III Measurement and Verification Guidelines - Retrofit

This section includes detailed information about the measurement and verification (M&V) requirements of the AEP Commercial Standard Offer Program, as well as guidance for Project Sponsors on how to prepare and execute an M&V plan.

Introduction to Measurement and Verification

Overview

In the Commercial (CSOP) Standard Offer Program, the demand and energy savings resulting from a project are determined through measurement and verification (M&V) activities. The M&V methods appropriate for a given measure will depend on the equipment type, operational predictability, and complexity involved in the retrofit. The M&V guidelines provided in the following sections vary in detail and rigor, but fall into three general categories:

- Deemed savings estimates
- Simple M&V approaches
- Full M&V approaches

The M&V methods presented in this section are guidelines for the Project Sponsor for developing project-specific M&V plans. All M&V plans will necessarily be unique and based on project and site conditions, but may have the common elements discussed here. With the exception of lighting measures and window film measures that qualify for deemed savings, these M&V approaches adhere to the standards of the 2001 *International Performance Measurement and Verification Protocol* (IPMVP). The Project Sponsor is welcome to recommend alternate M&V methods. However, any alternate methods must be approved by AEP and adhere to IPMVP standards.

M&V Approaches

AEP has outlined three distinct M&V approaches, representing increasing levels of detail and rigor - deemed savings, simple M&V, and full M&V. One of these three approaches will be taken for all projects associated with the CSOP. The most appropriate method will depend upon the availability of evaluation data from previous programs for particular measures, the predictability of equipment operation, and the benefits of the method relative to the costs associated with the particular M&V method chosen.

Deemed Savings

Deemed savings refer to a savings estimation approach that does not require short-term testing or long-term metering. Instead, demand and energy savings are stipulated based on evaluation data from past DSM programs or other publicly available industry data. The data are used to make assumptions about typical operating characteristics, manufacturer's nameplate efficiency data, and types of equipment likely to be installed. The deemed savings M&V approach is appropriate for energy efficiency measures for which savings are relatively certain, including lighting efficiency, window films, and some cooling equipment retrofits.

Simple M&V

A simple M&V approach may involve short-term testing or simple long-term metering, but relies primarily on manufacturer's efficiency data and pre-set savings calculation formulas. Simplified methods can reduce the need for some field monitoring or performance testing.

For example, chiller energy and demand savings can be determined using the simple approach by comparing rated efficiencies of high-efficiency equipment to standard equipment, and using post-installation kW spot-metering and long-term kWh metering.

Project measures must meet certain criteria in order to determine their savings using a simple M&V approach. These criteria are described in the M&V guidelines that follow.

Full M&V

Full M&V approaches estimate demand and energy savings using a higher level of rigor than the deemed or simple M&V approaches through the application of end-use metering, billing regression analysis, or computer simulation. All measures that do not meet the criteria for a more simplified approach must follow full, industry-standard M&V procedures. All Full M&V methods should be developed in accordance with the 2001 International Performance Measurement and Verification Protocol (IPMVP).

Organization of the Guidelines

The CSOP M&V guidelines define appropriate M&V procedures covering the majority of anticipated energy-efficiency measures (EEMs) that will be installed as part of the CSOP. The simplified and full M&V approaches are an application of the IPMVP adapted for use with this program. Table 1 lists the M&V methods provided in the guideline chapters.

Table 1: M&V approaches and guidelines

M&V Guideline	Energy Efficiency Measure	M&V Approach
1	Lighting Efficiency	Deemed or Simple (depending on building type)
2	Lighting Efficiency and Controls	Deemed or Simple (depending on building type)
3	Cooling equipment retrofits	Deemed, Simple or Full (depending on application)
4	Motor retrofits	Simple or Full (depending on application)
5	Window films	Deemed
6	Various – stipulated savings factors	Simple
7	Generic Variable Loads	Full
8	Various – billing analysis using regression models	Full
9	Various – computer modeling and simulation	Full

Measures that cannot utilize the M&V methods presented herein will be evaluated on a case-by-case basis, and M&V procedures will be defined accordingly.

Steps in the M&V Process

Table 2 highlights the basic steps required during the M&V process for most retrofit projects under this program.

Table 2: Steps in the M&V process

Step	M&V Activity	Performed by:
1	Develop a site-specific M&V plan	Sponsor and Utility
2	Conduct a pre-installation equipment survey	Sponsor
3	Conduct a pre-installation inspection	AEP
4	Install retrofit equipment	Sponsor
5	Conduct a post-installation equipment survey	Sponsor
6	Conduct a post-installation inspection	AEP
7	Execute the M&V plan (conduct M&V activities if necessary)	Sponsor
8	Calculate savings	Sponsor

Developing Project-Specific M&V Plans

This section defines the general guidelines for designing a project-specific M&V plan. Issues and requirements specific to each method are further described in the individual guidelines describing specific M&V methods for particular technologies.

The Project Sponsor should work with AEP to identify an M&V methodology and develop an M&V plan that is appropriate for the retrofits being performed as part of each project. The proposed M&V plan must be submitted with the Final Application (FA) for each project, and must be reviewed and approved by AEP.

A project-specific M&V plan shall demonstrate that any proposed metering and analysis will be done in a consistent and logical manner and with a level of accuracy acceptable to all parties. An M&V plan should be prepared for each project to be defined in a contract agreement, as shown on the approved Final Application.

At a minimum, a project-specific M&V plan should address the following (from the 2001 IPMVP):

1. Describe the project site and the project; include information on how the project saves energy and what key variables affect the realization of savings.
2. Describe the M&V method to be used.
3. Indicate who will conduct the M&V activities and prepare the M&V analyses and documentation.
4. Define the details of how calculations will be made. For instance: "List analysis tools, such as DOE-2 computer simulations, and/or show the equations to be used." A complete "path" should be defined indicating how collected survey and metering/monitoring data will be used to calculate savings. All equations should be shown.
5. Specify what metering equipment will be used, who will provide the equipment, its accuracy and calibration procedures. Include a metering schedule describing metering duration and when it will occur, and how data from the metering will be validated and

reported. Include data formats. Electronic, formatted data read directly from a meter or data logger are recommended for any short- or long-term metering.

6. Define what key assumptions will be made about significant variables or unknowns. For instance: "actual weather data will be used, rather than typical-year data," or "fan power will be metered for one full year for two of the six supply air systems." Describe any stipulations that will be made and the source of data for the stipulations.

7. Define how any baseline adjustments will be made.

8. Describe any sampling that will be used, why it is included, sample sizes, documentation on how sample sizes were selected, and information on how random sample points will be selected.

9. Indicate how quality assurance will be maintained and replication confirmed. For instance: "The data being collected will be checked every month," or "to ensure sufficient accuracy, results will be subjected to third-party review by the ABC company."

1 M&V Guidelines for Lighting Efficiency Measures

1.1 Overview

The lighting projects covered by this M&V procedure are lighting efficiency measures that may include the replacement of existing lamps and ballasts with new energy efficient lamps and ballasts.

For these types of projects, demand savings are based on coincident-load factors and changes in lighting load as determined using standard lighting fixture wattage values listed in the AEP Lighting Table of Standard Fixture Wattages (see Appendix C). To determine energy savings, the Sponsor should establish operating hours using one of two methods:

> **Stipulated Hours Method** – Energy savings are based on whole building stipulated operating hours established for certain building types (See Table 1.1).
>
> **Metered Hours Method** – Energy savings are determined by metering post-installation operating hours using defined sampling techniques.

For lighting efficiency measures installed in electrically cooled spaces, demand and energy savings are also given for lighting-HVAC system interaction. These savings are equal to **10%** of the lighting demand savings and **5%** of lighting energy savings, respectively.

In addition to determining operating hours, the Project Sponsor is required to conduct pre- and post-installation equipment surveys. The Project Sponsor should fill out and submit survey results in the standard Lighting Equipment Survey (FA.6) using fixture codes provided in the Table of Standard Fixture Wattages. AEP or its contractor will conduct pre- and post-installation inspections to verify the reported baseline and retrofit conditions, respectively.

1.2 Stipulated Hours Method

The procedures outlined below should be followed when the project qualifies for using the stipulated hours M&V approach for lighting efficiency projects. Qualifying projects are those accurately characterized by building type and lighting-system operation in Table 1.1. The Stipulated Hours Method may only be used for those building types listed in Table 1.1 without exception. Buildings of types not listed in Table 1.1 are required to use the Metered Hours Method of M&V (see Section 1.3).

1.2.1 Pre-installation M&V Activities

1.2.1.1 Pre-installation equipment survey

Prior to installing the lighting retrofit, the Project Sponsor conducts a pre-installation equipment survey, to be submitted as part of the Final Application. The purpose of the pre-installation equipment survey is to inventory all existing lighting equipment, and to propose the replacement equipment to be installed. This survey should provide the following information about all fixtures: room location, fixture, lamp and ballast types, lighting controls, area designations, counts of operating and non-operating fixtures, and type of control device. Surveys should include all baseline lighting fixtures and controls, regardless of whether they will be retrofitted. Fixture wattages are based on the fixture codes listed in the Table of Standard Fixture Wattages. This information should be tabulated electronically in the Lighting Equipment Survey (FA.6). Refer to Section II, Chapter 4 of this manual for an explanation of Lighting Equipment Survey (FA.6).

Non-operating fixtures

For non-operating fixtures, the baseline demand may be adjusted by using values from the Table of Standard Fixture Wattages. **The number of non-operating fixtures will be limited to 10% of the total fixture count per facility**. If, for example, more than 10% of the total number of fixtures is inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero. Thus, the total baseline demand for the project will be adjusted accordingly.

1.2.1.2 Pre-installation inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline. The criterion for baseline acceptance is that the error in the installed demand must be within ±5% of the demand reported on the Lighting Equipment Survey. If the error exceeds ±5%, the Sponsor is allowed to resubmit corrected lighting tables. If the project fails inspection twice due to incorrect survey forms, the Project Sponsor will bear the cost of subsequent inspections.

The operating hours of the baseline lighting system are assumed to be the same as those of the post-retrofit lighting system and are not measured as part of the pre-installation M&V activities.

1.2.2 Post-installation M&V Activities

1.2.2.1 Post-installation equipment survey

The Sponsor is required to conduct a post-installation lighting equipment survey as part of the Installation Report. The purpose of the post-installation equipment survey is to inventory the actual, as-built post-retrofit equipment. Fixture wattages shall be based on the Table of Standard Fixture Wattages. In the IR, the proposed equipment information listed in the approved Final Application shall be updated to reflect the actual post-retrofit conditions and equipment found during the survey after installation. Any equipment listed in the approved Final Application that was not in fact replaced should remain in the lighting equipment inventory – in this case, simply copy the pre-retrofit information to the post-retrofit columns.

1.2.2.2 Post-installation inspection

AEP or its contractor will conduct a post-installation inspection to verify that the retrofit was installed as reported. In most cases, AEP or its contractor will inspect statistically significant samples taken from the entire lighting population. The criterion for acceptance is that the error in the installed demand of the sample must be within ±5% of the demand reported on the post-installation lighting equipment inventory form. If the error exceeds ±5%, AEP will inform the Sponsor that the submitted lighting survey must be corrected and resubmitted, citing the major cause of the errors found.

1.2.2.3 Operating hours

The **Stipulated Hours Method** uses stipulated annual operating hours as listed in Table 1.1. If this table does not accurately characterize the building type, then the Project Sponsor should refer to the **Metered Hours Method** section for the appropriate M&V techniques for measuring operating hours for lighting efficiency measures.

Table 1.1: Stipulated Operating Hours, Coincidence Factors, and Interactive Savings

Building Type	Stipulated Annual Operating Hours	Avg. On-Peak Demand Coincidence Factor	Interactive HVAC Demand Savings	Interactive HVAC Energy Savings
24-Hour Supermarket/Retail	6,900	95%	10%	5%
College/University	2,085	67%	10%	5%
Education (K-12; no summer session)	2,150	82%	10%	5%
In-Patient Health Care	3,750	60%	10%	5%
Multi-Family Housing, Common Areas	4,772	87%	10%	5%
Non 24-Hour Supermarket/Retail/Restaurant	4,250	95%	10%	5%
Office	3,760	80%	10%	5%
Parking Structure	7,884	100%	0%	0%

The first column in Table 1.1 presents the stipulated, whole-building, annual operating hours for the building types listed. The retrofit energy savings are determined from the operating hours and the kW reduction determined from the lighting tables. The average on-peak demand coincidence factor (CF) in the second column is the ratio of the average on-peak operating hours of all lighting circuits to the total number of AEP on-peak hours during the monitoring period. The retrofit demand savings are determined from the CF in column two and the kW reduction determined from the Table of Standard Fixture Wattages.

1.2.3 Calculation of Demand and Energy Savings

The peak demand savings and energy savings are calculated according to Equations 1.1 through 1.6. Demand savings are only allowed for lighting fixtures that will be in operation on weekdays between the hours of 1 PM and 7 PM during the months of May through September. Total demand savings are calculated by multiplying the kW savings by the CF for the appropriate building type, from Table 1.1. The CF is used to adjust total installed lighting demand for the actual percentage of fixtures operating during AEP's peak demand hours. The CF is also applied to the interactive savings since interactive savings are a direct result of lighting operation.

Interactive HVAC demand and energy savings may be calculated only for lighting retrofits taking place in air-conditioned spaces. Lighting retrofits in unconditioned spaces, such as parking garages, are not eligible for interactive HVAC savings payments. For eligible projects, the interactive HVAC demand savings is a fixed percentage set at **10%** of the lighting demand savings. Similarly, the interactive HVAC energy savings is fixed and equal to **5%** of the lighting energy savings.

1.2.3.1 Peak Demand Savings

Equation 1.1:

Connected Lighting Load Reduction [kW] =	**Pre Lighting Demand [kW] – Post Lighting Demand [kW]**

Equation 1.2:

Interactive HVAC Demand Savings [kW]	**=**	**Connected Lighting Load Reduction [kW] * 0.10**

Equation 1.3:

Total Demand Savings [kW]	**=**	**(Connected Lighting Load Reduction [kW] + Interactive HVAC Demand Savings [kW]) * Coincidence Factor**

1.2.3.2 Energy savings

Equation 1.4:

Lighting Energy Savings [kWh]	**=**	**Connected Lighting Load Reduction [kW] * Annual Operating Hours [hrs]**

Equation 1.5:

Interactive HVAC Energy Savings [kWh]	**=**	**Lighting Energy Savings [kWh] * 0.05**

Equation 1.6:

Total Energy Savings [kWh]	**=**	**Lighting Energy Savings [kWh] + Interactive HVAC Energy Savings [kWh]**

1.2.4 Example

The following is an example of how the M&V procedures described above would be applied using the Stipulated Hours Method to determine the operating hours and annual energy savings.

Example[1]

A lighting efficiency project is proposed for a typical small office building. The Project Sponsor submits the Lighting Inventory survey forms as part of the Final Application detailing the existing and proposed equipment. The table below summarizes the existing and proposed connected lighting load for each usage group in the project. The CF for office buildings is **80%**.

Area Description	Survey Lines	Connected Lighting Load (kW)			Stipulated Operating Hours	Annual kWh Savings	Actual kW Savings
		Existing	Proposed	Difference			
Hallways and Stairs	20	3.6	2.0	1.6	3,760	6,016	1.3
Common Offices	72	66.0	14.4	51.6	3,760	194,016	41.3
Conference Rooms	20	15.6	9.6	6.0	3,760	22,560	4.8
Exit Signs	24	6.0	4.8	1.2	3,760	4,512	1.0
Private Offices	44	59.2	41.2	18.0	3,760	67,680	14.4
Restrooms	20	4.0	2.8	1.2	3,760	4,512	1.0
Total	**200**	**154.4**	**74.8**	**79.6**		**299,296**	**63.7**

Based on the collected data, the demand and energy savings are calculated:

(a) Connected Lighting Load Reduction = 154.4 kW – 74.8 kW
= 79.6 kW.

(b) Interactive HVAC Demand Savings = 79.6 kW * 0.10
= 8.0 kW.

(c) Total Demand Savings = (79.6 kW + 8.0 kW) * 0.80
= 70.1 kW.

(d) Lighting Energy Savings = 79.6 kW * 3,760 hours
= 299,296 kWh.

(e) Interactive HVAC Energy Savings = 299,296 kWh * 0.05
= 14,965 kWh.

(f) Total Energy Savings = 299,296 kWh + 14,965 kWh
= 314,261 kWh.

[1] Projects that consist of only lighting measures receive 65% of the total incentive.

1.3 Metered Hours Method

The **Metered Hours Method** involves monitoring a statistically significant sample of fixtures to determine post-installation operating hours. This involves developing a sampling plan to monitor the average operating hours for each lighting usage group. The Sponsor should conduct all meter installation, retrieval and data analysis.

1.3.1 Pre-installation M&V Activities

1.3.1.1 Pre-installation equipment survey

Prior to installing the lighting retrofit, the Project Sponsor conducts a pre-installation equipment survey, to be submitted as part of the Final Application. The purpose of the pre-installation equipment survey is to inventory all existing lighting equipment, and to propose the replacement equipment to be installed. Surveys shall include all baseline lighting fixtures and controls, regardless of whether they will be retrofitted. Fixture wattages should be based on the Table of Standard Fixture Wattages. This information should be organized by usage group and tabulated electronically in the Lighting Equipment Survey (FA.6). Refer to Section II, Chapter 4 of this manual for an explanation of the Lighting Equipment Survey (FA.6).

