Residential HVAC Programs in the Desert Southwest." Presented at *Counting on Energy Programs: It's Why Evaluation Matters*. Paris, France: International Energy Program Evaluation Conference.

Premium Efficiency Cooling Program. (2017). *2017 Equipment Incentive Schedule.* https://www.premiumcooling.com/upload/2017_PECP_Equipment_Incentive_Schedule%20(FINAL).pdf

Regional EM&V Methods and Savings Assumption Guidelines. (May 2010.) Northeast Energy Efficiency Partnerships (NEEP) EM&V Forum.

SAIC. (1998). *New England Unitary HVAC Research Final Report*. Sponsored by New England Power Service Company, Boston Edison Company, Commonwealth Electric, EUA Service Company, and Northeast Utilities.

TecMarket Works. (October 15, 2010). *New York Standard Approach for Estimating Energy Savings from Energy Efficiency Programs- Residential, Multi-Family and Commercial/ Industrial Measures*. Prepared for the New York Public Service Commission. http://efile.mpsc.state.mi.us/efile/docs/16671/0026.pdf. A more recent 2017 version is also available at: http://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/72c23decff52920a85257f1100671bdd/$FILE/TRM%20Version%205%20-%20January%202018.pdf

United Illuminating Company and Connecticut Lighting and Power Company. (October 2008). *UI and CL&P Program Savings Documentation for 2009 Program Year*.

Vermont Energy Investment Corporation. (August 6, 2010). *State of Ohio Energy Efficiency Technical Reference Manual Including Predetermined Savings Values and Protocols for Determining Energy and Demand Savings*. Prepared for the Public Utilities Commission of Ohio.