Non-operating fixtures

For non-operating fixtures, the baseline demand may be adjusted by using values from the Table of Standard Fixture Wattages. **The number of non-operating fixtures will be limited to 10% of the total fixture count per facility**. If, for example, more than 10% of the total number of fixtures is inoperative, the number of fixtures beyond 10% will be assumed to have baseline fixture wattage of zero. Thus the total baseline demand for the project will be adjusted accordingly.

Usage groups

When performing the pre-installation activities associated with this M&V approach, Project Sponsors should organize the equipment into **usage groups—**collections of equipment (e.g., rooms with lighting fixtures) with similar operating schedules and functional uses. For instance, although a site's open office lighting may have the same annual hours of operation as the private office lighting, the two have different functional uses. In this case, a change in the operating hours of the private office lights due to the installation of an occupancy sensor would not be relevant to the operating hours of the open office lights. Please refer to Table 1.2 to determine the recommended minimum number of usage groups for the project site type.

Table 1.2: Suggested minimum numbers of Usage Groups for project site types

Building Type	Minimum Number of Usage Groups	Examples of Usage Group types
Office Buildings	6	General offices, private offices, hallways, restrooms, conference, lobbies, 24-hr
Education (K-12)	6	Classrooms, offices, hallways, restrooms, admin, auditorium, gymnasium, 24-hr
Education (College/University)	6	Classrooms, offices, hallways, restrooms, admin, auditorium, library, dormitory, 24-hr
Hospitals/ Health Care Facilities	8	Patient rooms, operating rooms, nurses station, exam rooms, labs, offices, hallways
Retail Stores	5	Sales floor, storeroom, displays, private office, 24-hr
Industrial/ Manufacturing	6	Manufacturing, warehouse, shipping, offices, shops, 24-hr
Other	10	N/A

1.3.1.2 Pre-installation inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline. The criterion for baseline acceptance is that the installed demand must be within ±5% of the demand reported on the lighting survey form. If the error exceeds ±5%, the Sponsor is allowed to resubmit corrected lighting tables. If the project fails inspection twice due to incorrect survey forms, the Project Sponsor will bear the cost of subsequent inspections.

The operating hours of the baseline lighting system are assumed to be the same as those of the post-retrofit lighting system and are not measured as part of the pre-installation M&V activities.

1.3.2 Post-installation M&V Activities

1.3.2.1 Post-installation equipment survey

The Sponsor is required to conduct a post-installation lighting equipment survey as part of the Installation Report. The purpose of the post-installation equipment survey is to inventory the actual, installed replacement equipment. Fixture wattages shall be based on the Table of Standard Fixture Wattages. In the IR, the proposed equipment information listed in the approved Final Application should be updated to reflect the actual post-retrofit conditions and equipment found during the survey after installation. Any equipment listed in the approved Final Application that was <u>not</u> in fact replaced should remain in the lighting equipment inventory – in this case, simply copy the pre-retrofit information to the post-retrofit columns.

1.3.2.2 Post-installation inspection

AEP or its contractor will conduct a post-installation inspection to verify that the retrofit was installed as reported. In most cases, AEP or its contractor will inspect statistically significant samples taken from the entire lighting population. The criterion for acceptance is that the installed demand of the sample must be within ± 5% of the total demand submitted on the post-installation survey form. If significant errors are found that cause the error to be greater than ± 5%, AEP will inform the Sponsor that the submitted lighting survey table must be corrected and resubmitted, citing the major cause of the errors found.

1.3.2.3 Post-Installation operating hours

After the lighting retrofit has been installed, the Project Sponsor conducts short-term metering of the operating hours for a random sample of fixtures in each usage group. As part of the FA review and approval, AEP or their contractor can assist the Project Sponsor to randomly select the population of fixtures to be metered.

Metering requirements

For facilities with little variation in weekly operating schedules (such as offices), monitoring shall be conducted for each selected circuit for a recommended minimum of **two to four weeks** during the entire year. Monitoring should not be installed during significant holidays or vacations. If a holiday or vacation falls within the monitoring period, the duration should be extended for as many days as that holiday or vacation. For facilities such as schools, where operating hours vary seasonally, monitoring should be conducted for a minimum period during each season (i.e., in-session [fall], and out-of-session [summer]). In these cases, one of the monitoring periods should depict typical performance during the AEP peak-demand period.

The required sample sizes for each usage group are noted in Table 1.3. Note that, because light loggers sometimes fail, over-sampling is strongly recommended. Light loggers should be calibrated prior to installation to verify that the light loggers are functioning properly.

Table 1.3: Monitoring sample sizes*

Population of Lines in Usage Group (n)	Sample Size
n<4	3
5≤n<8	5
9≤n<12	6
13≤n<20	7
21≤n<70	8
71≤n<300	10
n>300	11

* Sample sizes assume a confidence interval of 80%, precision of 20%, and a coefficient of variation (cv) of 0.5 for the populations indicated.

Calculation of average operating hours

The Sponsor should extrapolate results from the monitored sample to the population to calculate the average lighting operating hours for every unique usage group. Simple, unweighted averages of operating hours should be calculated for each usage group using Equation 1.7. The Sponsor should use these average operating hours to calculate the energy savings for each respective usage group.

Equation 1.7: Calculation of annual operating hours for a usage group

$$Hours_{annual,u} = \frac{\sum_{i=1}^{n}\left[\frac{Hours_{on,i}}{Hours_{metered,i}} * 8{,}760\ ^{hours}/_{year}\right]}{n}$$

Where:

$Hours_{annual,u}$	=	Average annual operating hours for usage group *u*
$Hours_{on,i}$	=	Operating hours observed during the metering period for circuit *i*
$Hours_{metered,I}$	=	Total number of hours in the metering period for circuit *i*
n	=	Number of metered circuits in usage group *u*

Similarly, Equation 1.8 illustrates the calculation of average on-peak demand coincidence factor (CF) for a usage group. The CF multiplied by the difference in baseline and post-installation demand for each usage group, determined from the Table of Standard Fixture Wattages, gives the calculate demand savings. Demand savings are only allowed for lighting fixtures that will be in operation on weekdays between the hours of 1 PM and 7 PM during the months of May through September.

Equation 1.8: Calculation of coincidence factor for a usage group

$$CF_u = \frac{\sum_{i=1}^{n}\left[\frac{Hours_{peak\,on,i}}{Hours_{peak\,metered,i}}\right]}{n}$$

Where:

CF_u	=	Peak-demand coincidence factor for usage group *u*
$Hours_{peak\ on,i}$	=	Equipment on-hours observed during the AEP peak demand period during the metering period for circuit *i*
$Hours_{peak\ metered,i}$	=	Total number of AEP peak demand hours in the metering period for circuit *i*
n	=	Number of metered circuits in usage group *u*

1.3.3 Calculation of Demand and Energy Savings

The peak demand savings and energy savings are calculated according to Equations 1.1 through 1.6 in Sections 1.2.3.1 and 1.2.3.2, and Equations 1.9 and 1.10 below. The hours of operation should be calculated for each usage group and also for each season in which the usage groups' operating hours may vary (as for schools). The annual hours of operation are determined by adding together the operating hours that are calculated for each season. If the operating hours do not vary seasonally, use one year as the "season". Interactive HVAC demand and energy savings may be calculated only for lighting retrofits taking place in conditioned spaces. Lighting retrofits in unconditioned spaces, such as parking garages, are not eligible for interactive HVAC savings payments.

1.3.3.1 Hours of Operation (see Equation 1.7 above)

Equation 1.9:

$$\text{Seasonal Hours of Operation [hrs]} = \frac{\text{Hours Lights On}}{\text{Hours Lights Metered}} * \text{Hours in Season}$$

Equation 1.10:

$$\text{Annual Hours of Operation [hrs]} = \text{Sum of } \{\text{Seasonal Hours of Operation [hrs]}\}$$

1.3.3.2 Peak demand savings

Peak demand savings are calculated using Equations 1.1, 1.2, and 1.3 in Section 1.2.3.1.

1.3.3.3 Energy savings

Energy savings are calculated using Equations 1.4, 1.5, and 1.6 in Section 1.2.3.2.

1.3.4 Example

The following is an example of how the M&V procedures described above would be applied using the Metered Hours Method to determine the operating hours and annual energy savings.

Example[2]

A lighting efficiency project is proposed for a small, non-24-hour retail store. The Project Sponsor submits the Lighting Equipment Survey as part of the Final Application detailing the existing and proposed equipment inventory. The following table summarizes the existing and proposed connected lighting load (including calculated Coincidence Factors) for each usage group in the project, as well as the metering results and annual savings.

In this example, the operating hours are metered according to the required sample size for each usage group in the project. Because there is only one operating season, 13 light loggers are installed for one three-week period. The operating hours for each usage group are the average of observed operating hours from all meters. Using equations (a) through (g), the energy savings for *Receiving* will be

(a) $\text{Annual Operating Hours [hrs]} = \left\{\left[\frac{410}{504}\right] * 8{,}760\right\}$ **= 7,126 [hrs]**

(b) Lighting Demand Savings [kW] = 9.7 [kW] – 5.4 [kW] **= 4.3 [kW]**

(c) Interactive HVAC Demand Savings [kW] = 4.3 [kW] * 0.10 **= 0.4 [kW]**

(d) Total Demand Savings [kW] = {4.3 [kW] + 0.4 [kW]} * 0.82 **= 3.9 [kW]**

(e) Lighting Energy Savings [kWh] = 4.3 [kWh] * 7126 [hrs] **= 30,642 [kWh]**

(f) Interactive HVAC Energy Savings [kWh] = 30,642 [kWh] * 0.05 **= 1,532 [kWh]**

(g) Total Energy Savings [kWh] = 30,642 [kWh] + 1,532 [kWh] **= 32,174 [kWh]**

The energy savings is then calculated for each usage group.

	Equation Solutions						
Usage Group	(a)	(b)	(c)	(d)	(e)	(f)	(g)
Receiving	***7,126***	***4.3***	***0.4***	***3.9***	***30,642***	***1,532***	***32,174***
Continuous	8,760	0.2	0.0	0.2	1,752	88	1,840
Admin. Offices	3,024	0.6	0.1	0.5	1,814	91	1,905
Restrooms	2,120	0.5	0.1	0.5	1,060	53	1,113
Sales Floor	5,840	13.3	1.3	10.8	77,672	3884	81,556
Total				**15.9**			**118,588**

[2] Projects that consist of only lighting receive 65% of the total incentive.

2 M&V Guidelines for Lighting Efficiency Measures with Controls

2.1 Overview

The lighting projects covered by this M&V procedure are lighting efficiency measures in combination with lighting controls retrofit measures. Lighting efficiency measures may include the replacement of existing lamps and ballasts with new energy efficient lamps and ballasts. Controls measures may be occupancy sensors or daylighting controls. Stand-alone lighting controls measures are not eligible for incentives under this program because they do not significantly contribute to peak demand savings.

Demand savings are based on coincident-load factors and changes in lighting load as determined using lighting fixture wattage values listed in the AEP Lighting Table of Standard Fixture Wattages (see Appendix C). Energy savings are determined by subtracting the product of post-installation lighting load and operating hours from the pre-installation lighting load and operating hours for each applicable usage group or circuit in the project.

Changes in lighting load are determined using lighting fixture wattage values indicated in the Table of Standard Fixture Wattages.

The Sponsor should establish pre- and post-installation operating hours using one of the following methods:

> **Stipulated Control Savings Method** – Use stipulated operating hours and Coincidence Factor (CF), depending on building type. Use a stipulated Power Adjustment Factor (PAF) depending on type of lighting control (see Section 2.2 of this chapter).
>
> **Full M&V Method for Lighting Controls** – Meter pre- and/or post-installation operating hours using defined sampling techniques (see Section 2.3 of this chapter). Calculate the CF from metered data.

The method selected and the rigor of the M&V activities are a function of the project site conditions and value.

The demand and energy savings due to the reduction of lighting load on cooling equipment are stipulated. The demand savings are **10%** of the connected lighting load demand reduction, and the energy savings are **5%** of the connected lighting load energy reduction. These savings may only be claimed in conditioned spaces.

In addition to determining operating hours, the Project Sponsor is required to conduct pre- and post-installation equipment surveys. The Project Sponsor should fill out and submit survey results in the standard Lighting Equipment Survey (FA.6) using fixture codes provided in the Table of Standard Fixture Wattages. AEP or its contractor will conduct pre- and post-installation inspections to verify the reported baseline and retrofit conditions, respectively.

2.2 Stipulated Control Savings Method

This method requires the use of the appropriate stipulated hours from Table 2.1 and a PAF from Table 2.2. If values from these tables do not accurately characterize the building type and operation, then the Project Sponsor should refer to the *Full M&V Method for Lighting Controls* in Section 2.3 of this chapter for an appropriate M&V technique.

Table 2.1: Stipulated Operating Hours, Coincidence Factors, and Interactive Savings

Building Type	Stipulated Annual Operating Hours	Avg. On-Peak Demand Coincidence Factor	Interactive HVAC Demand Savings	Interactive HVAC Energy Savings
24-Hour Supermarket/Retail	6,900	95%	10%	5%
College/University	2,085	67%	10%	5%
Education (K-12; no summer session)	2,150	82%	10%	5%
In-Patient Health Care	3,750	60%	10%	5%
Multi-Family Housing, Common Areas	4,772	87%	10%	5%
Non 24-Hour Supermarket/Retail/Restaurant	4,250	95%	10%	5%
Office	3,760	80%	10%	5%
Parking Structure	7,884	100%	0%	0%

The first column in Table 2.1 presents the stipulated, whole-building, annual operating hours for the building types listed. The retrofit energy savings are determined from the operating hours and the kW reduction determined from the lighting tables. The average on-peak demand CF in the second column is the ratio of the average on-peak operating hours of all lighting circuits to the total number of AEP on-peak hours, during the monitoring period. The retrofit demand savings are determined from the CF in column two and the kW reduction determined from the Table of Standard Fixture Wattages.

Table 2.2: Power Adjustment Factors (PAFs)*

Control Type	PAF
Daylight controls (DC) – continuous dimming	0.70
DC – multiple-step dimming	0.80
DC – ON/OFF	0.90
Occupancy sensor (OS)	0.70
OS w/ DC – continuous dimming	0.60
OS w/ DC – multiple-step dimming	0.65
OS w/ DC – ON/OFF	0.65

*PAFs are adapted from ASHRAE Standard 90.1-1989, Table 6-3.

The PAF represents the average reduction in operating hours as a result of installing lighting controls. Multiplying the pre-retrofit (stipulated or measured) lighting operating hours by the PAF for a given control type results in the post-retrofit hours.

2.2.1 Pre-Installation M&V Activities

2.2.1.1 Pre-installation equipment survey

Prior to installing the lighting retrofit, the Project Sponsor conducts a pre-installation equipment survey, to be submitted as part of the Final Application. The purpose of the pre-installation equipment survey is to inventory all existing lighting equipment, and to propose the replacement equipment to be installed. This survey should provide the following information about all fixtures: room location, fixture, lamp, and ballast types, lighting controls, area designations, counts of operating and non-operating fixtures, type of control device, and whether the space is conditioned or unconditioned. Surveys should include all baseline lighting fixtures and controls, regardless of whether they will be retrofitted. Fixture wattages should be based on the Table of Standard Fixture Wattages. This information should be tabulated electronically in the Lighting Equipment Survey (FA.6). Refer to Section II, Chapter 4 of the Sponsor's Manual for an explanation of the Lighting Equipment Survey (FA.6).

Non-operating fixtures

For non-operating fixtures, the baseline demand may be adjusted by using values from the Table of Standard Fixture Wattages. **The number of non-operating fixtures will be limited to 10% of the total fixture count per facility**. If, for example, more than 10% of the total number of fixtures is inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero. Thus the total baseline demand for the project will be adjusted accordingly.

2.2.1.2 Pre-installation inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline. The criterion for baseline acceptance is that the installed demand must be within ±5% of the demand reported on the lighting survey form. If the error exceeds ±5%, the Sponsor is allowed to resubmit corrected lighting tables. If the project fails inspection twice due to incorrect survey forms, the Project Sponsor will bear the cost of subsequent inspections.

The pre-installation operating hours are not measured as part of the pre-installation M&V activities for the **Stipulated Controls Savings Method**. The stipulated pre-installation annual operating hours are listed in Table 2.1. If these tables do not accurately characterize the building type, then the Project Sponsor should refer to the *Full M&V Method Lighting Controls* in Section 2.3 of this chapter for the appropriate M&V techniques for measuring operating hours.

2.2.2 Post-Installation M&V Activities

2.2.2.1 Post-Installation equipment survey

The Sponsor is required to conduct a post-installation lighting equipment survey as part of the Installation Report (IR). The purpose of the post-installation equipment survey is to inventory the actual installed replacement equipment. Fixture wattages shall be based on the Table of Standard Fixture Wattages. In the IR, the proposed equipment information listed in the approved Final Application (FA) should be updated to reflect the actual post-retrofit conditions and equipment found during the survey after installation. Any equipment listed in the approved FA that was not in fact replaced should remain in the lighting equipment inventory – in this case simply copy the pre-retrofit information to the post-retrofit columns.

2.2.2.2 Post-installation inspection

AEP or its contractor will conduct a post-installation inspection to verify that the retrofit was installed as reported and documented. In most cases, AEP or its contractor will inspect statistically significant samples taken from the entire lighting population. The criterion for acceptance is that the installed demand of the sample must be within ±5% of the total demand submitted on the post-installation survey form. If significant errors are found that cause the error to be greater than 5%, AEP will inform the Sponsor that the lighting survey table must be corrected and resubmitted, citing the major cause of the errors found.

2.2.2.3 Operating hours

The **Stipulated Controls Savings Method** uses stipulated annual operating hours and PAF as listed in Table 2.1 and Table 2.2, respectively. The post-installation operating hours are the product of the stipulated pre-installation hours multiplied by the PAF corresponding to the installed control type. Note that the PAF for usage groups with no controls is 1.0, so the pre- and post-installation operating hours are equal. If these tables do not accurately characterize the building or control types under consideration, then the Project Sponsor should refer to the *Full M&V Method Lighting Controls* in Section 2.3 of this chapter for the appropriate M&V techniques for measuring operating hours.

2.2.3 Calculation of Demand and Energy Savings

The peak demand savings and energy savings are calculated according to Equations 2.1 through 2.6. Demand savings are only allowed for lighting fixtures that will be in operation on weekdays between the hours of 1 PM and 7 PM during the months of May through September. Total demand savings are calculated by multiplying the kW savings by the CF for the appropriate building type, from Table 2.1. The CF is used to adjust total installed lighting demand for the actual percentage of fixtures operating during AEP's peak demand hours. The CF is also applied to the interactive savings since interactive savings are a direct result of lighting operation. The PAF is applied to the pre-retrofit (stipulated or measured) lighting operating hours for a given control type, resulting in the post-retrofit hours. No demand savings are credited to the controls.

Interactive HVAC demand and energy savings may be calculated only for lighting retrofits taking place in air-conditioned spaces. Lighting retrofits in unconditioned spaces, such as parking garages, are not eligible for interactive HVAC savings payments. For eligible projects, the interactive HVAC demand savings is a fixed percentage set at **10%** of the lighting demand savings. Similarly, the interactive HVAC energy savings is fixed and equal to **5%** of the lighting energy savings.

2.2.3.1 Peak demand savings

Equation 2.1:

Connected Lighting Load Reduction [kW]	**=**	**Pre Lighting Demand [kW] – Post Lighting Demand [kW]**

Equation 2.2:

Interactive HVAC Demand Savings [kW]	**=**	**Connected Lighting Load Reduction [kW] * 0.10**

Equation 2.3:

Total Demand Savings [kW]	**=**	**(Connected Lighting Load Reduction [kW] + Interactive HVAC Demand Savings [kW]) * Coincidence Factor**

2.2.3.2 Energy savings

Equation 2.4:

Lighting Energy Savings [kWh]	**=**	**{Pre Lighting Demand [kW] – Post Lighting Demand [kW] } * Stipulated Annual Operating Hours [hrs] * PAF[%]**

Equation 2.5:

Interactive HVAC Energy Savings [kWh]	**=**	**Lighting Energy Savings [kWh] * 0.05**

Equation 2.6:

Total Energy Savings [kWh]	**=**	**Lighting Energy Savings [kWh] + Interactive HVAC Energy Savings [kWh]**

2.2.4 Example

The following is an example of how the M&V procedures described above would be applied using the Stipulated Controls Savings Method to determine the operating hours and annual energy savings.

Example*

A lighting efficiency and controls project is proposed for a typical small office building. Controls are to be installed in some common offices and private offices. The Project Sponsor submits the lighitng survey detailing the existing and proposed equipment inventory. The following table summarizes the existing and proposed connected lighting load and operating hours for each usage group in the project. For office buildings, the stipulated operating hours is 3760 hrs and the CF is **80%**.

Area Description	**Connected Load (kW)**		**New control type**	**PAF (Table 2.2)**	**Pre-retrofit hours (Table 2.1)**
	Existing	**Proposed**			
Common Offices w/ controls	9.0	4.3	Daylight control—multi-step dimming	0.8	3,760
Common Offices	10.1	4.1	n/a	1.0	3,760
Private Offices	5.2	2.1	n/a	1.0	3,760
Private Offices w/controls	4.3	2.0	Occupancy sensor	0.7	3,760
Conference Rooms	3.9	1.5	n/a	1.0	3,760
Restrooms†	0.3	0.1	n/a	1.0	3,760

* Projects that consist of only lighting measures receive 65% of the total incentive.

† The stipulated hours for a particular building type are averaged to inlclude all usage types.

Pre-retrofit operating hours are determined using the **Stipulated Hours Method**. The stipulated annual operating hours for office buildings is 3,760 hours/year. Usage groups that are being retrofitted with controls are divided into control and non-control usage groups. The pre-retrofit hours for the control usage groups are multiplied by the PAF corresponding to the type of control being utilized. The post-retrofit hours for the non-control usage groups remain unchanged from the pre-retrofit hours. Using Equations 2.1 through 2.6, the energy savings for the *Common Offices With Controls* will be

(a) Connected Lighting Load Reduction [kW] = 9.0 [kW] – 4.3 [kW] **= 4.7 [kW]**

(b) Interactive HVAC Demand Savings [kW] = 4.7 [kW] * 0.10 **= 0.5 [kW]**

(c) Total Demand Savings [kW] = (4.7 [kW] + 0.5 [kW]) * 0.80 **= 4.2 [kW]**

(d) Lighting Energy Savings [kWh] = {9.0 [kW] – 4.3 [kW]} * 3760 [hrs] * 0.8 **= 14,138 [kWh]**

(e) Interactive HVAC Energy Savings [kWh] = 14,138 [kWh] * 0.05 **= 707 [kWh]**

(f) Total Energy Savings [kWh] = 14,138 [kWh] + 707 [kWh] **= 14,845 [kWh]**

The energy savings is then calculated for each usage group.

Results

Area Description	(a)	(b)	(c)	(d)	(e)	(f)
Common Offices w/ Controls	***4.7***	***0.5***	***4.2***	***14,138***	***707***	***14,845***
Common Offices	6	0.6	5.3	22,560	1,128	23,688
Private Offices	3.1	0.3	2.7	11,656	583	12,239
Private Offices w/ Controls	2.3	0.2	2.0	6,054	303	6,357
Conference Rooms	2.4	0.2	2.1	9,024	451	9,475
Restrooms	0.2	0	0.2	752	38	789
Total			**16.5**			**67,393**

2.3 Full M&V Method for Lighting Controls

This measurement and verification (M&V) procedure is appropriate for projects that involve the installation of lighting controls in combination with the replacement of existing lamps and ballasts. This method requires the Project Sponsor to meter the operating hours of a statistically significant sample of fixtures both before and after measure installation.

The demand and energy savings due to the reduction of lighting load on cooling equipment are stipulated. The demand savings is **10%** of the connected lighting load demand reduction, and the energy savings is **5%** of the connected lighting load energy reduction. These savings may only be claimed in conditioned spaces.

2.3.1 Pre-installation M&V Activities

2.3.1.1 Pre-installation equipment survey

Prior to installing the lighting retrofit, the Project Sponsor conducts a pre-installation equipment survey, to be submitted as part of the FA. The purpose of the pre-installation equipment survey is to inventory all existing lighting equipment, and to propose the replacement equipment to be installed. Surveys shall include all baseline lighting fixtures and controls, regardless of whether they will be retrofitted. Fixture wattages should be based on the Table of Standard Fixture Wattages. This information should be organized by usage group and tabulated electronically in the Lighting Equipment Survey (FA.6). Refer to Section II, Chapter 4 of this manual for an explanation of the Lighting Equipment Survey (FA.6).

Non-operating fixtures

For non-operating fixtures, the baseline demand may be adjusted by using values from the Table of Standard Fixture Wattages. **The number of non-operating fixtures will be limited to 10% of the total fixture count per facility**. If, for example, more than 10% of the total number of fixtures is inoperative, the number of fixtures beyond 10% will be assumed to have a baseline fixture wattage of zero. Thus, the total baseline demand for the project will be adjusted accordingly.

Usage groups

When performing the pre-installation activities associated with this M&V approach (discussed in the following section), Project Sponsors should organize the equipment into **usage groups—**collections of equipment (e.g. motors, rooms with lighting fixtures) with similar operating schedules and functional uses. For instance, although a site's open office lighting may have the same annual hours of operation as the private office lighting, the two have different functional uses. In this case, a change in the operating hours of the private office lights due to the installation of an occupancy sensor would not be relevant to the operating hours of the open office lights. Refer to Table 2.3 for the recommended minimum number of usage groups for the site type.

Table 2.3: Suggested minimum numbers of usage groups for project site types

Building Type	Minimum Number of Usage Groups	Common Usage Groups
Office Buildings	6	General offices, private offices, hallways, restrooms, conference, lobbies, 24-hr
Education (K-12)	6	Classrooms, offices, hallways, restrooms, admin, auditorium, gymnasium, 24-hr
Education (College/University)	6	Classrooms, offices, hallways, restrooms, admin, auditorium, library, dormitory, 24-hr
Hospitals/ Health Care Facilities	8	Patient rooms, operating rooms, nurses station, exam rooms, labs, offices, hallways
Retail Stores	5	Sales floor, storeroom, displays, private office, 24-hr
Industrial/ Manufacturing	6	Manufacturing, warehouse, shipping, offices, shops, 24-hr
Other	10	Function or Usage/Characteristics

Metering Requirements

For facilities with little variation in weekly operating schedules (such as offices), monitoring should be conducted for each selected circuit for a recommended minimum of **two to four weeks** during the entire year. Monitoring should not occur during significant holidays or vacations. If a holiday or vacation falls within the monitoring period, the duration should be extended for as many days as that holiday or vacation. For facilities such as schools, where operating hours vary seasonally, monitoring should be conducted for a minimum period during each season (i.e., in-session [fall], and out-of-session [summer]). Table 2.4 shows the required minimum number of circuits to randomly sample depending on usage group population; note that, because lighting loggers sometimes fail, over-sampling is strongly recommended.

Table 2.4: Metering sample sizes*

Population of Lines in Usage Group (n)	Sample Size
n<4	3
5≤n<8	5
9≤n<12	6
13≤n<20	7
21≤n<70	8
71≤n<300	10
n>300	11

* Sample sizes assume a confidence interval of 80%, precision of 20%, and a coefficient of variation (cv) of 0.5 for the population indicated.

As part of the Final Application M&V plan, the Sponsor should specify the meter to be used on a site-specific basis. The light loggers employed should minimally record date and time and indicate fixture operation in a downloadable electronic format.

2.3.1.2 Pre-installation inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline. The criterion for baseline acceptance is that the installed demand must be within ±5% of the demand reported on the lighting survey form. If significant errors are found, the Sponsor is allowed to resubmit corrected lighting tables. If the project fails inspection twice due to incorrect survey forms, the Project Sponsor will bear the cost of subsequent inspections.

2.3.1.3 Monitoring of pre-installation hours

For fixtures that will have controls installed, the Project Sponsor must monitor the pre-installation operating hours of those lighting fixtures. For usage groups without controls, the pre-installation operating hours will be assumed equal to the monitored post-installation operating hours. These hours are determined by monitoring a statistically significant sample of fixtures in each usage group.

2.3.2 Post-installation M&V Activities

2.3.2.1 Post-Installation equipment survey

The Sponsor is required to conduct a post-installation lighting equipment survey as part of the IR. The purpose of the post-installation equipment survey is to inventory the actual installed replacement equipment. Fixture wattages should be based on the Table of Standard Fixture Wattages. In the IR, the proposed equipment information listed in the approved FA should be updated to reflect the actual, post-retrofit conditions and equipment found during the survey after installation. Any equipment listed in the approved FA that was <u>not</u> in fact replaced should remain in the lighting equipment inventory – in this case, simply copy the pre-retrofit information to the post-retrofit columns.

2.3.2.2 Post-installation inspection

AEP or its contractor will conduct a post-installation inspection to verify that the retrofit was installed as reported. In most cases, AEP or its contractor will inspect statistically significant samples taken from the entire lighting population. The criterion for acceptance is that the installed demand of the sample must be within ±5% of the total demand submitted on the post-installation survey form. If significant errors are found that cause the error to be greater than 5%, AEP will inform the Sponsor that the submitted lighting survey table must be corrected and resubmitted, citing the major cause of the errors found.

2.3.2.3 Post-installation operating hours

The Project Sponsor should determine the post-installation operating hours by monitoring a statistically significant sample of fixtures as documented and verified in the IR. The Project Sponsor should develop a sampling plan to monitor the average operating hours of a sample of fixtures in each usage group, <u>both with and without controls</u>. The required usage group sampling sizes and metering requirements, and equations for calculating average operating hours (Equation 1.7) and CF (Equation 1.8), are defined under *Metering Requirements* in Section 1.3.2.3.

2.3.3 Calculation of Demand and Energy Savings

The pre- and post-installation operation hours are calculated according to Equations 2.7 through 2.10 below. Peak demand savings, and energy savings are calculated according to Equations 2.11 through 2.16 below. The hours of operation should be calculated for each usage group and for each season that the operating hours may vary (as with schools). For each usage group, the annual hours of operation are determined by averaging all the seasonal hours of operation for that usage group. Interactive HVAC demand and energy savings may be calculated *only* for lighting retrofits taking place in conditioned spaces. Lighting retrofits in unconditioned spaces, such as parking garages, are not eligible for interactive HVAC savings payments.

2.3.3.1 Pre-Installation Hours of Operation (Usage Groups with Controls)

Equation 2.7:

$$\text{Average Pre-Seasonal Operating Hours [hrs]} = \frac{\text{Pre-Hours Lights On}}{\text{Pre-Hours Lights Metered}} * \text{Hours in Season}$$

Equation 2.8:

$$\text{Pre-Annual Hours Operating Hours [hrs]} = \text{Sum of \{ Average Pre-Seasonal operating hours [hrs] \}}$$

2.3.3.2 Post-Installation Hours of Operation (All Usage Groups)

Equation 2.9:

$$\text{Average Post-Seasonal Operating Hours [hrs]} = \frac{\text{Post-Hours Lights On}}{\text{Post-Hours Lights Metered}} * \text{Hours in Season}$$

Equation 2.10:

$$\text{Post-Annual Hours of Operation [hrs]} = \text{Sum of \{ Average Post-Seasonal operating hours [hrs] \}}$$

2.3.3.3 Peak Demand Savings

Equation 2.11:

$$\text{Connected Lighting Load Reduction [kW]} = \text{Pre Lighting Demand [kW]} - \text{Post Lighting Demand [kW]}$$

Equation 2.12:

$$\text{Interactive HVAC Demand Savings [kW]} = \text{Connected Lighting Load Reduction [kW]} * 0.10$$

Equation 2.13: (See Equation 1.8 for Coincidence Factor calculation)

Total Demand Savings [kW]	**=**	**(Connected Lighting Load Reduction [kW] + Interactive HVAC Demand Savings [kW]) * Coincidence Factor**

2.3.3.4 Energy savings

Equation 2.14:

Lighting Energy Savings [kWh]	**=**	**{Pre Lighting Demand [kW] * Pre Annual Operating Hours} – {Post Lighting Demand [kW] * Post Annual Operating Hours}**

Equation 2.15:

Interactive HVAC Energy Savings [kWh]	**=**	**Lighting Energy Savings [kWh] * 0.05**

Equation 2.16:

Total Energy Savings [kWh]	**=**	**Lighting Energy Savings [kWh] + Interactive HVAC Energy Savings [kWh]**

Example

A lighting efficiency and controls project is proposed for a small office building. Controls are to be installed in some common offices, private offices, and restrooms. The Project Sponsor submits a lighting survey detailing the existing and proposed equipment inventory. The following table summarizes the existing and proposed connected lighting load (including Coincidence Factors) and operating hours for each usage group in the project.

Usage Group	# of Survey Lines	Connected Lighting Load (kW)		Sample Size[2]	CF	Control Measure	Pre-Installation			Post-Installation		
		Existing	Pro-posed				On	Meter	Season	On	Meter	Season
Common Offices	45	50.5	20.5	9	82%		-	-	8760	450	504	8760
Common Offices w/controls	20	45	21.5	7	75%	Daylight Control	450	504	8760	202	504	8760
Private Offices	20	26	10.5	7	78%		-	-	8760	227	504	8760
Private Offices w/controls	10	21.5	10	6	54%	Occ. Sensor	300	504	8760	205	504	8760
Conf. Rooms	20	19.5	7.5	7	54%		-	-	8760	159	504	8760
Misc. Facilities	30	8.5	4	8	72%		-	-	8760	147	504	8760
Continuous	25	6	2.5	4	100%		-	-	8760	501	504	8760
Restrooms	10	1.5	0.5	3	95%		-	-	8760	135	504	8760
Restroom w/controls	10	3.5	1.5	6	66%	Occ. Sensor	480	504	8760	157	504	8760

[2] For this example, the sample sizes are reduced for certain usage areas below that indicated by the statistical accuracy requirements due to the small amount of savings in certain groups (e.g. restrooms) or the confidence in the estimated operating hours (continuous areas).

In this example, the operating hours are metered according to the required sample size for each usage group in the project. All fixtures have only one operating season; therefore, the light loggers are installed for one three-week pre-installation period (usage groups with controls only), and one three-week post-installation period (all usage groups). The operating hours for each usage group are the average of observed operating hours from all meters. The CF values were determined using **Equation 1.8**.

Using equations (a) through (h), the energy savings for *Common Offices with Controls* will be

(a) $\text{Pre - Annual Operating Hours [hrs]} = \left\{ \left[\frac{450}{504} \right] * 8{,}760 \right\}$ **= 7,821 [hrs]**

(b) $\text{Post - Annual Operating Hours [hrs]} = \left\{ \left[\frac{202}{504} \right] * 8{,}760 \right\}$ **= 3,511 [hrs]**

(c) Connected Lighting Load Reduction [kW] = 45.0 [kW] – 21.5 [kW] **= 23.5 [kW]**

(d) Interactive HVAC Demand Savings [kW] = 23.5 [kW] * 0.10 **= 2.4 [kW]**

(e) Total Demand Savings [kW] = { 23.5 [kW] + 2.4 [kW]} * 0.75 **= 19.4 [kW]**

(f) Lighting Energy Savings [kWh] = 45.0 [kW] * 7,821 [hrs] – 21.5 [kW] * 3511 [hrs]

= 276,459 [kWh]

(g) Interactive HVAC Energy Savings [kWh] = 276,459 [kWh] * 0.05 **= 13,823 [kWh]**

(h) Total Energy Savings [kWh] = 276,459 [kWh] + 13,823 [kWh] **= 290,282 [kWh]**

The energy savings are then calculated for each usage group.

Equation Solutions

Usage Groups	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(f)**	**(g)**	**(h)**
Common Offices	-	7,821	30.0	3.0	27.1	234,630	11,732	246,362
Common Offices w/Controls	***7,821***	***3,511***	***23.5***	***2.4***	***19.4***	***276,459***	***13,823***	***290,282***
Private Offices	-	3,945	15.5	1.6	13.3	61,148	3,057	64,205
Private Offices w/Controls	5,214	3,563	11.5	1.2	6.8	76,471	3,824	80,295
Conference Rooms	-	2,764	12.0	1.2	7.1	33,168	1,658	34,826
Misc. Facilities	-	2,555	4.5	0.5	3.6	11,498	575	12,073
Continuous	-	8,708	3.5	0.4	3.9	30,478	1,524	32,002
Restrooms	-	2,346	1.0	0.1	1.0	2,346	117	2,463
Restrooms w/Controls	8,343	2,729	2.0	0.2	1.5	25,107	1,255	26,362
Total					**83.8**	**751,305**		**788,870**

3 M&V Guidelines for Replacement of Cooling Equipment

3.1 Overview

Cooling equipment retrofits involve the replacement of the existing equipment with high-efficiency equipment. This chapter presents both a deemed savings approach and a simple approach to the measurement and verification of savings from the retrofit of cooling equipment. In general, the measurement and verification (M&V) methods described in this chapter can be used for projects involving the one-for-one change-out of cooling equipment. Potential qualifying equipment includes:

- Unitary air conditioners (DX, air-cooled, evaporative, or water-cooled)
- Heat pumps (air-cooled, evaporative, or water-cooled)
- Chillers (air-cooled centrifugal, water-cooled centrifugal, air-cooled screw, etc.)
- Compressors (centrifugal, screw, reciprocating)
- Fuel switching from electric to gas-driven cooling equipment

The retrofits must have the following characteristics:

- The newly installed electric cooling equipment capacity must be within **80%** to **120%** of the replaced electric cooling equipment capacity.
- No additional measures are being installed that directly affect the operation of the cooling equipment (i.e., control sequences, cooling towers, condensers).

If the proposed retrofit does not meet these requirements, refer to the Full M&V guidelines presented in Chapters 7, 8, and 9 for appropriate M&V techniques.

The baseline efficiency used in the savings calculation is based on ASHRAE Standard 90.1-1989. Efficiency values from this standard can be found in the Standard Cooling Equipment Tables, Appendix A.

3.2 Deemed Savings for Cooling Equipment

The *deemed savings* approach to M&V for cooling equipment is applicable to both one-for-one equipment replacement as well as equipment replacement involving a change in equipment type, e.g. changing from air-cooled DX units to a water-cooled chiller.

Projects that are eligible to use the deemed savings approach meet the following requirements:

- The existing and proposed cooling equipment are electric.
- The Project Sponsor and AEP agree on the correct climate zone to use for the calculation.
- Coefficients are listed in Tables A.10 through A.13 for the type of building in which the retrofit occurs and the type of equipment involved.

- The building falls into one of the categories described in Table 3.1.

Table 3.1: Building descriptions for use in the air-conditioning equipment deemed savings M&V methodology

Building Type	Description
Religious Worship	A religious worship building that experiences full operation on Sundays, and a partial schdule on weekdays and Saturdays.
College	A multi-story college building that operates a full day five days per week and a partial day on weekends.
Convenience	A small convience store that operates 24 hours per day, 7 days per week.
Fast-Food	A small fast food restaurant that operates a full day, seven days per week. Generally smaller than 3,000 sq. ft.
Grocery	Typical supermarket that operates between 16 and 24 hours per day, 7 days per week.
Hospital	A multi-story hospital building that operates 24 hours per day, 7 days per week.
Hotel	A typical multi-story hotel that operates 24 hours per day, 7 days per week. Usually larger than 50,000 sq. ft.
Motel	A low rise motel that operates 24 hours per day, 7 days per week. Usually smaller than 50,000 sq. ft.
Nursing Home	An assisted care facility that operates 24 hours per day, 7 days per week.
Office, Large	Typical multi-story office building that operates 12 to 16 hours per day, Monday through Friday, a half day on Saturday and a few hours on Sunday. Applicable for buildings greater than 50,000 sq. ft.
Office, Small	Typical low rise office building that is operated mostly Monday through Friday and a minimal number of hours on Saturday and Sunday. Applicable for buildings up to 50,000 sq. ft.
Public Assembly	A large public assembly building that operates on a partial schedule all days.
Retail	Retail store that operates typical business hours Monday through Saturday and a reduced day on Sundays.
Restaurant	Typical small restaurant operating full day six days per week with a reduced schedule on Sundays. Generally larger than 3,000 sq. ft.
School	A low rise elementary or high school that operates all day Monday through Friday, 50 weeks per year.
Service	A light commercial building that operates a full day six days per week. Examples include beauty parlors, automotive shops and so on.
Warehouse, Non Refrig.	A conditioned warehouse, not refrigerated, that operates 24 hours/ day, 7 days per week.

Tables A.10 through A.13 do not list coefficients for every type of cooling equipment in every building type. For example, the deemed savings M&V approach is not available for water-cooled chillers for small building types such as convenience stores and fast food restaurants because water-cooled chillers are uncommon in these types of buildings.

3.2.1 Pre-Installation M&V Activities

3.2.1.1 Pre-installation Site Survey

The goals of the pre-installation site survey are to identify the cooling equipment and establish the baseline efficiency. The information collected should include: equipment type, year, make/model, rated capacity, rated efficiency.

The baseline efficiency is determined by comparing the rated efficiency of the existing unit to the minimum efficiency listed in the Standard Cooling Equipment Table, which are based on ASHRAE 90.1-1989, provided in Appendix A. The baseline efficiency is equal to the more efficient of the two values.

3.2.1.2 Pre-installation Inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline in the FA. **Demolition or removal of existing equipment and/or installation of new equipment cannot commence until the pre-installation inspection is completed and AEP has issued the Project Authorization**

3.2.1.3 Pre-installation Performance Monitoring

The deemed savings M&V procedure for electric-to-electric cooling equipment replacements does not require pre-installation monitoring of existing equipment. The existing equipment efficiency is determined from the Standard Cooling Equipment Tables, Appendix A. The existing equipment load and operating schedule are assumed to be the same as those of a typical facility in a specific building type group.

3.2.2 Post-Installation M&V Activities

3.2.2.1 Post-installation Equipment Survey

Once the new equipment retrofit is complete, the Sponsor conducts and submits a post-installation equipment survey as part of the Installation Report (IR). The survey should include: installed equipment type, year, and make/model, rated capacity, and rated efficiency. The cooling equipment description and its location should be included with the IR submittal.

The Sponsor must submit manufacturer's documentation of the rated efficiency of all newly installed cooling equipment, based upon ARI test conditions. This documentation will be in the form of manufacturer cut sheets or factory performance test results that document the part load performance of the equipment.

3.2.2.2 Post-installation Inspection

AEP or its contractor will conduct a post-installation inspection to verify that the equipment was installed as reported and is documented accurately.

3.2.3 Deemed Savings Calculations

The deemed savings methodology involves the application of two mathematical equations shown in Equation 3.3 and Equation 3.4.

Equation 3.1: Calculation of peak demand savings for cooling equipment

$$kW_{\text{savings}} = Tons * (a \cdot \eta_{\text{baseline}} - b \cdot \eta_{\text{post-installation}})$$

Where:

kW_{savings}	=	Calculated demand savings
$Tons$	=	the rated equipment cooling capacity at ARI standard conditions
a	=	The demand coefficient from the applicable table (A.10 through A.13) in the Appendix for the appropriate climate zone, building type and baseline equipment type.
η_{baseline}	=	Efficiency of the baseline equipment (kW/Ton)
b	=	The demand coefficient from the applicable table (A.10 through A.13) in the Appendix for the appropriate climate zone, building type and retrofit equipment type.
$\eta_{\text{post-installation}}$	=	Rated efficiency of the installed equipment (kW/Ton)

Equation 3.2: Calculation of energy savings for cooling equipment

$$kWh_{\text{savings}} = Tons * (c \cdot \eta_{\text{baseline}} - d \cdot \eta_{\text{post-installation}})$$

Where:

kWh_{savings}	=	Calculated energy savings
$Tons$	=	the rated equipment cooling capacity at ARI standard conditions
c	=	The energy coefficient from the applicable table (A.10 through A.13) in the Appendix for the appropriate climate zone, building type and baseline equipment type.
η_{baseline}	=	Efficiency of the baseline equipment (kW/Ton)
d	=	The energy coefficient from the applicable table (A.10 through A.13) in the Appendix for the appropriate climate zone, building type and retrofit equipment type.
$\eta_{\text{post-installation}}$	=	Rated efficiency of the installed equipment (kW/Ton)

To calculate savings for cooling equipment retrofits using the deemed savings methodology, follow these steps:

1. Determine the applicable baseline efficiency for the existing equipment in kW/ton (η_{baseline}). Record either the minimum baseline efficiency (ASHRAE 90.1-1989), or the actual full load rated efficiency if it is better than ASHRAE 90.1-1989.

Use the following conversions to get kW/Ton where necessary[3]:

kW/ton = 12 / EER

kW/ton = 3.516 / COP

kW/ton = 12 / (SEER*0.697 + 2.0394)

2. Determine the applicable efficiency for the new equipment in kW/ton ($\eta_{\text{post-installation}}$).
3. Determine the applicable equipment capacity (*Tons*). Record the lesser of the existing unit tonnage or the replacement unit tonnage.
4. Determine the applicable demand and energy coefficients (*a, b, c,* and *d*). Go to the applicable table (A.10 through A.13) in Appendix A. Look up the demand and energy coefficients for the appropriate building and equipment type.
5. Use equations 3.1 and 3.2 to calculate peak demand and energy savings.

Example

A 150-ton air-cooled packaged unit in a retail application is being replaced with a more efficient unit (of similar size and type) in Brownsville, TX.

Step 1 The Sponsor finds the appropriate baseline efficiency from Appendix A, Table A.6. A 150-ton air-cooled packaged unit has an EER of 8.2. Using the conversion, kW/Ton = 12/EER, the sponsor finds that η_{baseline} = 1.46 kW/Ton.

Step 2 The manufacturer's data for the new equipment shows that the EER = 9.5. Using the conversion, kW/Ton = 12/EER, the sponsor finds that $\eta_{\text{post-installation}}$ = 1.26 kW/Ton.

Step 3 The existing and new packaged units are each 150-ton units.

Step 4 The sponsor looks in Appendix A, Table A.13 to find the appropriate coefficients. The demand coefficient for a retail building with a DX air-cooled unit in Brownsville is 0.84, so $a = b$ = 0.84. The energy coefficient for a retail building with a DX air-cooled unit in Brownsville is 2,917, so $c = d$ = 2,917.

Step 5 By inserting the information gathered in Steps 1-4 into Equations 3.1 and 3.2, the Sponsor calculates the savings:

$$kW_{savings} = 150 * (0.84 * 1.46 - 0.84 * 1.26) = 25.2\ \text{kW}$$

$$kWh_{savings} = 150 * (2{,}917 * 1.46 - 2{,}917 * 1.26) = 87{,}510\ \text{kWh}$$

In some cases where a piece of cooling equipment is replaced with a different type of cooling equipment, adjustments must be made to the savings calculations. The replacement of an air-cooled machine with a water-cooled machine is an example. In this case, the savings calculations must consider the additional auxiliary loads for the condenser water pump and the cooling tower fan. Energy and peak demand savings will need to be adjusted

[3] The conversion from SEER to kW/ton is an approximation based on published data from the Carrier Corporation

downward to account for the peak demand and energy consumption of the auxiliary equipment. The next example, below, provides an illustration of the required calculation. The Project Sponsor must include information about the auxiliary equipment in the required SOP submittals.

Example

A 200 ton air-cooled chiller with condenser is replaced with a water-cooled chiller of the same size in a large office building in Houston, TX.

Step 1 The Sponsor finds the appropriate baseline efficiency from Appendix A, Table A.7. A 200-ton air-cooled chiller with condenser has an COP = 2.50. Using the conversion, kW/ton = 3.516 / COP, the sponsor finds that η_{baseline} = 1.407 kW/Ton.

Step 2 The manufacturer's data for the new equipment shows that the COP = 4.9. Using the conversion, kW/ton = 3.516 / COP, the sponsor finds that $\eta_{\text{post-installation}}$ = 0.718 kW/Ton.

Step 3 The existing and new chillers are each 200-ton units.

Step 4 The sponsor looks in Appendix A, Table A.12 to find the appropriate coefficients. The demand coefficient for a large office building with an air-cooled chiller in Houston is 0.81, so a = 0.81. The demand coefficient for a large office building with a water-cooled chiller in Houston is 0.90, so b = 0.90. The energy coefficient for a large office building with air-cooled chiller in Houston is 2,501, so c = 2,501. The energy coefficient for a large office building with a water-cooled chiller in Houston is 2,786, so d = 2,786.

Step 5 By inserting the information gathered in Steps 1-4 into Equations 3.1 and 3.2, the Sponsor calculates the savings:

$$kW_{savings,GROSS} = 200*(0.81*1.407 - 0.90*0.718) = 98.7\ \text{kW}$$

$$kWh_{savings,GROSS} = 200*(2{,}501*1.407 - 2{,}786*0.718) = 303{,}712\ \text{kWh}$$

Extra Step: Additional Adjustments for Auxiliary Equipment The equipment efficiency for the air-cooled chiller includes the condenser fans, but the equipment efficiency for the water-cooled chiller does not include the condenser water pump and cooling tower. Therefore, the savings must be reduced to account for the peak demand and energy consumption of the water-cooled system's additional equipment. Assuming a 5 hp condenser pump and a 5 hp cooling tower fan is added as a part of the retrofit, the kW and kWh savings are reduced as follows:

$$kW_{\text{CW pump and CT fan}} = (5+5)\text{hp} * .746\ \text{kW/hp} \ / \ .86\ (\text{efficiency}) * .80 (\text{load factor}) = 7\ \text{kW}$$

$$kWh_{\text{CW pump and CT fan}} = 7\ \text{kW} * 8760\ \text{hours} = 61{,}320\ \text{kWh}$$

$$kW_{\text{saving,NET}} = 98.7 - 7.0 = 91.7\ \text{kW}$$

$$kWh_{\text{savings,NET}} = 303{,}712 - 61{,}320 = 242{,}392\ \text{kWh}$$

3.3 Simple M&V for Cooling Equipment

The simple M&V procedure for electric-to-electric cooling equipment replacement involves collecting one year of post-consumption kWh data. To determine demand savings, the maximum equipment demand that occurs during the utility peak summer hours must be measured. This can be accomplished with continuous demand metering or spot metering during peak conditions.

3.3.1 Pre-Installation M&V Activities

3.3.1.1 Pre-installation Site Survey

The goals of the pre-installation site survey are to identify the existing equipment, evaluate its schedule of use, and establish the baseline efficiency or coefficient of performance (COP). The Project Sponsor will conduct a survey of all the existing cooling equipment for buildings with a central plant, regardless of whether they will be retrofitted. The information collected should include: equipment type, year, make/model, rated capacity, rated efficiency, operating schedule, and operating sequence. The information will be needed to complete the program application process.

The baseline efficiency is determined by comparing the rated efficiency of the existing unit to the minimum efficiency listed in the Standard Cooling Equipment Table, which are based on ASHRAE 90.1-1989, provided in Appendix A. The baseline efficiency is equal to the more efficient of the two values.

3.3.1.2 Pre-installation Inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline in the FA. The M&V administrator will make any necessary corrections to the pre-installation survey based on the results of the inspection. **Demolition or removal of existing equipment and/or installation of new equipment cannot commence until the pre-installation inspection is completed and AEP has issued the Project Authorization**

3.3.1.3 Pre-installation Performance Monitoring

The simple M&V procedure for electric-to-electric cooling equipment replacements does not require pre-installation monitoring of existing equipment. The existing equipment efficiency is determined from the Standard Cooling Equipment Tables, Appendix A. The existing equipment load and operating schedule are assumed to be the same as those of the post-retrofit equipment.

The simple M&V procedure for electric-to-gas cooling equipment replacement does require pre-installation monitoring of the existing equipment. The maximum demand (measured for a one-hour period) that coincides with the utility peak demand period must be determined, through spot measurements or continuous metering.

3.3.2 Post-Installation M&V Activities

3.3.2.1 Post-installation Equipment Survey

Once the new equipment retrofit is complete, the Sponsor conducts and submits a post-installation equipment survey as part of the Installation Report (IR). The survey should include: installed equipment type, year, and make/model, rated capacity, rated efficiency, operating schedule, and operating sequence. The cooling equipment description, its location, as well as mechanical design drawings should be included with the IR submittal.

The Sponsor must submit manufacturer's documentation of the rated efficiency of all newly installed cooling equipment, based upon ARI test conditions. This documentation will be in the form of manufacturer cut sheets or factory performance test results that document the part load performance of the equipment.

3.3.2.2 Post-installation Inspection

AEP or its contractor will conduct a post-installation inspection to verify that the retrofit was installed as reported and is documented accurately.

3.3.2.3 Post-installation Performance Monitoring

Two basic steps comprise the necessary post-retrofit M&V monitoring activities for electric-to-electric cooling equipment replacements:

1. Measure the maximum demand (measured for a one hour period) that occurs between the hours of 1 PM and 7 PM on weekdays during the months of May through September. This can be accomplished with continuous demand metering (at 15-minute intervals) or a spot measurement during peak conditions.

2. Collect twelve months of post-installation consumption (kWh) data.

For electric-to-gas fuel switching cooling equipment replacements, there are no post-installation metering requirements in the simple M&V procedure.

3.3.3 Calculation of Demand and Energy Savings

3.3.3.1 Electric to Electric Equipment Replacements

Incentive payments based on demand and energy savings are made for electric-to-electric cooling equipment replacement measures. However, demand savings are allowed only for new equipment that will be in operation on weekdays between the hours of 1 PM and 7 PM Monday through Friday for the months of May through September. Peak demand and energy savings are calculated according to Equation 3.3 and Equation 3.4, respectively.

Equation 3.3: Peak Demand Savings

$$\Delta kW = kW_{meter} \cdot \left\{ \left[\frac{COP_{new}}{COP_{base}} \right] - 1 \right\}$$

Where:

kW_{meter}	=	Maximum 15-minute cooling equipment demand measured during the utility peak-demand period.
COP_{new}	=	Newly-installed cooling equipment coefficient-of-performance (COP) at ARI design conditions.
COP_{base}	=	Baseline efficiency for retrofitted cooling equipment from Appendix A.

Equation 3.4: Energy Savings

$$\Delta kWh = kWh_{meter} \cdot \left\{ \left[\frac{COP_{new}}{COP_{base}} \right] - 1 \right\} * \left(\frac{CDD(65)_{TMY}}{CDD(65)_{meter}} \right)$$

Where:

kWh_{meter}	=	Summed metered kWh cooling equipment energy use determined for one year.
COP_{new}	=	Newly-installed cooling equipment coefficient-of-performance (COP) at ARI design conditions.
COP_{base}	=	Baseline efficiency for retrofitted cooling equipment from Appendix A.
$CDD(65)_{TMY}$	=	Cooling degree days (base 65 F) for a typical meteorological year (TMY) for the National Climatic Data Center (NCDC) station nearest the site. The value is available in Appendix A, Table A.9.
$CDD(65)_{meter}$	=	Cooling degree days (base 65 F) determined for the metering period for the National Climatic Data Center (NCDC) station nearest the site. The value is determined by AEP based on the metering period start and stop dates.

Example

In a Houston office building, a 600-ton, water-cooled, electric centrifugal chiller is replaced with a new chiller of the same type and capacity. The new chiller has an ARI rated COP of 6.6 (0.530 kW/ton). After one year of metering the new chiller energy use totals 697,374 kWh. The maximum demand recorded for the chiller during the metering period that coincided with the utility peak demand period was 286 kW.

This measure is a one-for-one electric chiller replacement. The chiller's performance exceeds the minimum COP (has a higher efficiency) required by the program. One year of continuous, energy-consumption data has been collected. Thus, this measure qualifies for the simple M&V analysis procedure. To complete the savings calculation for the simple M&V, the following additional information is required:

- ASHRAE 90.1-1989 minimum chiller efficiency
- The NCDC station nearest the site
- The NCDC station TMY CDD(65) – Provided in the Appendices.
- The NCDC station CDD(65) determined for the metering period

From Standard Cooling Equipment Tables, the minimum COP for a water-cooled centrifugal chiller of 300 tons or more is **4.7** (or 0.748 kW/ton; see the Standard Cooling Equipment Tables). The NCDC weather station is the **Houston** station. The cooling degree day data for the station are **2810 (°F day) for TMY2** and **2675 (°F day) for the metering year**.

Based on the collected data and system characteristics, the demand savings are determined to be:

$$\Delta kW = kW_{meter} * \left\{ \left[\frac{COP_{new}}{COP_{base}} \right] - 1 \right\}$$

$$\Delta \mathrm{kW} = 286 * \left\{ \left[\frac{6.6}{4.7} \right] - 1 \right\}$$

Thus, the estimated demand savings are **115.6 kW**.

Based on the collected data and system characteristics, the energy savings are determined to be:

$$\Delta kWh_{chiller} = kWh_{meter} * \left\{ \left[\frac{COP_{new}}{COP_{base}} \right]_{rated} - 1 \right\} * \left(\frac{CDD(65)_{TMY}}{CDD(65)_{meter}} \right)$$

$$\Delta \mathrm{kWh} = 697{,}374 * \left\{ \left[\frac{6.6}{4.7} \right] - 1 \right\} * \left(\frac{2810}{2675} \right)$$

Thus, the energy savings are **296,145 kWh**.

3.3.3.2 Electric to Gas Equipment Replacements (Fuel switching)

Incentive payments based on demand and energy savings are made for electric-to-gas fuel switching projects involving the replacement of cooling equipment. Demand savings are allowed only for equipment that operates on weekdays between the hours of 1 P.M. and 7 P.M. Monday through Friday for the months of May through September. Peak demand savings are calculated according to Equation 3.5.

Equation 3.5: Peak Demand Savings for Fuel Switching Measures

$$\Delta kW = kW_{meter}$$

Where:

kW_{meter}	=	Maximum existing, electric, cooling equipment demand measured during the utility peak-demand period

Energy savings are calculated by subtracting the new fuel consumption (converted to kWh using a heat rate of 10,500 Btu/kWh) from the pre-installation energy consumption. Energy savings are calculated according to Equation 3.6.

Equation 3.6: Energy Savings for Fuel Switching Measures

$$\Delta \text{kWh} = \text{kWh}_{\text{meter}} - \text{Btu}_{\text{gas}} \times \left(\frac{1}{10{,}500\ (\text{Btu/kWh})} \right)$$

Where:

kWh_{meter}	=	Existing, electric, cooling equipment annual energy consumption measured or predicted
Btu_{gas}	=	Measured annual post-retrofit gas consumption

4

Simple M&V Guidelines for Constant Load Motor Measures

4.1 Overview

This measurement and verification (M&V) method is appropriate for projects involving existing motors serving a constant load being replaced with higher efficiency motors of equal or lesser capacity (horsepower). The rated efficiency of the new motor must exceed the minimum efficiency standard defined in the Table of Standard Motor Efficiencies in Appendix B to be eligible for the program. Potential retrofit equipment includes:

- Constant load chilled water, hot water, or condenser water pumps
- Constant speed exhaust, return, and supply fans without dampers or pressure controls
- Single-speed cooling tower fans
- Constant load industrial processes
- Similar capacity, constant speed, energy efficiency motors
- Smaller, constant speed, energy efficiency motors when the existing motor is oversized

These M&V procedures are not appropriate for motor change outs that are accompanied by:

- Changes in operating schedule
- Changes in operating hours
- Changes in flow rate
- Changes in motor controls (except VSDs)

If the proposed retrofit does not meet the constant load requirements, or involves scheduling or operational changes, refer to the *Full M&V Guidelines for Generic Variable Loads* in Chapter 7 for appropriate M&V techniques.

In the CSOP, the calculation of demand and energy savings for motor replacements is based on the baseline and post-installation kW, the difference in efficiency of the baseline and new motors, and the motor operating hours. The operating hours are assumed the same for existing and new motors. The baseline motor efficiency is based on the minimum efficiency rating defined by the Table for Standard Motor Efficiencies in Appendix B. The Table of Standard Motor Efficiencies is categorized by motor size and rotation speed. No incentive payments are made for replacement motors with efficiencies equal to or less than the baseline efficiency. In addition to having a higher efficiency than baseline motors, all new motors should meet minimum equipment standards as defined by state and federal law.

The recommended M&V approach for motors includes some or all of the following data collection activities:

- Compiling inventories for existing and new motors
- Short-term metering of existing motors to verify constant loading (if warranted)

- Spot metering of all existing and new motors
- Short-term metering of a sample of the new motors to determine operating hours

4.2 Determination of Baseline Operating Characteristics

The M&V steps that characterize the existing motors are:

1. Pre-installation equipment survey (to be conducted by the Sponsor)
2. Spot measurement of demand (kW), and short-term metering of existing motors, where needed (to be conducted by the Sponsor)
3. Pre-installation inspection (to be conducted by AEP or its contractor)

4.2.1 Pre-installation Equipment Survey

The Sponsor should conduct a pre-installation survey to inventory the equipment to be replaced. Motor location and corresponding facility mechanical plans should be included with the survey submittal as part of the Final Application. At a minimum, the surveys should include the following for each existing motor:

- Motor name
- Load served
- Motor location
- Operating schedule
- Equipment manufacturer
- Nameplate data including model, horsepower, and speed

The baseline motor efficiency should be determined from the Table of Standard Motor Efficiencies based on the existing motor data provided in the Final Application.

Any M&V activities that need to be conducted prior to the demolition of existing equipment (i.e., short-term measurements) should take place at this time. **Demolition of existing equipment and/or installation of new equipment cannot begin until baseline M&V activities are completed, the pre-installation inspection is completed, and AEP has approved the Final Application and issued a Project Authorization.**

4.2.2 Spot and Short-term Measurement of Existing Motors

To establish the baseline kW, the Sponsor must conduct spot measurements of the power draw of the existing motors. If the constant load criterion cannot be verified by visual inspection, then short-term metering of the power draw or current (amperes) of the existing motors may also be required.

The verification of constant motor loading by short-term metering is warranted in situations where the effect of piping, valves, controls, or processes on motor load is uncertain. A motor load is considered to be constant if **90%** of all non-zero observations are within **±10%** of the running average kW. If short-term metering demonstrates that the proposed retrofit does not meet the constant load definition, then the Sponsor should refer to the *Full M&V Guidelines for Generic Variable Loads* in Chapter 7 for appropriate M&V techniques.

To compensate for the variations in spot measurements that occur even in constant-load motors, the Sponsor may need to develop normalization factors for groups of like motors serving similar loads. A normalization factor is the ratio of a motor's average current (from short-term metering) to its spot measured current. AEP may require the use of a normalization factor for projects with a group or groups of identical motors.

The minimum efficiency standard for the existing motor type is listed in the Table of Standard Motor Efficiencies. If the efficiency of the existing motor is greater than or equal to the minimum efficiency standard, then the baseline demand is equal to the spot measured value. If not, then the baseline demand is calculated according to Equation 4.1.

Equation 4.1:

$$\text{Baseline Demand [kW]} = \frac{\text{Existing Motor Efficiency}}{\text{Standard Minimum Efficiency}} * \text{Spot Measured Existing Motor Demand [kW]}$$

4.2.3 Pre-installation Inspection

AEP will conduct a pre-installation inspection to verify that the existing condition is as reported in the pre-installation equipment survey in the Final Application. AEP will require the Sponsor to make any necessary corrections to the Final Application based upon the results of the inspection.

Demolition of existing equipment and/or installation of new equipment cannot begin until the pre-installation inspection is completed and AEP has approved the Final Application and issued a Project Authorization.

4.3 Document Post-Retrofit Operating Characteristics

The M&V steps that characterize the new motors are:

1. Post-installation equipment survey (to be conducted by the Sponsor)
2. Spot measurements of the power draw (one-hour average values) of all the new motors (to be conducted by the Sponsor)
3. Post-installation inspection (to be conducted by AEP or its contractor)
4. Short-term metering of operating hours for a sample of existing motors (to be conducted by the Sponsor)

4.3.1 Post-installation Equipment Survey

The Sponsor shall conduct a post-installation equipment survey, similar to the pre-installation equipment survey described above. The survey shall reflect the actual, as-built conditions of the project. The post-installation survey will be included in the Installation Report.

4.3.2 Spot Measurements of Motor Demand

The Sponsor must conduct spot measurements of the power draw (one-hour average values) of each new, high-efficiency motor in order to establish the post-installation demand. The Sponsor will report the measured kW as part of the Installation Report.

4.3.3 Post-installation Inspection

Once AEP receives the Installation Report for the motor project, AEP or its contractor will conduct a post-installation inspection to verify that the equipment specifications are correctly reported in the Installation Report. AEP will require the Sponsor to make any necessary corrections to the Installation Report based upon the results of the inspection.

4.3.4 Short-term Metering of Motor Operating Hours

Baseline motor operating hours are assumed to be the same as post-installation operating hours, and should be determined after new motor installation. Short-term metering is used to determine both pre- and post-installation operating hours.

After AEP approves the Installation Report, the Sponsor should begin short-term metering of motor operating hours. The metering must be conducted for a minimum period of one week, or a sufficient amount of time to capture the full range of operation. The motor annual operating hours are calculated from the metering data according to Equation 4.2.

Equation 4.2:

$$\text{Annual Operating Hours [hrs/yr]} = \frac{\text{Motor On-time during Metering Period [hrs]}}{\text{Length of Metering Period [hrs]}} * \text{8,760 [hrs/yr]}$$

For projects in which a large number of equal-sized motors with the same application and operating schedule will be replaced, metering may be conducted on a sample of the motors and the results extrapolated to the applicable population. If this approach is adopted, AEP will assist the Sponsor in selecting the motors to be metered.

The Sponsor should include electronic copies of the unprocessed data files as part of the Savings Report.

4.4 Calculation of Peak Demand and Energy Savings

Demand savings are calculated for equipment that operates during the summer peak period, which is defined as weekdays between the hours of 1 p.m. and 7 p.m. from May 1 through September 30. The peak demand savings and energy savings are calculated according to Equation 4.3 and Equation 4.4, respectively.

Equation 4.3:

$$\text{Peak Demand Savings [kW]} = \text{Baseline Demand [kW]} - \text{Spot Measured New Motor Demand [kW]}$$

Equation 4.4:

$$\text{Energy Savings [kWh]} = \text{Peak demand savings [kW]} * \text{Annual Operating Hours [hrs]}$$

The Sponsor reports the peak demand and energy savings to AEP in the project Savings Report.

Example

A constant-speed process motor at an agricultural processing plant will be replaced with a smaller, high-efficiency motor. As indicated on its nameplate, the existing motor is a 200 hp, 1800 RPM enclosed motor with a nominal efficiency of 0.91. This motor will be down-sized to a 150 hp motor with a nominal efficiency of 0.96.

As the first step in the M&V, a spot measurement of the existing motor was made and indicated a power draw of 165.3 kW.

The minimum efficiency standard for the existing motor is 0.95 (as given in the Minimum Standard Motor Table) which is greater than the efficiency of the existing motor; therefore, the baseline demand is calculated according to Equation 4.1.

(a) Baseline motor demand = 165.3*(0.91/0.95) **= 158.3 kW**

Following installation of the new motor, a spot measurement was made, and indicated an average, one hour, power draw of 117.9 kW.

Post-installation metering of operating hours was then conducted for a one-week period. The metering results show that the motor was operating for 81 hours out of the 168 hours in the metering period. The annual operating hours were calculated using Equation 4.2, as shown below.

(b) Annual operating hours = (81/168)*8760 **= 4224 hrs**

The peak demand savings and energy savings were then calculated using Equations 4.3 and 4.4, respectively, as shown below.

(c) Peak demand savings = 158.3 - 117.9 **= 40.4 kW**

(d) Annual energy savings = 40.4 * 4224 **= 170,650 kWh**

4.5 Variable Speed Drives on Constant Baseline Motors

Installing variable-speed drive (VSD) controllers on motors that serve a constant baseline load requires a modified motor M&V procedure. In order to qualify for the AEP 2010 CSOP, projects including VSDs as an energy efficiency measure should also include other energy efficiency measures that deliver demand as well as energy savings. Potential retrofit projects that might include VSDs include:

- Converting constant air volume (CAV) systems to variable air volume (VAV)
- Retrofitting central chiller plants
- Replacing standard efficiency electric motors with high efficiency models

Motors that are scheduled for the installation of VSDs follow the same **Determination of Baseline Operating Characteristics** described earlier in this chapter. If the efficiency of the existing motor is greater than or equal to the minimum listed in the Table of Standard Motor Efficiencies, then the baseline demand is equal to the spot measured value; if not, then it is calculated according to Equation 4.1.

After the VSD and associated project retrofit has been installed, the Sponsor will again **Document Post-Retrofit Operating Characteristics**. The **Post-installation equipment survey** and the **Post-installation inspection** procedures are the same as described earlier in this chapter.

After AEP has conducted a post-installation inspection and approved the project Installation Report, the Sponsor should begin short-term metering[1] of the power draw (kW) of the motors. The data must be recorded at intervals of 15 minutes or less. However, averaged one-hour values are used in the calculation of demand and energy savings. For calculating peak demand, the metering must occur during the summer peak period.

The duration of the metering period must be sufficient to capture the full range of motor operation. If the motor load varies only on a daily basis and not seasonally, then a metering period of one week is generally sufficient. If the motor load or operating hours vary with weather or other seasonal parameters (e.g., production schedules, school calendars), then at least two weeks of metering during each operating period is generally necessary. For example, if the motor serves cooling equipment, then the metering should occur for at least two weeks during the winter months and two weeks during the summer months.

The metering data are used to determine three values:

1. **Peak summer period demand (kW):** Equal to the maximum-recorded peak summer period demand (one hour average values, where the summer peak period is defined as weekdays, between the hours of 1 PM and 7 PM, from May 1 through September 30).

2. **Average demand (kW):** Equal to the average recorded demand. For motors with seasonal load patterns, the average demand should be weighted according to the relative length of each seasonal period (see VSD example).

3. **Annual operating hours:** Calculated from the metering data according to Equation 4.5. For motors with seasonal load patterns, the annual operating hours should be weighted according to the relative length of each seasonal period.

Equation 4.5:

$$\text{VSD Annual Operating Hours [hrs/yr]} = \frac{\text{Motor On-time during Metering Period [hrs]}}{\text{Length of Metering Period [hrs]}} * 8{,}760 \text{ [hrs/yr]}$$

For projects in which a large number of equal-sized motors with the same application and operating schedule will be replaced, M&V may be conducted on a sample of the motors and the results extrapolated to the applicable population.

The peak demand savings and energy savings are calculated according to Equation 4.6 and Equation 4.7, respectively.

Equation 4.6:

$$\text{VSD Peak Demand Savings [kW]} = \text{Baseline Demand [kW]} - \text{Peak Summer Period Demand [kW]}$$

[1] Long-term monitoring may be required for motors with non-uniform or unpredictable load patterns.

Equation 4.7:

$$\text{VSD Energy Savings [kWh]} = (\text{Baseline Demand [kW]} - \text{Average Demand [kW]}) * \text{Annual Operating Hours [hrs]}$$

VSD Example

The constant air volume ventilation system at a commercial office building will be converted to a variable air volume (VAV) system. The conversion involves retrofitting four 50 hp supply fan motors with variable speed drives (VSDs). Additionally, the existing motors will be replaced with premium efficiency motors. The M&V procedures for a single motor are illustrated below. In general, the same procedure would be followed for all four motors.

A spot measurement of the power draw of the existing motor was made and gave a reading of 42.3 kW. The nameplate on the existing motor indicates that it is an 1800 RPM, enclosed motor with a nominal efficiency of 0.92. From Appendix B, the mininum efficiency standard for this type of motor is 0.93; therefore, the baseline demand is calculated according to Equation (a)

(a) Baseline demand = (0.92/0.93)*42.3 = 41.8 kW

Because the motor load is weather dependent, short-term post-installation metering must be conducted during both summer and winter months. Thus, after the new motor and VSD are installed, short-term metering of the motor's power draw (kW) is conducted for two weeks in January (winter) and two weeks in July (summer).

The metering data indicates that the peak (one hour) summer period demand was 37.6 kW. The average demand during the January metering period was 5.3 kW, and the average demand during the July metering period was 19.8 kW. The summer and winter periods are assumed to account for equal portions of the year; therefore, the metering results are weighted evenly for the two periods. Thus, the average demand is 12.6 kW.

The metering data indicates that motor was operating for 88 hours during the 336-hour January metering period, and for 110 hours during the 336-hour July metering period. As discussed above, the results from the two metering periods are weighted evenly; thus, the annual operating hours are calculated as shown in Equation (b).

(b) Annual operating hours = [(88/336+110/336)/2]*8760 = 2581 hours

The peak demand savings and energy savings for this motor are calculated according Equations (c) and (d), respectively.

(c) Peak demand savings = 41.8-37.6 = 4.2 kW

(d) Energy savings = (41.8-12.6)*2581 = 73,365 kWh

5 Simple M&V Guidelines for Application of Window Films

5.1 Overview

The installation of window films decreases the window-shading coefficient and reduces the solar heat transmitted to the building space. During months when perimeter cooling is required in the building, this measure decreases cooling energy use.

The simple M&V guidelines developed for this measure are applicable for window films applied to south- and west-facing windows only. The measure demand and energy savings are calculated based on the window-film area, change in shading coefficient, and cooling equipment efficiency. Savings for window film measures are determined using the online calculation spreadsheet available on the AEP CSOP Web site at http://www.AEPefficiency.com.

The following steps comprise the simple M&V procedure for window-film installations.

1. Collect data characterizing the existing south and west windows including: shading coefficient, type of interior shading devices, and presence of exterior shading from buildings or other obstacles. Identify the type and rated efficiency of the cooling equipment in the building.
2. Document the installed window-film shading coefficient and window application area for the south and west windows.
3. Based on the characteristics of the existing windows, newly installed window-films, and cooling equipment; determine the annual demand and energy savings using the window-film calculation spreadsheet.

5.2 Pre-installation M&V Activities

5.2.1 Pre-installation Site Survey

The goal of the pre-installation site survey is to identify the existing south and west window characteristics. At a minimum, the surveys should include the following data for the south and west windows:

- Existing window description
- Existing window shading coefficient
- Window area by cardinal orientation
- Description of interior shading devices
- If applicable, an estimate of combined window-interior shading coefficient determined from 1997 ASHRAE Fundamentals, Chapter 29, Tables 24-29
- Description of exterior shading
- Description of building cooling equipment

This information will be included as part of the Initial Application (IA). For window film measures, the IA should be submitted after the project site has been identified. Submitting the IA prior to site identification could result in significant under or over estimation of savings since variations in window area and shading characteristics between sites are large.

5.2.2 Pre-installation Inspection

After the FA is submitted, AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline characteristics of the building, including: window area by orientation, shading devices, and cooling equipment type. The M&V administrator will inform the Project Sponsor of any necessary corrections to be made to the pre-installation survey based on the results of the inspection. Removal or demolition of existing shading devices and equipment or installation of new films, shading devices, and equipment cannot commence until the pre-installation inspection is completed.

5.3 Post-Installation M&V Activities

5.3.1 Post-installation Survey

The Sponsor should provide manufacturer's data for the window films; specifically the National Fenestration Rating Council (NFRC) shading coefficient for the installed window films. The area of the window films applied for each different solar orientation must also be specified. These data are required as part of the Installation Report (IR).

5.3.2 Post-installation Inspection

AEP or its contractor will conduct a post-installation inspection to verify the documented characteristics of the building, windows, shading, cooling equipment, and window films. The M&V administrator will inform the Project Sponsor of any necessary corrections to be made to the pre-installation survey based on the results of the inspection. If the project is comprised of many small installations, AEP will inspect a randomly selected sample of the window-film installations completed by the Sponsor.

5.4 Calculation of Energy Savings

The window film demand and energy savings result from a reduction in demand and energy use of cooling equipment. For evaluating savings, a calculation worksheet is available as part of the online program applications on the AEP CSOP Web site. The savings estimates rely on tabulated values of solar heat gain factors (SHGF) as published in the 1997 ASHRAE Fundamentals, Chapter 29, Table 17. The ASHRAE data represent the amount of solar radiation that is transmitted through single-pane clear glass for a cloudless day at 32^{o} N Latitude for the 21^{st} day of each month by hour of day and solar orientation. The solar gain values are translated to electric energy savings by considering the cooling equipment efficiency. In the calculation, the cooling equipment efficiency equals the rated efficiency of the installed equipment or the ASHRAE Standard 90.1-1989 minimum cooling equipment efficiency (see the Standard Cooling Equipment Tables – Appendix A), whichever is more efficient.

To determine the coincident, peak summer demand savings associated with window films, the highest, hourly, ASHRAE SHGF value that occurs during the summer peak period is identified for each of the south and west building orientations. The available data nearest the AEP service territory are presented in Table 5.1. The building demand savings are determined from the maximum of these peak SHG values for the applicable window orientations.

To determine cooling energy savings associated with window films, the ASHRAE SHGF data are aggregated into daily totals for weekdays during the months of April through October. These totaled, SHG values are presented in Table 5.1. In the table, orientations that are symmetrical relative to the southern sky have the same SHGF values.

Table 5.1: Solar Heat Gain Determined for 32°N Latitude

Orientation	Solar heat gain (Btu/ft^2-year)	Peak hour solar heat gain (Btu/hr-ft^2-year)
SE	158,323	59
SSE	133,894	119
S	120,095	164
SSW	133,894	189
SW	158,323	219
WSW	168,978	228
W	162,388	220
WNW	139,995	208
NW	106,876	176

The data from Table 5.1 are used to determine the demand and energy savings associated with the window film measure using the equations below. Equation 5.1 presents the demand savings calculation. Demand savings are determined for the window orientation that results in the highest savings. Demand savings by orientation are not additive.

Equation 5.1: Calculation of peak demand savings for window films

$$kW_{savings,o} = \frac{A_{film,o} \cdot SHGF_o \cdot (SC_{pre,o} - SC_{post,o})}{3413 \cdot COP}$$

$$kW_{savings,peak} = kW_{savings,o,\max}$$

Where:

$kW_{savings,o}$	=	Peak demand savings per window orientation.
$kW_{savings,peak}$	=	Peak summer demand savings.
$A_{film,o}$	=	Area of window film applied to orientation (ft^2).
$SHGF_o$	=	Peak solar heat gain factor (Btu/hr-ft^2-yr) for orientation of interest from Table 5.1 on vertical glazing at 32°N latitude.
SC_{pre}	=	Shading coefficient for existing glass/interior-shading device.
SC_{post}	=	Shading coefficient for new film/interior-shading device.
COP	=	Cooling equipment COP or SEER based on ASHRAE Standard 90.1-1989 or actual COP of equipment, whichever is greater.
3413	=	Conversion factor (Btu/kW).

Equation 5.2 presents the annual energy savings calculation for window films. The total annual energy savings is equal to the sum of the savings determined for each orientation, as shown below.

Equation 5.2: Calculation of annual cooling energy savings

$$kWh_{savings,o} = \frac{A_{film,o} \cdot SHGF_o \cdot (SC_{pre,o} - SC_{post,o})}{3413 \cdot COP}$$

$$kWh_{savings} = \sum kWh_{savings,o}$$

Where:

SHG_o	=	Solar heat gain factor (Btu/yr) for orientation of interest from Table 5.1.

The following is an example of the savings calculations for a window film project.

Example

Window films are installed on an office building in Houston. The building does not have interior shading devices. The building is not self-shaded or shaded externally by neighboring buildings. The window shading characteristics, film surface area, and SHGFs are presented below. The SHG and SHGF values are based on the data presented in Table 5.2. Cooling is provided to the building by a 600 ton, water-cooled, centrifugal chiller. The ASHRAE 90.1-1989 rated COP for this type of chiller is 4.7, as specified in the AEP Standard Cooling Equipment Tables.

Orientation	Area (ft^2)	Window SC (baseline)	Window SC (w/films)	Interior Shading	SHG (Btu/ft^2-yr)	Peak SHGF (Btu/hr-ft^2-yr)
South	10,000	0.95	0.35	None	120,095	164
West	10,000	0.95	0.35	None	162,388	220

The energy savings for installing the window films can be found using the information provided and Equations 1a and 1b. Due to the absence of interior shading devices in the building, the window shading coefficients are used in the savings calculation. The energy savings for the south and west films are equal to:

$$kWh_{savings,s/w} = \frac{10{,}000 \cdot 120{,}095 \cdot (0.95 - 0.35)}{3{,}413 \cdot 4.7} + \frac{10{,}000 \cdot 162{,}388 \cdot (0.95 - 0.35)}{3{,}413 \cdot 4.7}$$

$$kWh_{savings,s/w} = 44{,}920 + 60{,}739 = 105{,}659$$

The demand savings for installing the window films can be found using the information provided and Equation 5.1. Due to the absence of interior shading devices in the building, the window shading coefficients are used in the savings calculation. The demand savings for the south and west films are equal to:

$$kW_{savings,s} = \frac{10{,}000 \cdot 164 \cdot (0.95 - 0.35)}{3{,}413 \cdot 4.7} = 61.3$$

$$kW_{savings,w} = \frac{10{,}000 \cdot 220 \cdot (0.95 - 0.35)}{3{,}413 \cdot 4.7} = 82.2$$

$$\therefore \quad kW_{savings,peak} = kW_{savings,w} = 82.2\ kW$$

6 Measurement and Verification Using Stipulated Savings Factors

6.1 Overview

Stipulated savings factor measurement and verification (M&V) techniques involve establishing the efficiency of a system before and after a retrofit by multiplying the difference by an agreed-upon or "stipulated" factor, such as operating hours or system load. These stipulated factors represent a project's potential to generate savings based on engineering analysis and simple verification activities.

Stipulated savings factor M&V methods are appropriate only for projects in which the following apply for the baseline and post-installation case:

- Electrical demand is constant, or varies as a function of operating scenarios, e.g., damper position for baseline or motor speed for post-installation; the electrical demand for each operating scenario can be defined with spot measurements.
- Operating hours as a function of operating scenario can be stipulated.

If the equipment involved in a project has a complex load profile and/or a complicated operating schedule, a different M&V method should be used.

Any Sponsor considering the use of stipulated savings factors not specified in this program should consult with AEP prior to submitting an M&V plan.

The M&V method described here is based on Option A of the 2001 International Performance Measurement and Verification Protocol (IPMVP). Valuable insights on this method can be found in the IPMVP.

6.2 Data Types

Three general types of data may be needed to estimate energy savings with an M&V plan using stipulated savings factors:

- Stipulated values based on: manufacturer's data, historical values, documented schedules from Energy Management Systems, operator's logs, results from measures in similar facilities.
- Observations or inspections used to verify equipment type, nameplate data, counts, applications, and general operating characteristics.
- Spot/short term metering may be used to determine power draw for different operating characteristics.

The types of data needed to verify energy savings for a specific project will depend on its complexity and the type of relevant stipulated data available. All stipulated factors must be clearly explained and supported by the Sponsor in the M&V plan. Note that there may be sizable differences between published equipment performance information and actual operating data. Where discrepancies exist or are believed to exist, equipment performance parameters should be measured directly.

6.3 Documenting Baseline Operating Characteristics

To establish the baseline operating characteristics of the existing equipment, the following steps are taken:

1. The Sponsor conducts a pre-installation equipment survey.
2. AEP and/or its contractor conduct a pre-installation inspection.
3. The Sponsor develops and verifies stipulated savings factors.

6.3.1 Pre-installation Equipment Survey

The Sponsor is required to conduct a pre-installation equipment survey to be submitted as part of the Final Application. The purpose of the survey is to inventory all existing equipment to be affected by the project, and to propose equipment to be installed. For each piece of existing equipment, the survey should list (as applicable): location, manufacturer, model number, rated capacity, energy use factors (such as voltage, rated amperage, fixture wattage), nominal efficiency, the load served, and any other identifiers that affect system energy consumption.

6.3.2 Pre-installation Inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline equipment in the survey, and that the stipulated savings values in the M&V plan are appropriate. If significant errors are found, AEP will inform the Sponsor that the submitted survey (which is a part of the Final Application) must be corrected and resubmitted.

6.3.3 Development and Verification of Stipulated Savings Factors

The Sponsor may use a variety of sources in the development of stipulated savings factors, including manufacturer's data, historical values, documented schedules from energy management systems, operator's logs, and results from measures in similar facilities. The pre-installation equipment inspection will be used to confirm that the stipulated factors proposed in the M&V plan are appropriate for the equipment type, application, and general operating characteristics of the project. Spot- or short-term monitoring may be required to confirm the applicability of a stipulated savings factor to a specific project.

AEP must approve all stipulated savings factors, so all data sources, methodologies, and assumptions used in their development by the Sponsor must be clearly outlined in the M&V plan.

6.4 Compliance with Energy Standards

When using stipulated savings methods, the M&V plan should document how baseline consumption values will be adjusted to comply with minimum state and federal energy standards with respect to the following:

- Baseline equipment should meet prescriptive efficiency standards requirements for affected equipment (e.g., ASHRAE Standard 90.1).
- The baseline does not have to comply with performance compliance methods that require the project site to meet an energy budget.

- Demand and energy savings should be calculated with the incorporation of minimum state and federal energy efficiency standards or codes into the determination of baseline energy use.

6.5 Documenting Post-Installation Operating Characteristics

To establish the post-installation operating characteristics of the newly installed equipment, the following steps should be taken:

1. The Sponsor conducts a post-installation equipment survey.
2. AEP or its contractor conducts a post-installation inspection.
3. The Sponsor verifies stipulated savings factors using data from the installed system.

6.5.1 Post-installation Equipment Survey

The Sponsor is required to conduct a post-installation equipment survey to be submitted as part of the Installation Report. The purpose of this equipment survey is to document the equipment that was actually installed as part of a project. For each piece of equipment, the survey should list (as applicable): location, manufacturer, model number, rated capacity, energy use factors (such as voltage, rated amperage, fixture wattage), nominal efficiency, the load served, and any independent variables that affect system energy consumption.

6.5.2 Post-installation Inspection

AEP or its contractor will conduct a post-installation inspection to verify that the Sponsor has properly documented the installed equipment and that the stipulated savings values in the M&V plan are appropriate. After the inspection, AEP will either accept or reject the Installation Report and the proposed stipulated savings factors based on the inspection results and project review.

6.5.3 Verification of Stipulated Savings Factors

The post-installation inspection results will be used to verify that the stipulated factors proposed in the M&V plan are still appropriate for the installed equipment and its general operating characteristics. Spot- or short-term post-installation monitoring may be required to confirm their applicability to a specific project.

6.5.4 Calculation of Demand and Energy Savings

Once the installed equipment has been verified to be operating properly and the proposed stipulated savings factors have been approved by AEP, the Sponsor must calculate the demand and energy savings generated by the project. The best approach for calculating the project's savings will vary depending on the type of project and the data collected, but, in general, actual metered/measured equipment operating data should be used as much as possible.

All equations to be used in calculating energy savings should be included in the project's M&V plan. For example, for a project that decreases equipment electric demand but causes no change in operating hours, the stipulated savings calculations might appear as follows:

Equation 6.1:

$$\text{Demand Savings [kW]} = kW_{Baseline} - kW_{Post\text{-}installation}$$

Equation 6.2:

$$\text{Annual Energy Savings [kWh]} = (kW_{Baseline} - kW_{Post\text{-}installation}]) * Hours_{Stipulated}$$

Where:

$kW_{Baseline}$ = Baseline equipment demand as measured by pre-installation short-term metering during the utility peak, summer coincident load period.

$kW_{Post\text{-}installation}$ = Post-installation equipment demand as measured by short-term metering during the utility peak, summer coincident load period.

$Hours_{Stipulated}$ = Annual operating hours determined using stipulated factor.

6.6 Project-Specific M&V Issues

When stipulated factors will be used to calculate energy savings, the M&V plan must address the following issues:

- How accurately stipulated factors will reflect actual energy savings
- How well the stipulated factors are supported by other data sources, physical observations, or monitoring data
- How appropriate the stipulated factors are to the equipment and operating conditions involved in the project
- How the baseline energy consumption estimates will incorporate minimum state and federal energy efficiency standards or codes

7 Measurement and Verification for Generic Variable Loads

7.1 Overview

Projects that improve the efficiency of end-uses that exhibit variable energy demand or operating hours may require continuous post-installation metering to measure and verify energy savings. Examples of such projects include:

- Upgrading building automation systems
- Installing new industrial process equipment or systems
- Comprehensive chiller plant modifications, including chillers, cooling towers, pumps, etc.

The use of continuous metering for measurement and verification (M&V) of variable loads normally involves four steps:

1. Surveying the pre-installation system(s). As with all M&V methods, the Sponsor must audit existing systems to document relevant components (e.g., piping and ductwork diagrams, control sequences, and operating parameters).

2. Establishing a baseline model (e.g., an equation that determines energy use when key independent variables are known). All, or a representative sample, of the existing systems should be metered to establish regression-based equations or curves for defining baseline system energy use as a function of appropriate variables (e.g., weather or cooling load). Adjustments may be required for the models to comply with minimum energy efficiency standards.

3. Monitoring post-installation energy use and/or independent variables e.g., weather. Monitoring can be done continuously throughout a full year or for representative periods of time during each performance year.

4. Determining the savings by subtracting the post-installation energy use from the baseline energy use (as indicated in the baseline model).

Most energy retrofits can be monitored and savings verified using this method. However, there are retrofits that cannot be quantitatively verified using continuous post-installation metering, such as window tinting.

The M&V method described here is based on Option B of the 2001 International Performance Measurement and Verification Protocol (IPMVP). Valuable insights on this method can be found in the IPMVP.

7.2 Documenting Baseline Operating Characteristics

To establish the baseline operating characteristics of the existing systems, the following steps are taken:

1. The Sponsor conducts a pre-installation equipment survey.
2. AEP and/or its contractor conduct a pre-installation inspection.
3. The Sponsor conducts any necessary M&V activities.
4. The Sponsor develops a baseline energy consumption model based on metered system data.

7.2.1 Pre-installation Equipment Survey

The Sponsor is required to conduct a pre-installation equipment survey, to be submitted as part of the Final Application. The purpose of the pre-installation equipment survey is to inventory all existing equipment to be affected by a project, and to propose the replacement equipment to be installed. For each piece of equipment, the survey should list (as applicable): location, manufacturer, model number, rated capacity, energy use factors (such as voltage, rated amperage, MBtu/hr, fixture wattage), nominal efficiency, the load served, and any independent variables that affect system energy consumption.

7.2.2 Pre-installation Inspection

AEP or its contractor will conduct a pre-installation inspection to verify that the Sponsor has properly documented the baseline equipment. If significant errors are found in the survey, AEP will inform the Sponsor that the submitted survey (which is a part of the Final Application) must be corrected and resubmitted.

7.2.3 Pre-installation Data Collection

Before making any efficiency modifications to existing equipment, the Sponsor must monitor the following variables simultaneously:

- **Independent variables that affect energy use.** Examples of such data are ambient temperature, control outputs, flow rate, cooling tons, and building occupancy.
- **System energy consumption.** Energy demand (e.g., kW) of the equipment to be affected by the project metered over a representative time period sufficient to document the full range of system operation.

Typically, metering observations should be made in 15-minute intervals, unless the Sponsor can demonstrate that longer intervals are sufficient and AEP approves such intervals.

If multiple, identical equipment components or systems are to be modified (e.g., multiple heating boilers), the M&V plan may specify metering of only a statistical sampling of the equipment.

In some cases, a dependent variable may serve as an accurate proxy for energy demand and may be monitored in lieu of energy metering. Examples of dependent variables that may be used as a proxy for energy include amperes and rotating equipment speed. If proxy variables are used, the Sponsor must show that the proxy variable is representative of the actual demand.

7.2.4 Baseline Model Development

The energy use of most projects will be influenced by independent variables. For such projects, a model must be developed (typically using regression techniques) that links independent-variable data to energy use. The methodologies for creating such a model must be included in the Final Application and approved by AEP.

The results of energy-input metering and variable(s) monitoring will be used to establish the pre-installation relationship between these quantities. This relationship will be known as the "System Baseline Model" and will probably be presented in the form of an equation. Regression analysis is typically used to develop such an equation, although other mathematical methods may be approved. If regression analysis is used, it must be demonstrated that that the model is statistically valid.

The criteria for establishing statistical validity of the model are:

- The model makes intuitive sense; e.g., the explanatory variables are reasonable, and the coefficients have the expected sign (positive or negative) and are within an expected range (magnitude).
- The modeled data represent the population.
- The model's form conforms to standard statistical practice and modeling techniques for the system in question.
- The number of coefficients is appropriate for the number of observations.
- The T-statistic for each term in the regression equation is equal to at least 2 (indicates with 95% confidence that the associated regression coefficient is not zero). The regression R^2 is at least 80%.
- All data entered into the model are thoroughly documented and model limits (range of independent variables for which the model is valid) are specified.

Raw data used in model development must be submitted with the Final Application or Installation Report. AEP or its contractor will make a final determination on the validity of models and monitoring plans and may request additional documentation, analysis, or metering as necessary.

7.3 Compliance with Energy Standards

The baseline model must comply with all applicable federal and state energy standards and codes. If any existing equipment that will be part of the project does not meet the applicable standards, the Sponsor must document how the baseline model will be adjusted to account for the standards. It is possible that two baseline models will be developed – an existing system baseline model and a minimum-standard system baseline model. In general, however, the M&V plan should document how baseline values are in compliance, or will be adjusted to comply, with the following:

- Baseline equipment characterization should meet prescriptive efficiency standards requirements for affected equipment (e.g., ASHRAE Standard 90.1).
- The baseline does not have to comply with performance compliance methods that require the project site to meet an energy budget.

- Demand and energy savings should be calculated with the incorporation of minimum state and federal energy efficiency standards or codes into the determination of baseline energy use.

7.4 Documenting Post-installation Operating Characteristics

To establish the post-installation operating characteristics of the affected systems, the following steps are taken:

1. The Sponsor conducts a post-installation equipment survey.
2. AEP and/or its contractor conduct a post-installation inspection.
3. The Sponsor conducts any necessary M&V activities.

7.4.1 Post-installation Equipment Survey

The Sponsor is required to conduct a post-installation equipment survey to be submitted as part of the Installation Report. The purpose of this equipment survey is to document the equipment that was actually installed as part of a project. For each piece of equipment, the survey should list (as applicable): location, manufacturer, model number, rated capacity, energy use factors (such as voltage, rated amperage, MBtu/hr, wattage), nominal efficiency, the load served, and any independent variables that affect system energy consumption.

7.4.2 Post-installation Inspection

AEP or its contractor will conduct a post-installation inspection to verify that the Sponsor has properly documented the installed equipment. After the inspection, AEP will either accept or reject the Installation Report based on the inspection results and project review.

7.4.3 Post-installation Data Collection

After the retrofit, the Sponsor must monitor one or both of the following variables simultaneously:

- **Independent variables that affect energy use.** Examples of such data are ambient temperature, control outputs, flow rate, cooling tons, and building occupancy.
- **System energy consumption.** Energy demand (e.g., kW) of the equipment to be affected by the project metered over a representative time period sufficient to document the full range of system operation.

The variable(s) that must be monitored will depend on the savings calculation methodology used for the retrofit, as described further in the next section. Note that the same guidelines for pre-installation data collection should be followed for all post-installation data collection.

7.5 Calculation of Demand and Energy Savings

There are two approaches for calculating demand and energy savings from generic variable load projects. Both approaches require pre- and post-installation metering. The pre-installation metering includes short-term measurements of equipment demand and metering of independent variables. The pre-installation metering is necessary to develop the baseline energy use model.

For the post-installation monitoring, the first approach requires continuous metering of demand and independent variables. The second approach relies on short-term measurements of demand and continuous metering of independent variables. The two methods are summarized below.

1. Short-term, pre-installation metering of demand and independent variables to develop baseline model. Continuous measurement of post-installation demand and the independent variables used in the baseline model. Post-installation variable data are used with the baseline model to calculate baseline energy use.

2. Short-term, pre-installation metering of demand and independent variables to develop baseline model. Short-term, post-installation metering of demand and independent variables to develop post-installation model. Continuous measurement of post-installation variables. Post-installation variable data are used with the baseline and post-installation models to calculate baseline and post-installation energy use.

7.5.1 First Approach: Metering Post-installation Energy Use & Variables

To calculate energy savings using the first approach, the Sponsor will monitor demand and the same independent variables that were used to develop the System Baseline Model after installing the project. The Sponsor will then compare metered post-installation energy use with pre-installation energy use as estimated by inputting the post-installation monitored independent variables into the System Baseline Model. Demand and energy savings will be calculated using the following equations:

Equation 7.1:

$$\text{Demand Savings [kW]} = kW_{Baseline,Max} - kW_{Measured,Max}$$

Equation 7.2:

$$\text{Energy Savings}_i\ \text{[kWh]} = (kW_{Baseline,i} - kW_{Measured,i}) * T_i$$

Equation 7.3:

$$\text{Annual Energy Savings [kWh]} = \text{Sum of (Energy Savings)}_i$$

Where:

$kW_{Baseline,Max}$ = Maximum, pre-installation equipment demand occurring during utility peak, summer, coincident load period.

$kW_{Measured,Max}$ = Maximum, post-installation equipment demand occurring during utility peak, summer, coincident load period.

$kW_{Baseline,i}$	=	Baseline kW calculated from Baseline Model and corresponding to same time interval, system output, weather, etc., conditions as $kW_{Measured,i}$.
$kW_{Measured,i}$	=	Measured kW obtained through continuous, or representative period, post-installation metering.
T_i	=	Length of time interval.

7.5.2 Second Approach: Metering Post-installation Variables

To calculate energy savings using the second approach, the Sponsor must first develop a Post-Installation System Model for use as a proxy for direct post-installation energy use measurement. Then, the Sponsor monitors the relevant independent variables and uses that data to estimate post-installation energy use. Note that the development of the Post-Installation System Model is subject to the same requirements outlined for development of the Baseline System Model. Once the post-installation energy use is estimated, energy savings over the course of a single observation interval will be calculated using the following equations:

Equation 7.4:

$$\text{Demand Savings [kW]} = kW_{Baseline,Max} - kW_{Post\text{-}installation,Max}$$

Equation 7.5:

$$\text{Energy Savings}_i\ \text{[kWh]} = (kW_{Baseline,i} - kW_{Post\text{-}installation,i}]) * T_i$$

Equation 7.6:

$$\text{Annual Energy Savings [kWh]} = \text{Sum of (Energy Savings)}_i$$

Where:

$kW_{Baseline,Max}$	=	Maximum, pre-installation equipment demand occurring during utility peak, summer, coincident load period.
$kW_{Post\text{-}installation,Max}$	=	Maximum, post-installation equipment demand occurring during utility peak, summer, coincident load period.
$kW_{Baseline,i}$	=	Baseline kW calculated from Baseline Model and corresponding to same time interval, system output, weather, etc., conditions as $kW_{Post\text{-}installation,i}$.
$kW_{Post\text{-}installation,i}$	=	Post-installation kW calculated from Post-Installation Model and corresponding to the measured time interval; measured system output, measured weather variables, etc. in the post-installation period.
T_i	=	Length of time interval.

For a particular observation interval, the monitored data must be applied to the Baseline System Model and to the Post-Installation Model to determine the baseline-system energy and post-installation system energy input. The modeled-system post-installation is then subtracted from the baseline energy input value. Energy savings are determined by multiplying this difference by the length of the observation interval.

7.6 Project-Specific M&V Issues

Specific M&V issues that need to be addressed for generic variable load projects include:

- Determination of post-installation metering approach -- i.e., monitoring of energy use or post-installation variables.
- Modeling methodology for Baseline System Model(s) and Post-Installation Model (if used).
- How minimum energy efficiency standards will be defined for the Baseline System Model?
- Identification of appropriate variables.
- Duration of baseline and post-installation monitoring.

8 Measurement and Verification Using Billing Analysis and Regression Models

8.1 Overview

Billing analysis involves the use of regression models with historical utility billing data (kW and kWh) to calculate annual demand and energy savings. In general, billing analysis is used with complex equipment retrofits and controls projects. Examples of the types of projects where billing analysis may be employed include the installation of an energy management control system (EMCS), and a comprehensive building retrofit involving multiple types of energy efficiency measures (EEMs).

Billing analysis provides retrofit performance verification for projects where whole-facility baseline and post-installation data are available. Billing analysis usually involves collection of historical whole-facility baseline energy use data and a continuous measurement of the whole-facility energy use after measure installation. Baseline and periodic inspections of the equipment may also be warranted. Energy consumption is calculated by developing statistically representative models (multivariate regression models) of historical whole-facility energy consumption (kWh).

The M&V method described here is based, in part, on Option C of the 2001 International Performance Measurement and Verification Protocol (IPMVP). Valuable insights on utility bill analysis can be found in the IPMVP.

8.2 Baseline and Post-Retrofit Data Collection

Collecting and validating data, as well as ensuring alignment of data start and end dates are important elements of billing analysis. Data types and some data analysis protocols are discussed below.

8.2.1 Data Types

As input to the multivariate regression models, billing data provide the basis for calibrating models and post-installation energy use. Site data provide a means for controlling changes in energy use not associated with measure installation. These data elements are discussed below.

- **Monthly Energy Billing Data.** There are typically two types of monthly energy billing data; total energy usage for the month, or energy usage aggregated by time-of-use periods. While either type of data can be used with a regression model, time-of-use is preferable as it provides more insight into usage patterns.
- **Interval Demand Billing Data.** This type of billing data records the average demand for a given interval (e.g., 15 minutes) associated with the billing period.
- **Site Data.** Site data provide the information necessary to account for either changes in or usage of energy consumption that is not associated with the retrofit equipment. Typical site data that can be incorporated in regression models include weather parameters, occupancy, facility square footage and operating hours. These data are typically used to

help define the independent variables that explain energy consumption or change associated with equipment other than the equipment installed as part of an EEM.

8.2.2 Data Analysis Protocols

The following are some of the required data analysis protocols:

- **Baseline Energy Consumption.** This regression analysis requires at least 12 months' worth of data prior to the date of installation. However, if energy consumption is sensitive to weather, or other highly variable factors, then at least 24 months worth of data are required.
- **Post-installation Energy Consumption.** This regression analysis requires at least nine months, and preferably twelve months of data after the date of installation to determine impacts for the first year.
- **Outliers.** Outliers are data beyond the expected range of values (e.g., a data point more than two standard deviations away from the average of the data). However, the elimination of outliers should be explained. It is not sufficient to eliminate a data point because it is beyond the expected range of values. If there is reason to believe that the data point is abnormal because of specific mitigating factors, then it can be eliminated from the analysis. Nevertheless, if a reason for the unexpected data point cannot be found, it should be included in the analysis. Outliers should be defined based on "common sense" as well as common statistical practice. Outliers can be defined in terms of consumption changes and actual consumption levels.

8.3 Calculation of Energy Savings: Multivariate Regression Method

Multivariate regression is an effective technique that controls for non-retrofit-related factors that affect energy consumption. If the site data (all relevant explanatory variables, such as weather, occupancy, and operating schedules) are available and/or collected, the technique should result in more accurate and reliable savings estimates than a simple comparison of pre- and post-installation energy consumption.

The use of the multivariate regression approach is dependent on and limited by the availability of site and billing data. The decision to use a regression analysis technique should be based on the availability of this information. Thus, on a project-specific basis, it is critical to investigate the EEM dependent and independent variables that have direct relationships to energy use. Data need to be collected for these variables in a suitable format over a significant period of time.

Separate models may be proposed that define pre-installation energy use and post-installation energy use with savings equal to the difference between the two equations. It is assumed, however, that a single "savings" model will be simpler and generate more reliable estimates since it is also based on more data points.

8.3.1 Overview of the Regression Approach

Regression models should be developed that describe pre-installation and post-installation energy use for the affected site (or sites), taking into account all explanatory variables.

For projects with time-of-use utility billing data, the regression models should yield savings by hour or critical time-of-use period. For projects with only monthly consumption data, the models should be used to predict monthly savings.

8.3.2 Standard Equation for Regression Analysis

In the regression analysis, utility billing data (monthly or hourly) on a project-specific basis are used to develop the models for comparing the pre-installation energy use to post-installation energy use. After adjusting for non-retrofit-related factors in the models, the models' energy use difference is defined as the gross performance impact of the EEMs.

The regression equations should be specified so as to yield as much information as possible about savings impacts. For example, with hourly data, it should be possible to estimate the savings impacts by time of day, day of week, month, and year. With only monthly data, however, it is only possible to determine the effects by month or year. Data with a frequency lower than monthly should not be used under any circumstances.

8.3.3 Independent Variables

Independent variables that affect energy consumption should be specified for use in the regression analysis. These variables can include weather, occupancy patterns, and operating schedules.

If the multivariate regression models discussed above incorporate weather in the form of heating degree-days (HDD) and/or cooling degree-days (CDD), the following issues must be considered:

- The use of the building "temperature balance point" for defining degree-days versus an arbitrary degree-day temperature base.
- The relationship between temperature and energy use that tends to vary depending upon the time of year. For example, a temperature of 55°F in January has a different implication for energy usage than the same temperature in August. Thus, seasonality should be addressed in the model.

8.3.4 Testing Statistical Validity of Models

The statistical validity of the final regression model should be tested by the Sponsor and AEP or its contractor and should demonstrate the following:

- The model makes intuitive sense; e.g., the independent variables are reasonable, and the coefficients have the expected sign (positive or negative) and are within an expected range (magnitude).
- The modeled data are representative of the population.
- The form of the model conforms to standard statistical practice.
- The number of coefficients is appropriate for the number of observations (approximately no more than one explanatory variable for every five data observations).
- The T-statistic for all key parameters in the model is at least 2 (95% confidence that the coefficient is not zero).
- The model is tested for possible statistical problems and, if present, appropriate statistical techniques are used to correct for them.

- All data input to the model are thoroughly documented, and model limits (range of independent variables for which the model is valid) are specified.

8.3.5 Compliance with Energy Standards

When using billing analysis methods, the baseline should comply with minimum state and federal energy standards with respect to the following:

- Baseline equipment/systems should not include devices (e.g., lamps and ballasts) that are not allowed to be installed under current regulations.
- Baseline equipment should meet *prescriptive* efficiency standards requirements for affected equipment.
- Surveys and analysis correction methods (potentially outside of the model) should be documented in a project-specific M&V plan.
- The baseline *does not* have to comply with *performance compliance* methods that require the facility to meet an energy budget.

8.3.6 Detailed Calculation Issues

The details of the savings calculations are dependent on such issues as:

- The use of hourly versus monthly utility meter billing data
- The format of the data (e.g., corresponding to same time interval as the billing data) and availability of *all* relevant data for explanatory variables
- The amount of available energy consumption data
- The use of actual or typical data to calculate savings
- Compliance with energy standards when calculating baseline energy use. Energy savings should be calculated with the incorporation of minimum state and federal energy efficiency standards or codes into the determination of baseline energy use.

8.4 Project Specific M&V Issues

When billing analysis methods are used, the project specific M&V plan should address, in addition to other topics generic to all M&V methods, the following:

- How billing data covering an adequate period of time should be used to calculate savings in the performance year?
- How the baseline will be adjusted in order to have the baseline meet minimum energy standards?

9

Measurement and Verification Using Calibrated Simulation Analysis

9.1 Overview

Computer Simulation Analysis for measurement and verification of energy savings is used when the energy impacts of the energy efficiency measures (EEMs) are too complex[1] or too costly to analyze with traditional M&V methods. Situations where computer-based building energy simulations may be appropriate include:

- The EEM is an improvement or replacement of the building energy management or control system.
- There is more than one EEM and the degree of interaction between them is unknown or too difficult or costly to measure.
- The EEM involves improvements to the building shell or other measures that primarily affect the building load (e.g., thermal insulation, low-emissivity windows).

Conducting simulation analysis is a time-consuming task. In some instances, the high costs of conducting simulation analysis may not justify this type of M&V. Also, building simulation software programs are not capable of modeling every conceivable building and equipment or control EEM.

The M&V method described here is based, in part, on Option D of the 2001 International Performance Measurement and Verification Protocol (IPMVP). Valuable insights on computer simulation analysis can be found in the IPMVP.

The Sponsor should take the following steps in performing Computer Simulation Analysis M&V:

1. Work with AEP and its contractor to define a strategy for creating a calibrated building simulation model in the project-specific M&V plan.
2. Collect the required data from utility bill records, architectural drawings, site surveys, and direct measurements of specific equipment installed in the building.
3. Adapt the data and enter them into the program's input files.
4. Run the simulation program for the "base" building model. The base building is the existing building without the installed EEMs. The base building should comply with minimum state and federal energy standards.
5. Calibrate the base model by comparing its output with measured data. The weather data for the base model should be the actual weather occurring during the metering period. Refine the base building model until the program's output is within acceptable tolerances of the measured data.

[1] Wolpert, J.S. and J. Stein, "Simulation, Monitoring, and the Design Assistance Professional," 1992 International Energy and Environment Conference.

6. Run the calibrated base model using typical weather data to normalize the results.
7. Repeat the process for the post-installation model. Calibration of the retrofit model, if done, should use data collected from site surveys (to validate that all of the equipment and systems are installed and operating properly) and possibly spot, short-term, or utility metering.
8. Estimate the savings. Savings are determined by subtracting the post-installation results from the baseline results using typical conditions and weather. The savings estimates and simulation results will be reviewed and verified by AEP or its contractor.

These steps are described in more detail in the following sections.

9.2 Baseline and Post-Retrofit Data Requirements

9.2.1 Simulation Software

To conduct Calibrated Simulation Analysis M&V, it is recommended that the Sponsor use the most current version available of the DOE-2.1E hourly building simulation program. For projects with small projected incentive payments, the Sponsor may use other models if the model can be shown to adequately model the project site and the EEMs, can be calibrated to a high level of accuracy, and the calibration can be documented.

9.2.2 Weather Data

Calibrating a computer simulation of a real building for a specific year requires that actual weather data be used in the analysis. Actual weather data should be collected from a source such as National Climatic Data Center (NCDC) weather station data. The physical location of the weather station should be the closest available to the project site. These data should be translated into weather data files that are compatible with DOE-2. The project-specific M&V plan should specify which weather data sources will be used.

Typical weather data used in the calculation of energy savings should be either Typical Meteorological Year (TMY) or TMY2 data types, obtained from the National Renewable Energy Laboratory (NREL).

9.3 Calculation of Energy Savings

9.3.1 Develop a Calibrated Simulation Strategy

The following are issues that either the Sponsor or AEP will need to address in order to define the simulation approach:

- **Define the existing building.** In general, the existing building represents the building, as it exists prior to installation of EEMs by the Sponsor.
- **Define the baseline building.** The baseline building represents the existing building but with baseline equipment efficiencies as specified by state or federal standards.
- **Define the post-installation building.** The post-installation building represents the building with the project-related EEMs installed.
- **Define the calibration data interval.** The building models should be calibrated using either hourly, daily or monthly data. Calibrations to hourly or daily data are preferred, since they are generally more accurate than calibrations to monthly data because there

are more points to compare. If monthly project site billing data are used then spot or short term data collection for calibrated key values may be used.

- **Specify spot and short-term measurements to be taken of building systems.** These measurements augment the whole-building data and enable the modeler to accurately characterize building systems. Spot and short-term measurements are valuable, but may add significant cost and time to the project.
- **Employ an experienced building modeling professional.** Although new simulation software packages make much of the process easier, a program's capabilities and real data requirements are not fully understood by inexperienced users. Employing inexperienced users for this purpose will result in inefficient use of time in data processing, and in checking and understanding of simulation results.

9.3.2 Building Data Collection

The data required for simulating a real building are voluminous. The main categories of data to be collected for the building and proposed EEMs are described below.

- **Building plans.** The Sponsor should obtain as-built building plans. If as-built plans are not available, the Sponsor should work with the building owner to define alternative sources.
- **Utility bills.** The Sponsor should collect a minimum of twelve consecutive months (preferably 24 months), with applicable dates of utility bills for the months immediately before installation of the EEMs. The billing data should include monthly kWh consumption and peak electric demand (kW) for the month. Fifteen minute or hourly data are also desired for calibration. The Sponsor should determine if building systems are sub-metered, and collect these data if available. If hourly data are required to calibrate the simulation, but no data are available, metering equipment may need to be installed to acquire hourly data.
- **Conduct on-site surveys.** AEP or its contractor will assist the Sponsor to identify the necessary data to be collected from the building. The Sponsor should visit the building site to collect the data. AEP or its contractor may accompany the Sponsor during the building survey. Data that may be collected include:
  - HVAC systems - primary equipment (e.g. chillers and boilers): capacity, number, model and serial numbers, age, condition, operation schedules, etc.
  - HVAC systems - secondary equipment (e.g. air handling units, terminal boxes): characteristics, fan sizes and types, motor sizes and efficiencies, design flow rates and static pressures, duct system types, economizer operation and control
  - HVAC system controls, including location of zones, temperature set-points, control set-points and schedules, and any special control features
  - Building envelope and thermal mass: dimensions and type of interior and exterior walls, properties of windows, and building orientation and shading from nearby objects
  - Lighting systems: number and types of lamps, with nameplate data for lamps and ballasts, lighting schedules, etc.

- Plug loads: summarize major and typical plug loads for assigning values per zone
- Building occupants: population counts, occupation schedules in different zones
- Other major energy consuming loads: type (industrial process, air compressors, water heaters, elevators), energy consumption, schedules of operation, etc.

- **Interview operators.** The Sponsor may choose to interview the building operator. Building operators can provide much of the above listed information, and also indicate if any deviation in the intended operation of building equipment exists.
- **Make spot measurements.** The Sponsor may find it necessary to record power draw on certain circuits (lighting, plug load, HVAC equipment, etc.) to determine actual equipment operation power.
- **Conduct short-term measurements.** Data-logging monitoring equipment may be set up to record system data as they vary over time. These data reveal how variable load data changes with building operation conditions such as weather, occupancy, daily schedules, etc. These measurements may include lighting systems, HVAC systems and motors. The period of measurement should be from one to several weeks.
- **Obtain weather data.** For calibration purposes, representative site weather data should be obtained for a nearby NCDC site.

9.3.3 Base Building Simulation Models

Once all necessary information is collected, the Sponsor should input the simulation data into DOE-2 code to create the base building model. The modeler should refine the model to obtain the best representation of the base building. Where possible, the modeler should use measured data and real building information to verify or replace the program's default values.

9.3.3.1 Minimum energy standards

The baseline model should comply with minimum state and federal energy standards with respect to the following:

- Baseline equipment/systems models should not include devices (e.g. lamps and ballasts) that are not allowed to be installed under current regulations.
- Baseline equipment models should meet *prescriptive* efficiency standards requirements for affected equipment.
- Baseline calculations *do not* have to comply with *performance compliance* methods that require the project site to meet an energy budget.

If the existing conditions of the EEMs do not comply with minimum state and federal standards, the modeler should calibrate the simulation model with the building as it currently exists, and then modify the existing building model to reflect the baseline efficiencies. This modified, or baseline building is then used as the base case for computing energy savings.

9.3.3.2 Calibration

After the base building model has been created and debugged, the modeler should make a comparison of the energy flows and demand projected by the model to that of the measured utility data. All utility billing data should be used in the analysis, electric as well as heating fuels, such as natural gas. The modeler may use either monthly utility bills, or measured hourly data to calibrate the model when available.

The calibration process should be documented to show the results from initial runs and what changes were made to bring the model into calibration. Statistical indices are calculated during the calibration process to determine the accuracy of the model. If the model is not sufficiently calibrated, the modeler should revise the parameters of the model and recalculate the statistics.

9.3.3.3 Hourly data calibration

In hourly calibration, two statistical indices are required to declare a model "calibrated": monthly mean bias error (MBE) and the coefficient of variation of the root mean squared error (CV(RMSE))[2]. MBE is calculated as in Equation 9.1. CV(RMSE) is calculated as in Equation 9.2.

Equation 9.1: Monthly mean bias error

$$MBE(\%) = \frac{\sum_{month}(M-S)_{hr}}{\sum_{month} M_{hr}} \times 100$$

Where:

M_{hr}	=	the measured kWh for any hour during the month
S_{hr}	=	the simulated kWh for any hour during the month

[2] Kreider, J. and J. Haberl, "Predicting Hourly Building Energy Usage: The Great Energy Predictor Shootout: Overview and Discussion of Results," ASHRAE Transactions Technical Paper, Vol. 100, pt. 2, June, 1994
Kreider, J. and J. Haberl, "Predicting Hourly Building Energy Usage: The Results of the 1993 Great Energy Predictor Shootout to Identify the Most Accurate Method for Making Hourly Energy Use Predictions,": ASHRAE Journal, pp. 72-81, March, 1994
Haberl, J. and S. Thamilseran, "Predicting Hourly Building Energy Use: The Great Energy Predictor Shootout II, Measuring Retrofit Savings – Overview and Discussion of Results, ASHRAE Transactions, June, 1996.

Equation 9.2: Coefficient of variation of the root mean squared error

$$CV(RMSE_{month}) = \frac{\sqrt{\sum_{month}(M-S)_{hr}^2 * N_{hr}}}{\sum_{month} M_{hr}} * 100$$

Where:

M_{hr}	=	the measured kWh for any hour during the month
S_{hr}	=	the simulated kWh for any hour during the month
N_{hr}	=	the number of hours in the month

The acceptable tolerances for these values when using hourly data calibration are shown in Table 9.1.

Table 9.1: Acceptable tolerances for hourly data calibration

	Value
MBE_{month}	± 10%
$CV(RMSE_{month})$	± 30%

9.3.3.4 Monthly data calibration

Comparing energy use projected by simulation to monthly utility bills is straightforward. First the model is developed and run using weather data that corresponds to the monthly utility billing periods. Next monthly-simulated energy consumption and monthly measured data are plotted against each other for every month in the data set. The error in the monthly and annual energy consumption are calculated by Equation 9.3 and Equation 9.4, respectively.

Equation 9.3: Error in monthly energy consumption

$$ERR_{month}(\%) = \frac{(M-S)_{month}}{M_{month}} * 100$$

Where:

M_{month}	=	the measured kWh for the month
S_{month}	=	the simulated kWh for the month

Equation 9.4: Error in annual energy consumption
$ERR_{year} = \sum_{year} ERR_{month}$

The acceptable tolerances for these values when using hourly data calibration are shown in Table 9.2.

Table 9.2: Acceptable tolerances for monthly data calibration

	Value
ERR_{month}	± 25%
ERR_{year}	± 15%

9.3.4 Post-installation models

After measure installation a post-installation model can be prepared. The post-installation model should usually be the baseline model with the substitution of new energy-efficient equipment and systems. This new model should also be calibrated and documented. The possible calibration mechanisms are:

- Using site survey data to validate that all of the specified equipment and systems are installed, have the nameplate data used in the model, and are operating properly.
- Using spot and/or short-term metering data to calibrate particular model modules of equipment, systems or end-uses.
- Using utility (15 minute, hourly or monthly) metering data to calibrate the model, as was done with the pre-installation model.

The above mentioned post-installation model calibration mechanisms are not necessarily mutually exclusive. If the first two mechanisms are used the model can be calibrated soon after measure installation. If the last mechanism is used then the model can only be calibrated after sufficient (e.g., 12 months) billing data are available.

In some instances the post-installation model should be the only model calibrated. This can occur when the baseline project site cannot be easily modeled due to significant changes during the 12 months prior to the new measures being installed and thus the recent billing data are not representative.

9.3.5 Detailed Energy Savings Calculations

Energy savings are determined from the difference between the outputs of the baseline and post-installation models. Savings are determined with both models using the same conditions (weather, occupancy schedules, etc.). To calculate savings, the energy consumption projected by the post-installation model is subtracted from energy consumption projected by the baseline model. Energy savings are calculated with Equation 9.5:

Equation 9.5: Energy savings calculation

$$kWh_{saved} = kWh_{baseline} - kWh_{post}$$

Where:

$kWh_{savings}$	=	The kilowatt-hour savings realized during the year.
$kWh_{baseline}$	=	The kilowatt-hour consumption of the baseline building operating under the same conditions (weather, operation and occupancy schedules, etc.) as the post-installation building.
kWh_{post}	=	The kilowatt-hour consumption of the post-installation building operating under the same conditions (weather, operation and occupancy schedules, etc.) as the baseline building.

9.4 Project-Specific M&V Issues

Specific M&V issues that need to be addressed in the project-specific M&V plan and that are related to this M&V method include:

- Which version of DOE-2 will be used, the supplier of the program, and what if any pre- and post-processors will be used?
- Baseline building description (age square footage, location, etc.) including a description of building systems to be replaced.
- Description of any building operation conditions (set-points, schedules, etc.) that are affected by the EEMs.
- Documentation of compliance for the baseline model with state and federal standards.
- Documentation of the calibrated simulation strategy and project procedure, including differences in calibration parameters between the existing and post-installation cases.
- A summary of the building data to be collected and sources (e.g., site surveys, drawings).
- Identification of spot and short-term measurements to be made.
- Selection of the calibration data interval (should be hourly or monthly).
- Identification and source of weather data used (NCDC weather station or typical weather data).
- Identification of the statistical calibration tolerances and graphical techniques to be used.
- Indication of whom will do the simulation analysis and calibration.
- Specification of format for documentation.